



# **SECTION 6: TECHNICAL SPECIFICATIONS**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

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**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 1  
GENERAL TOPICS AND DEFINITIONS**

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## **SECTION 1: GENERAL TOPICS AND DEFINITIONS**

### **1.1 Scope**

This part of the Solicitation Package describes the low floor light rail vehicle (LFLRV) and related technical products that Sound Transit intends to procure. Contractual and other requirements appear in the other sections of this Solicitation Package. This Section includes requirements that apply to every section included in the Specifications.

### **1.2 Specifications**

#### **1.2.1 Introduction**

The Contractor shall design, manufacture, and deliver the products as described by these Technical Specifications (“the Specifications”). Deviations from these requirements are permitted only with specific approval of Sound Transit.

The Contractor is responsible for the design and integration of all vehicle systems such that all specified requirements are achieved without conflict or error within or between systems. The Contractor shall ensure that all managers, engineers, designers, suppliers, and subcontractors are informed of all specified requirements and that appropriate engineering management tools are used to ensure that coordination and communication occurs between the designers of inter-related systems.

The Contractor is required to cooperate and coordinate with construction contractors on certain interface issues between the vehicle and wayside systems that are identified elsewhere in the Specifications.

#### **1.2.2 Type of Specifications**

The Specifications contain both performance-based requirements and specific design requirements. Where requirements are performance-based, Sound Transit (ST) retains the right to review and approve Contractor-proposed designs, and to require changes to those proposed designs at no additional cost to Sound Transit, in order to meet the specified performance requirements and the intent of the Specifications, as determined by Sound Transit.

#### **1.2.3 Organization of Specifications**

The Specifications are divided into sections according to technical discipline and traditional supplier arrangements. This format is for convenience only and does not imply or suggest a weakening of system integration requirements or preferred supplier arrangements.

Explicit references may appear within sections linking requirements appearing in other sections. Such references shall, in no way, be assumed to limit the applicability of any requirements in the Specifications, whether referenced or not.

### **1.2.4 Specification Language**

The Specifications include statements written in imperative mood. This imperative language is directed to the Contractor, unless specifically noted otherwise. For example, "Comply with worker training and supervision requirements..." means that the Contractor shall comply with the specified requirements.

### **1.3 Contract Deliverables**

The Specifications require the submittal of drawings, documents, analyses, test results, manuals and similar information for review by Sound Transit to verify compliance with specified requirements, and for after-delivery support of the vehicles. Specific submittal requirements are listed at the conclusion of each section under the heading contract deliverables requirements list, or CDRL.

In addition to the explicit CDRL requirements, Sound Transit reserves the right to require additional submittals for review and approval based on the Specifications Compliance Matrix (SCM) specified in Section 19. These submittals shall be in the form of documents, drawings, analyses, test procedures and results, etc., and are required to verify that each requirement of the Specifications has been satisfied.

Unless otherwise noted, each submittal, whether listed in the CDRL or required based on the SCM, must be both reviewed and approved by Sound Transit, whether specifically stated or not.

### **1.4 Materials and Equipment**

Name brands, specific equipment, or specific materials may be referenced in the Specifications. Such equipment has been shown to be successful in previous applications, where correctly applied and integrated with other equipment. Such references shall not be interpreted as pre-approval of any Contractor designs or applications. The Contractor is responsible for the selection, application, and integration of equipment and materials as necessary to conform to specified requirements.

All equipment provided under this Contract shall be new. Rebuilt or refurbished equipment is prohibited. New equipment damaged during execution of this Contract may be restored to new condition only where approved by Sound Transit on a case-by-case basis, and all restorations shall be performed by the original equipment manufacturer.

### **1.5 Industry Standards and Regulations**

Where standards, codes, or reference books are referenced in the Specifications, use the most current version available at the release date of the Request For Proposal (RFP), unless otherwise noted. Where laws, statutes, or regulations are specified, such as the Code of Federal Regulations (CFR), use the version in force at the time of bid.

## **1.6 Definitions**

The following terms may appear in this document. They are defined as indicated:

Acceptance	The full and satisfactory physical completion of all or part of the Work including all physical Punch List work.
Adhesion, Coefficient of	During rolling contact, the ratio between the tangential force (tractive effort) at the wheel-rail interface and normal force.
Alteration	A change or substitution in the form, character, or detail of the work done or to be done within the original scope of the Contract.
Approval	Acceptance in writing by Sound Transit.
Approved or Approved Type	Design, type material, procedure, or method given approval by Sound Transit.
Assembly	A collection of subassemblies and components typically performing a variety of functions within the context of a larger system. Examples of assemblies are trucks, electronic control units, air compressors, etc.
AW0	Weight of empty vehicle.
AW1	Weight of vehicle with full seated load including one operator.
AW2	Weight of vehicle with design load - full seated load including one operator plus standees at four passengers/m <sup>2</sup> .
AW3	Weight of vehicle with full load - full seated load including one operator plus standees at six passengers/m <sup>2</sup> .
AW4	Weight of vehicle with crush load - full seated load including one operator plus standees at eight passengers/m <sup>2</sup> .
Blending	In braking, the simultaneous control of dynamic (rheostatic and regenerative) and friction braking, with the effort of each continuously proportioned to achieve the required total braking effort.
Burn-In	Operating a component, system, or device in a test mode, often in an extreme or cycled temperature environment, for a specified period of time or distance, to confirm reliable operation.
Car	Refer to definition for vehicle.
Coast	The mode of operation in which no propulsion (positive traction) or braking effort is in effect, except for normal drivetrain losses.
Component	Portions of equipment not typically repaired or disassembled, such as nuts, bolts, resistors, fittings, single-piece castings. Used interchangeably with "parts".

## *General Topics and Definitions*

Contract Deliverables Requirements List (CDRL)	List of select documents and other deliverable items that the Contractor is required to deliver to Sound Transit. CDRL is also used to refer to a specific item on the list.
Contract Drawings	Drawings provided by Sound Transit as part of this procurement.
Contractor	The person or persons, firm, partnership, corporation, or combination thereof which has entered into a procurement contract with Sound Transit to supply the vehicle.
Contractor's Drawings	Items such as general drawings, detail drawings, graphs, diagrams, sketches, calculations, and catalog cuts prepared by the Contractor for use in its manufacturing facility, assembly facility, or shop, to fabricate, assemble, and install parts of the vehicle whether manufactured by it from raw materials or purchased from others in a ready to use condition.
Days	Unless otherwise designated, days as used in the Contract Document will be understood to mean calendar days.
Days, Working	Those calendar days during which regular business is conducted excluding Saturdays and Sundays and all Federal, State, and municipal holidays that are observed in Seattle, Washington.
Drive	A system consisting of one or several motors or actuators, their direct control equipment (power circuits) and the associated mechanical devices required to produce a useful output.
Equal	Providing the same function, performance, and reliability.
Failsafe	A system is "failsafe" when it is designed such that any malfunction will not cause the system to achieve an unsafe state.
Failure	A condition in which equipment does not function as specified, designed, or expected, and which requires maintenance or replacement to restore the affected equipment to its normal operating condition.
Failure, Independent	A failure which is not caused by the failure of another vehicle, system, subsystem, assembly or component.
Failure, Relevant	Any independent failure which results in an unscheduled maintenance action of any vehicle subsystem or component.
Failure Rate	The frequency of failure, expressed as failures per hour or failures per mile. Failure rate is the mathematical reciprocal of MTBF or MDBF.

## *General Topics and Definitions*

Final Acceptance	Written notice from Sound Transit acknowledging that the Contractor has fulfilled all of its obligations under the Contract and that Sound Transit has accepted the Work as of the date stated in the Notice. Final Acceptance is a condition precedent to Final Payment.
First Article	The first item of production that fixes and defines all subsequent production items, once approved by Sound Transit as a consequence of remedying all defects noted during First Article Inspection.
Indicated	As presented in this document.
Inspector	The person or firm designated by Sound Transit as a quality control representative. Sound Transit may designate multiple inspectors for this project.
Interface	The points where two or more systems, subsystems, components or structures meet, transfer force, electrical signals, mechanical signals, energy, or transfer information.
Jerk	Time rate of change of acceleration and deceleration, equal to the second derivative of velocity.
Light	The transparent portion of a window.
Light Rail Vehicle (LRV)	Refer to definition for Vehicle, Low Floor Light Rail.
Liner (as in interior liner)	The visible covering material for the walls, ceiling, and other interior surfaces.
Line Replaceable Unit (LRU)	Units that can be replaced on the vehicle.
Load Weighing	The measurement of apparent passenger load for the purpose of adjusting tractive effort to produce a constant acceleration or braking rate regardless of load.
Lowest Level Replaceable Unit (LLRU)	The lowest unit (component) of a system or subsystem, which is removable and replaceable from an installed position by standard attachments (e.g., bolts and nuts, quick-disconnects, etc.).
Low Floor Light Rail Vehicle (LFLRV)	Refer to definition for vehicle.
Manufacturer	The builder or producer supplying materials, equipment, or apparatus for installation on the car.
Mask, Window	Interior liner that surrounds the windows, often molded to include the sill and other portions of the sash.
Mean Distance Between Failures (MDBF)	The mean operating mileage between independent failures.

## *General Topics and Definitions*

Mean Distance Between Component Failures (MDBCF)	The mean operating mileage between independent failures of a component.
Mean Distance Between Train Delays (MDBTD)	The mean operating mileage between train delays caused by equipment or system failures.
Mean Time Between Failures (MTBF)	The mean operating time between independent failures.
Metro	King County Department of Transportation Metro Transit Division, transit provider for the Metropolitan Seattle area.
Nominal	In name only, as for a general classification or type. Not implying an actual operating value.
No Motion (Speed)	The vehicle speed at or below the lowest speed detectable by the vehicle control systems.
Normal	As in, example, "Normal operating conditions" or "operating normally" -- A condition in which relevant vehicle equipment is not in a failure mode and the environment is as specified.
Part	See component, above.
Proof (used as a suffix)	As in splashproof, dustproof. The device and contents are impervious to, or unharmed by, application of the indicated material.
Reliability	The probability of performing a specified function, without failure and within design parameters, for the period of time indicated.
Safe	Secure from liability to harm, injury, danger, or risk; free from danger or risk.
Safety	The condition in which persons and equipment are free from threat or danger, harm, or loss arising from improper design, manufacture, assembly, malfunction, or failure of the car or any of its components or systems.
Safety Critical	A term applied to an event, device or circuit critical to personnel and equipment safety.
Service	As in Service Use, Service Braking. The operation of the cars under normal conditions.
Shop Drawings	Refer to definition for Contractor's Drawings.
Signal, Step	A signal having a constant value prior to the step and a different constant value immediately thereafter.

## *General Topics and Definitions*

Slide, Wheel	During braking, the condition when the rotational speed of the wheel is less than that for pure rolling contact between tread and rail.
Specified or As specified	As stated in this document.
Speed, Balancing	The speed attained by the vehicle or train when resisting forces exactly equal the maximum tractive force.
Speed, Base	The speed to which the maximum constant acceleration can be maintained at the nominal line voltage.
Speed, Schedule	The average speed of a vehicle or train, from terminal to terminal, obtained by dividing the distance between these points by the time taken to make the trip, including time for intermediate station stops.
Spin, Wheel	During acceleration, the condition when the rotational speed of the wheel is greater than that for pure rolling contact between tread and rail.
Stop, Emergency	The stopping of a vehicle or train by an emergency brake application.
Stop, Service	The stopping of a vehicle or train by application of service braking.
Subassembly	A collection of components used to perform a distinct function, usually in conjunction with other subassemblies and components, as part of a larger system. Subassemblies are usually replaceable as units, such as circuit boards, bearings, and valves.
Subcontractor	An individual, firm, partnership, corporation, or joint venture to whom the Contractor, with prior written approval of Sound Transit, subcontracts any part, subsystem, component, or hardware for the Contract.
Tight (used as a suffix)	As in watertight, airtight. Enclosed or protected as to completely exclude the indicated material from passage.
Time, Build-Up	In response to a change in a control signal, time interval from 10% of the total change in value to the attainment of 90% of the total change in value of the controlled variable. Build-up time is equal to response time minus dead time.
Time Constant	Slope of curve in units of controlled variable per unit of time, measured during the build-up time interval.
Time, Dead (also Time, Reaction)	Time from the occurrence of a change in a control signal to the attainment of 10% of the total change in value of the controlled variable.

## *General Topics and Definitions*

Time, Down	The time during which equipment is not capable of doing useful work because of maladjustment, malfunction, or maintenance in progress.
Time, Response	Time from the occurrence of a change in a control signal to the attainment of 90% of the total change in value of the controlled variable.
Time, Warm-up	The elapsed time from application of power to an operable device until it is capable of performing its intended function.
Traction System	The system of wheels, motors, gears, brakes, axles, direct controls, and appurtenances that propels or retards a car in response to control signals.
Train	Any number of cars, from one to the maximum, coupled together and moving as one.
Tram	(Slang) "In tram" is the condition of ideal truck geometry in which the axles are perfectly parallel and the wheels longitudinally in perfect alignment. The centers of the journal bearings represent the corners of a perfect rectangle. Verification that a truck is "in tram" is determined by measuring the diagonal and longitudinal distance between reference points on the axle bearing housings. This is generally done by using a "tram gauge" supplied by the truck manufacturer.
Vehicle	A complete light rail vehicle assembly, ready to operate, consisting of three sections, the A (end) Section, the B (end) Section, and the C (center) or articulation Section.
Vehicle, Low Floor Light Rail	The light rail vehicle described by this Specification.
Vital	A term applied to an event, software function, device or circuit which has known failure modes, certain of which occur with extreme rarity.
Wainscot	The lower portion of a wall, especially if finished differently from the upper portion.
Warp, Track	The vertical distance between the plane of any three of four rail head contact points (two on each rail) forming a rectangle and the remaining point.
Wayside Construction Contractors	The contractors responsible for the construction of the East Link light rail wayside and shop elements.

### **1.7 Acronyms and Abbreviations**

The following acronyms and abbreviations appear in this document. They are defined as indicated:

## *General Topics and Definitions*

AAR	Association of American Railroads
ABS	Automatic Block Signals
ac	Alternating Current
AFI	Air Filter Institute
AFO	Audio Frequency Overlay
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
APTA	American Public Transit Association
AREMA	American Railway Engineering and Maintenance Association
ARI	Air Conditioning and Refrigeration Institute
ASCII	American Standard Code for Information Interchange
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASIC	Application Specific Integrated Circuit
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transportation Association of America
ATP	Automatic Train Protection
ATS	Automatic Train Stop
AWG	American Wire Gauge
AWS	American Welding Society
BAFO	Best and Final Offer
BFM	Brake Failure Monitoring
BLS	Bureau of Labor Statistics
CCD	Charge-Coupled Device
CCH	Communication Control Head
CCTV	Closed Circuit Television
CDA	Copper Development Association
CDRL	Contract Data Requirements List
CFR	Code of Federal Regulations
DB	Dry Bulb
DBE	Disadvantaged Business Enterprise
dc	Direct Current
DIN	Deutsche Industrie Norm (German Industrial Standard)
DSTT	Downtown Seattle Transit Tunnel
DVR	Digital Video Recorder
EB	Emergency Brake
ECU	Electronic Control Unit
EEPROM	Electrically Erasable Programmable Read Only Memory
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EN	European Standards
EPROM	Electrically Programmable Read Only Memory
ESD	Electrostatic Discharge
FAA	Federal Aviation Administration
FCC	Federal Communications Commission

## *General Topics and Definitions*

FDA	Force Density Level
FEA	Finite Elements Analysis
FRA	Federal Railroad Administration
FSB	Full Service Brake
FST	Full Service plus Track Brake
FTA	Federal Transit Administration
HPCU	Hydraulic Pressure Control Unit
HSCB	High Speed Circuit Breaker
HSLA	High Strength Low Alloy (Steel)
HVAC	Heating, Ventilating, and Air Conditioning
IGBT	Insulated-gate bipolar transistor
ICEA	Insulated Cable Engineers Association
IEC	International Electro-technical Committee
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bi-polar Transistor
ISO	International Organization for Standards
JEDEC	Joint Electronic Device Engineering Council
JIC	Joint Industrial Council
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LFLRV	Low Floor Light Rail Vehicle
LLRU	Lowest Level Replacement Unit
LRU	Line Replacement Unit
LRV	Light Rail Vehicle
LVPS	Low Voltage Power Supply
MDBCF	Mean Distance Between Component Failure
MDBTD	Mean Distance Between Train Delays
MDS	Monitoring and Diagnostics System
MIL	Military Specification
MIMO	Multiple-Input, Multiple-Output
NBS	Obsolete, refer to NIST
NEMA	National Electrical Manufacturers Association
NFL	No Field Lubrication
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NTP	Notice to Proceed
NTSC	National Television System Committee
NVR	Network Video Recorder
OCS	Overhead Contact System
PHA	Preliminary Hazard Analysis
PI	Proportional, Integral
PID	Proportional, Integral, Derivative
PIV	Peak Inverse Voltage
PTE	Portable Test Equipment
PTU	Portable Test Unit
PWM	Pulse-Width Modulation

## *General Topics and Definitions*

RFP	Request for Proposal
RH	Relative Humidity
RHCP	Right-Hand Circularly Polarized
rms	Root Mean Square
SAE	Society of Automotive Engineers
SCA	Safety Compliance Analysis
SCM	Specifications Compliance Matrix
SHA	Systems Hazard Analysis
SHR	Sensible Heat Ratio
SIC	Standard Industrial Code, U.S. Department of Labor
SSP	System Safety Program
STFE	Sound Transit Furnished Equipment
t	Time
TCP/IP	Transmission Control Protocol/Internet Protocol
TIR	Total Indicated Runout
TOD	Train Operator Display
TOR	Top of rail
TWC	Train to Wayside Communication
UL	Underwriters Laboratories Inc.
UMTA	Obsolete, refer to FTA
USDOT	United States Department of Transportation
v	Velocity
VGA	Video Graphics Array
VPI	Vacuum Pressure Impregnation
VSWR	Voltage Standing Wave Ratio
WB	Wet Bulb
WBE	Women's Business Enterprise
WRIS	Wheel-to-Rail Interface Study

### **1.8 Units of Measure**

A	Ampere
A/in <sup>2</sup>	Ampere per square inch
A/mm <sup>2</sup>	Ampere per square millimeter
Btu	British thermal unit
Btu/h	British thermal units per hour
Btu/h/°F	British thermal units per hour per degree Fahrenheit
Btu/lb	British thermal units per pound
°C	degree Celsius
cd/ft <sup>2</sup>	candela per square foot
cd/m <sup>2</sup>	candela per square meter
cm	centimeter
cm <sup>2</sup>	square centimeter
dB	decibel
dBA	decibel on the 'A' weighted scale
dB <sub>i</sub>	decibel relative to isotropic
dB <sub>m</sub>	decibel-milliWatt (dB referenced to 1 mW)

## General Topics and Definitions

dB/s	decibels per second
dyne/cm <sup>2</sup>	dyne per centimeter squared
°F	degree Fahrenheit
°F/min	degrees Fahrenheit per minute
Fps	frames per second
ft	foot
ft <sup>2</sup>	square foot
ft <sup>3</sup>	cubic foot
ft-lbf	foot pound force
ft-lb/in	foot-pound per inch
ft/min	feet per minute
ft <sup>3</sup> /min	cubic feet per minute
ft/s	feet per second
G	acceleration due to Gravity (32.2 ft/s <sup>2</sup> = 9.81 m/s <sup>2</sup> )
g	gram
g/ft <sup>2</sup>	grams per square foot
g/m <sup>2</sup>	grams per square meter
mg/cm <sup>2</sup>	milligrams per square centimeter
mg/in <sup>2</sup>	milligrams per square inch
GB	gigabyte
GHz	gigaHertz
GJ	gigaJoule
GJ/h	gigaJoules per hour
GPa	gigaPascal
gpm	gallons per minute
gpm/ft <sup>2</sup>	gallons per minute per square foot
h	hour
Hz	Hertz
in	inch
in <sup>2</sup>	square inch
μin	microinch
μm	micrometer
in/s	inch per second
J	Joule
J/cm	Joule per centimeter
J/h	Joule per hour
J/kg	Joule per kilogram
kJ/hr	kiloJoule per hour
K	Kelvin
K/min	Kelvin per minute
kg	kilogram
kg/cm	kilogram per centimeter
kgf	kilogram force
kg/m <sup>2</sup>	kilogram per square meter
kg/min	kilograms per minute
kHz	kiloHertz

## *General Topics and Definitions*

km	kilometer
km/h	kilometers per hour
kN	kiloNewton
kN/m	kiloNewton per meter
kPa	kiloPascal
kWh	kiloWatt-hour
kW/m <sup>2</sup>	kiloWatts per square meter
L	liter
l/s	liters per second
l/h/m <sup>2</sup>	liters per hour per square meter
lb	pound
lb/ft <sup>2</sup>	pound per square foot
lbf	pound-force
lbf-ft	pound-force foot
lbf/in <sup>2</sup>	pound-force per square inch
lb/in	pounds per inch
lb/min	pounds per minute
m	meter
m <sup>2</sup>	square meter
m <sup>3</sup>	cubic meter
m <sup>3</sup> /h	cubic meter per hour
m/s	meters per second
m/s <sup>2</sup>	meters per second squared
m/s <sup>3</sup>	meters per second cubed
mA	milliAmpere
mbar	millibar
mG	milliGauss
MHz	megaHertz
mi	mile
MPa	megaPascal
mph	miles per hour
mphps	miles per hour per second
mph/s <sup>2</sup>	miles per hour per second squared
min	minute
mm	millimeter
mm <sup>2</sup>	square millimeters
mm/s	millimeter per second
ms	millisecond
mV	milliVolt
mW	milliWatt
μm	micrometer
μPa	microPascal
μV/m	microVolt per meter
N	Newton
N-m	Newton-meter
N/mm	Newtons per millimeter

*General Topics and Definitions*

N/mm <sup>2</sup>	Newtons per square millimeter
nT	nanoTesla
oz	Ounce
ozf-in	ounce force-inch
oz/yd <sup>2</sup>	ounce per square yard
Pa	Pascal
ppm	parts per million
s	second
T	Tesla
V	Volt
Vac	Volt alternating current
Vdc	Volt direct current
V p-p	Volts peak-to-peak
W	Watt
W/°C	Watt per degree Celsius

**END OF SECTION 1**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
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**SECTION 2  
DESIGN AND PERFORMANCE CRITERIA**

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## **SECTION 2: DESIGN AND PERFORMANCE CRITERIA**

### **2.1 General Design Requirements**

This Section establishes system performance, environmental and general design criteria for the Sound Transit 2 light rail vehicle (LRV), subsequently referred to as the ST2 LRV. Included are configuration, capacity, dimensional, performance, environmental, noise and vibration, ride quality, weight, and other requirements which affect vehicle system and subsystem design. These requirements apply to all aspects of vehicle and equipment design as well as associated off-vehicle equipment.

The LRV shall be designed and manufactured to operate successfully within the Seattle, Washington metropolitan area environment as described herein. All requirements identified herein shall be met. Sound Transit uses a mileage based maintenance program. All maintenance references, preventive maintenance and requirements shall be represented in miles.

The Contractor shall design the ST2 vehicles to ensure full anti-climber compatibility with the existing Sound Transit 1 LRVs (ST1). Additionally, it shall be possible to mechanically couple, with no electrical connections, ST2 and ST1 vehicles for dead-car towing operation. The ST2 vehicles shall be fully mechanically compatible with the existing ST1 vehicles.

Subject to the maintenance intervals specified in this Section, and also to maintenance practices agreed to by Sound Transit and the Contractor and normal industry accepted operating procedures, the LRVs shall be designed for a normal revenue service maximum speed of 55 mph (88 km/h) and a minimum service life of 30 years in the Seattle environment. Annual average mileage is estimated to be approximately 80,000 miles (129,000 km) per vehicle.

### **2.2 General Vehicle Configuration**

#### **2.2.1 Vehicle Type**

The vehicle shall be a, double articulated, six-axle unit (refer to Figure 2-4, General Arrangement).

The car floor between the end trucks and including the articulation sections shall be low floor. The low floor portion shall comprise at least 70% of the vehicle's interior length, as measured from back cab wall to back cab wall. Steps or ramps between low and high floor sections shall not be included in the low floor length determination.

There shall be eight passenger doorways, four per side directly across from one another. The doorways shall all be in the low floor area of the body. Doors shall be arranged for passenger boarding from low-level platforms. The door locations and spacing shall be same as the existing fleet.

The cars shall be equipped with a load leveling system which shall maintain a constant floor height to permit level boarding without the use of platform gap bridging devices.

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Each end of the vehicle shall have a fully equipped operator's position. Operating control and performance shall be equal in both directions.

The vehicle shall be capable of multiple unit operation in normal consists of up to four cars and emergency consists of up to eight cars, with limited trainlined functionality for the towed cars. At a minimum in an emergency consist, all trainlined brake, lighting, door and communications functions shall properly operate on the towed cars.

### **2.2.2 Seating Arrangement**

Each vehicle shall have a minimum of 74 passenger seats. The predominant seating arrangement shall be transverse, bi-directional, knee-to-back, and four abreast (2 plus 2). Refer to Section 15 for additional requirements and dimensions. Longitudinal seats shall be provided in the center car body section.

### **2.2.3 Elderly and Handicapped Accessibility**

Full accessibility to elderly, handicapped, and non-ambulatory persons in wheelchairs shall be provided at all doorways. Floor height at all doorways, and the load leveling system, shall comply with ADA requirements.

One wheel chair space shall be provided at each of the four door vestibules of the vehicle, with two spaces located on each side of the vehicle. Seats which flip up to allow space for the wheelchairs may be provided at each location, and these seats shall count as full seats in meeting the requirement for a minimum of 74 seats per vehicle. Non-skid flat flooring shall be provided in the wheelchair areas (refer to Section 15 for requirements).

Suitable graphics shall be provided at each wheelchair area to indicate that the primary use of the area is for wheelchairs and to provide instructions for operating the flip up seats.

See Sections 6 and 15 for additional information.

### **2.2.4 Bicycle Space**

Two dual-usage locations shall be provided for bicycle and luggage storage in each car section (A and B). The locations shall be at the articulation end of each main car body section, on opposite sides of the car. At each location provide a hanging type bicycle stowing racks that secures two bicycles in place. The bicycle racks shall be mounted as close to the sidewall as possible to allow for maximum passenger aisle width.

Bicycle stowage arrangement shall be submitted to Sound Transit for review and approval. (CDRL 2-1)

### **2.2.5 Identification**

Vehicles shall be sequentially numbered from the first production vehicle to the last. The numbering scheme shall utilize three-digit numbers, starting with 201 for the first vehicle. Vehicle numbers shall be installed on the exterior on both ends of the vehicle above the L/H and R/H cab

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side windows and on both sides of the center section. These vehicle numbers shall be reflective. In addition, vehicle numbers and body half identification letters (i.e. A or B) shall be installed on the side wall above the left side cab window in each cab area, and in the passenger compartment on the upper part of each cab and articulation bulkhead. Numbering locations, font and size, shall be submitted to Sound Transit for review and approval. (CDRL 2-2)

### 2.3 Critical Vehicle Dimensions

The dimensions shall be as indicated. Construction tolerances of dimensions shall be as approved by Sound Transit during the design review.

#### 2.3.1 Car Body Dimensions

<b>Car Body Dimensions</b>	
Length of vehicle over coupler faces:	90 to 95 ft (27,430 to 28,960 mm)
Length of vehicle over anticlimbers:	88 to 93 ft (26,820 to 28,350 mm)
Width of car body at widest point:	8.7 ft (2,650 mm)
Width of vehicle including door thresholds:	8.8 ft (2,680 mm)
Maximum high floor height above top-of-rail (AW0):	39 in (990 mm)
Low floor threshold height above top-of-rail at entrance (AW0):	14.0 in (356 mm)
Low floor height above top-of-rail may taper from entrance height to a maximum of (AW0):	16.0 in (406 mm)
Maximum low floor height variation above top-of rail at doorways, with loads from AW0 to AW3, (sum of suspension tolerances and deflection, and car body and truck tolerances and deflection) and under all environmental conditions:	+0.25 in, -0.625 in (+6 mm, - 16 mm)
Minimum interior ceiling height, finished floor to finished ceiling, on vehicle centerline (high floor, low floor, and articulation sections), except in the cabs:	6.7 ft (2,040 mm)
Minimum interior ceiling height in cabs:	6.5 ft (1,980 mm)
Side door minimum clear opening width with doors fully opened:	48 in (1,220 mm)
Distance from coupler face to centerline of cab-end doorway (see Figure 2-9)	20.0 ft $\pm$ 0.25 ft (6.1 m $\pm$ 0.076 m)
Distance from TWC transponder to centerline of cab-end doorway of opposite car section (see attachment drawing):	825.9 in (20,978 mm)
Distance from front of anticlimber to centerline of nearest motor truck	10 ft 7.9 in (3249mm)
Centerline of motor truck to centerline of center truck:	35 ft 10 in (10,922m)

<b>Car Body Dimensions</b>	
Fore jacking post location to aft jacking post location:	28 ft 6.6 in (8703 mm)
Aft jacking post location to aft jacking post location, opposite car body section:	15 ft 1.1 in (4600 mm)
Minimum clear side door height from finished floor:	6.5 ft (1,980 mm)
Maximum roof-mounted equipment height, including roof shrouds, exclusive of pantograph, above TOR with new wheels and vehicle at AW0:	12.4 ft (3,780 mm)
Coupler vertical centerline height above TOR, vehicle at AW0, with new wheels:	18.5 to 26.6 in (470 to 676 mm)
Top of anticlimber height over TOR, vehicle at AW0, with new wheels:	same as top of high floor
Minimum anticlimber height:	6 in (150 mm)
Minimum depth of interior step treads:	11 in (280 mm)
Maximum height of interior step riser:	9.85 in (250 mm)

Diagonal corner height difference due to construction tolerance, vehicle lateral imbalance, and suspension spring deflection, shall be equalized. This shall apply to the entire articulated vehicle or to each main body section depending on the design of the articulation.

### 2.3.2 Pantograph Dimensions

<b>Pantograph Dimensions</b>	
Maximum height above TOR of the highest point on the pantograph in the lockdown position, new wheels and vehicle at AW0:	12.7 ft (3,870 mm)
Pantograph operating height, dynamic conditions any vehicle weight AW0 to AW4, and with new to fully worn wheels:	Maximum: 22.3 ft (6,800 mm) Minimum: 13.0 ft (3,960 mm)
Collector head width over horns:	75 in (1,905 mm)
Minimum collector head carbon shoe length:	47 in (1,194 mm)
Radius of curved collector head carbon shoe:	19.7 ft (6.0 m)
Overall longitudinal width of shoe assembly in contact with the contact wire:	Nominal: 14.0 in (356 mm)
Maximum longitudinal distance from center truck centerline to center of pantograph shoe, locked down:	46 in (1,168 mm)
Static pantograph shoe force on contact wire:	Nominal: 18 lbf (80 N) Adjustable: 14 to 25 lbf (62 to 111 N)

### 2.3.3 Wheel Dimensions

<b>Wheel Dimensions*</b>	
Profile:	The tentative wheel profile for motor truck wheels is shown on Figure 2-5, Wheel Profile.
Motor truck, diameter	
New, nominal:	26 to 28 in (660 to 711 mm)
Minimum allowable wheel-diameter wear:	2 in (51 mm)
Center truck, diameter	
New, nominal:	24 to 26 in (610 to 660 mm)
Minimum allowable wheel-diameter wear:	2 in (51 mm)
Track gauge:	56.5 in (1435 mm)
Back-to-back dimension:	53.80 in, $\pm 0.06$ in (1,367 mm, $\pm 1.5$ mm)
Wheel width	
Motor truck:	5.25 in (133 mm)
Center truck:	5.0 to 5.25 in (127 to 133 mm)

\*Note: The dimensions given are nominal, and may ultimately be modified as a result of the Wheel-to-Rail Interface Study (WRIS), Reference 2.5.3.1 Wheel-to-Rail Interface Study section, below.

### 2.3.4 Truck Dimensions

<b>Truck Dimensions</b>	
Motor truck centerline-to-pivot center spacing:	Sufficient to comply with dynamic envelope
Motor truck wheelbase:	71 in to 75 in (1,800 mm to 1,900 mm)
Center truck wheelbase:	67 in to 75 in (1,700 mm to 1,900 mm)

### 2.3.5 Clearance Requirements

#### 2.3.5.1 General

Vertical undercar clearance is defined from TOR with the maximum suspension deflection (fully deflated air bags, down on the stops) and car body roll, minimum vertical curve radius, and fully worn wheels. Minimum vertical clearance shall be 2 in (51 mm)

Clearances between truck components and the car body shall be as specified in Section 11.

### 2.3.5.2 Dynamic Envelope

The dynamic envelope of the vehicle shall be limited to that shown on Figures 2-6, Vehicle Dynamic Envelope, and 2-7, Maximum Curve Offset. The Contractor shall prepare a dynamic envelope study to confirm that the vehicle complies with the specified dynamic envelope and to report on the actual dynamic envelope for the supplied vehicle. (CDRL 2-3)

The maximum dynamic roll angle, with a failed suspension, shall be limited to three degrees.

### 2.3.5.3 Station Platform Interface

The nominal horizontal gap between the platform edge and the edge of vehicle floor at the doorway shall be 2.48 in (63 mm), and in no case shall be greater than 3.0 in (76 mm) nor less than 1.5 in (38 mm), including platform tolerance. On tangent track, the platform edge is located at 55.25 in (1,403 mm) from track centerline. Refer to Figure 2-8, Platform Interface (dated October 14, 2004).

The nominal vertical gap between the platform horizontal surface at the platform edge and the vehicle floor surface at the doorway shall be 0 in (0 mm) and in no case shall be greater than 0.625 in (15 mm), including platform tolerance. Refer to Figure 2-8.

The Contractor shall communicate and cooperate with the ST wayside construction contractors on platform interface issues to ensure that the wayside/vehicle system complies with ADA requirements. The Contractor shall ensure that the LRVs comply with the ADA requirements on the existing North Link and East Link station platforms (CDRL 2-4). See Section 19.

## 2.4 Weight and Passenger Loading

### 2.4.1 Weights

The maximum empty vehicle operating weight shall be 103,000 lb (46,720 kg); exceeding this maximum weight will require remediation and/or redesign at the expense of the Contractor to bring the vehicle weight down to this maximum value. The maximum permitted weight of each vehicle, including passengers at 154 lb (70 kg) each, is defined as follows:

AW0	Maximum empty vehicle operating weight:	103,000 lb (46,720 kg)
AW1	Fully seated load of 74 persons minimum (74 passengers plus operator, plus AW0).	114,550 lb (51,960 kg)
AW2	Standees at 4 persons per m <sup>2</sup> of suitable standing space per passenger, 120 persons minimum, plus fully seated load.	131,182 lb (59,504 kg)
AW3	Standees at 6 persons per m <sup>2</sup> of suitable standing space per passenger, 180 persons minimum, plus fully seated load.	140,422 lb (63,695 kg)
AW4	Standees at 8 persons per m <sup>2</sup> of suitable standing space per passenger, 240 persons minimum, plus fully seated load.	149,662 lb (67,886 kg)

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All weights above are based on a ready-to-run vehicle, complete in all respects with all equipment, materials and fluids. Standing space is defined as all areas of the aisles where it is possible for passengers to stand, including wheelchair areas (assume no wheelchair passengers for the purpose of these calculations), but excluding the transition steps or ramps from low floor to high floor areas and an area 12 in (300 mm) wide in front of the longitudinal passenger seats for the legs of seated passengers. Note that the specified passenger loadings are minimum requirements. The ratings and safety factors of all vehicle equipment and systems shall be based on the actual weight and passenger capacity of the vehicle. The Contractor shall prepare a report on vehicle weight, passenger load calculations, and weight unbalance. (CDRL 2-5)

### **2.4.2 Weight Balance**

The equipment shall be so arranged such that each vehicle, complete with all necessary apparatus and for all passenger loading conditions specified, shall meet the following balancing requirements:

- The vehicle weight supported at the rail by the center truck shall be within the range of 25% to 40% of the total vehicle weight for all loading conditions from AW0 to AW2.
- The difference in vehicle weight supported at the rail by the A-End and B-End trucks shall not exceed 2,000 lb (900 kg) for all loading conditions from AW0 to AW3.
- The lateral imbalance shall not exceed 2,083 lbf-ft (2,824 N-m) for all loading conditions from AW0 to AW3.

### **2.4.3 Weight Control**

Beginning 90 days after Contract Notice to Proceed and every 90 days thereafter until the weighing of the first vehicle, the Contractor shall submit to Sound Transit a report on the estimated total vehicle weight and weight balance. (CDRL 2-6) The submission shall include the most recent weights for the vehicle carshell, including the body bolster but less trucks, each truck, and the complete vehicle. It shall also include a list of weights for every system on the vehicle, and an indication of the percentage of the estimated weight that the system contributes to the total estimated weight. As scale weights become available, they shall replace the estimated weights in these reports. The Contractor shall require the full cooperation of its subcontractors in this effort, and shall require weighing of sample components at the earliest possible dates. The Contractor shall provide a Sound Transit approved form for submitting this information. (CDRL 2-7)

## **2.5 Operating Environment**

### **2.5.1 Right-of-Way Description**

The vehicle shall operate successfully on the Sound Transit Link light rail system, as described below.

## **2.5.2 Line Segments**

### **2.5.2.1 North Link Segment**

The Sound Transit North Link light rail system extends from Northgate in the North, south to South 200th Street.

From the SeaTac Airport Station to South 200<sup>th</sup> Street the line will run on aerial guide way above 28<sup>th</sup> Avenue South to a station at South 200<sup>th</sup> Street.

The North Link project continues in a tunnel from the University of Washington Station to a cut-and-cover station on Brooklyn Avenue south of 45<sup>th</sup> Street. From there it continues in a tunnel to a cut-and-cover station in the Roosevelt neighborhood. The tunnel then extends north under the Lake City interstate ramps to a portal where it travels along Interstate 5 at roughly the same level as the freeway to an elevated station west of the Northgate Transit Center.

### **2.5.2.2 East Link Segment**

The East Link project will connect to the existing line at the International District/Chinatown Station in Seattle and extend to the Overlake Transit Center in Redmond. The alignment uses I-90 across Lake Washington with stations at Rainier Avenue and Mercer Island. In South Bellevue, a station is planned at the South Bellevue Park and Ride. There are either one or two downtown Bellevue stations planned, a Hospital station, one or two Bel-Red stations, an Overlake Village station and a terminal station at the Overlake Transit Centre

### **2.5.2.3 Lynnwood Link Segment**

The North Corridor Project extends from the Northgate Station to a station in Lynnwood. The project serves the cities Seattle, Shoreline, Montlake Terrace and Lynnwood. The alignment is assumed to be primarily elevated along Interstate 5. There are four stations planned north of the Northgate Station.

### **2.5.2.4 Future Stations**

Future passenger stations will be constructed as existing stations with 380-foot long platforms to accommodate 4-car trains.

### **2.5.2.5 Maintenance Facilities**

Sound Transit's Operations and Maintenance Facility (OMF) is located in SODO (SOuth of DOwntown). The OMF is a four-story, 162,000-ft<sup>2</sup> (15,050 m<sup>2</sup>) building that contains component repair shops, electronics repair shop, a signals and communications lab and a communications maintenance shop. The storage yard can accommodate 104 LRVs and will reach full capacity by 2020 as Sound Transit expands the light rail vehicle fleet from 62 to 184 LRVs as part of the Sound Transit 2 voter approved ballot measure. The plan adds regional express bus and commuter rail service while building 36 mi (58 km) of additional light rail to form a 55-mi (89-km) regional system.

Sound Transit will construct a secondary maintenance facility in Bellevue, WA. This future Operations and Maintenance Satellite Facility (OMSF) site will be used to store, maintain and dispatch vehicles for daily service as well as preventive maintenance inspections, light maintenance, emergency maintenance, interior vehicle cleaning, and exterior car washing.

### **2.5.3 Right-of-Way Interface Design Constraints**

The tentative physical constraints of the Track, Yard and Wayside are included below. The dimensions shall be confirmed by the Wheel-to-Rail Interface Study described in this Section. No warranty is made by Sound Transit that track will be maintained in its new condition.

<b>Track Geometry</b>	
Rail Types:	115 RE and Ri-52N
Rail Cant (115 RE):	1:40, except for special track work sections.
Minimum horizontal curve radius:	82 ft (25 m)
Minimum vertical curve radius, crest:	820 ft (250 m)
Minimum vertical curve radius, sag:	1,150 ft (350 m)
Minimum frog number:	5
Track gauge:	56-1/2 in (1435 mm)
The track gauge may be narrowed in paved track curves.	
Maximum track super-elevation:	6 in (150 mm)
Maximum track super-elevation, unbalance:	3 in (75 mm)
Maximum gradient:	7%

A two-car train shall be capable of negotiating the following curves:

- Reverse vertical curves: A reverse vertical curve section involving,
  - First, a crest curve of 820 ft (250 m) and a sag curve of 1,150 ft (350 m), separated by a tangent section of 43 ft (13 m); and
  - Second, a crest and sag curve of 1,640 ft (500 m) with no separation..
- Compound curves: A compound (horizontal and vertical) curve involving,
  - First, an 82 ft (25 m) radius horizontal curve and a 1640 ft (500 m) radius vertical curve, either crest or sag;
  - Second, an 89 ft (27 m) radius horizontal curve and an 1150 ft (350 m) radius sag curve; and
  - Third, a 95 ft (29 m) radius horizontal curve and an 820 ft (250 m) radius crest curve.

### **2.5.3.1 Wheel-to-Rail Interface Study**

Within 90 days of NTP, the Contractor shall submit its Wheel-to-Rail Interface Study (WRIS) plan and schedule to Sound Transit for review. (CDRL 2-8)

Upon receipt of Sound Transit's written approval, the Contractor shall conduct the WRIS of the entire ST alignment. The WRIS shall include determination of the optimal wheel-set back-to-back dimension, wheel dimensions, track gauge under varying conditions on tangent track, curved track, and in special trackwork, for both tee rail and girder rail, and rail head and wheel profiles. The report of the WRIS shall be submitted to Sound Transit for review upon completion of the study, and, upon approval of the report by Sound Transit, the recommendations of the study shall become part of the Contract Documents and the vehicle design requirements. (CDRL 2-9)

The WRIS shall, as a major goal, ensure the compatibility among the chosen rail sections, track design, the car truck design, and the wheels. It shall optimize the combined design of the wheel to rail interface for long term wheel and rail wear, minimum propensity to derail, wheel/rail noise reduction, wayside vibration reduction and ride quality enhancement.

The Contractor shall be responsible for coordination among the various parties to the wheel-to-rail interface in the conduct of the study, and shall implement the results of the ST-approved WRIS on the vehicle elements.

Vehicle dynamic simulations shall also be included in the WRIS to confirm analytically, prior to actual track testing, that the following requirements in Section 11 will be met:

- High speed stability, ride quality and center truck performance.
- Primary suspension longitudinal stiffness.
- Safe operation with inoperative secondary suspension.
- Truck swiveling.
- Wheel load equalization.

### **2.5.4 Anticipated Climatic Conditions**

The vehicle shall be capable of being operated at the specified performance levels, stored, and maintained without impairment resulting from the natural or induced environmental conditions within which Sound Transit will operate the vehicle.

The following climatic factors shall be used as design guidelines and shall be considered as operational requirements. Actual localized temperatures and conditions within and under the car body may be more severe than the ambient climatic conditions and the Contractor shall be responsible for evaluating these during its design effort and submitting these for review and approval (CDRL 2-10). Additionally, the Contractor shall be responsible for advising Sound Transit if there are any special environmental factors to which its equipment may be sensitive that are not listed below. The Contractor shall ensure that no equipment damage occurs during manufacture, storage, shipment and revenue service as a result of climatic conditions which may differ from those below.

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The vehicle shall operate as specified in the Seattle metropolitan area. Equipment and hardware, including seals, elastomers, and lubricants, shall be selected for the Seattle metropolitan area temperature extremes. Exposed equipment shall be selected or designed to operate with 1 in (25 mm) of ice accumulation. Equipment and equipment ventilation systems shall be designed to operate in dry or wet blowing snow conditions of the Seattle metropolitan area.

The following environmental conditions shall be considered as design guidelines:

### Temperature:

Minimum ambient temperature:	0°F (-18°C)
Maximum ambient temperature:	107°F (42°C)

### Humidity

Minimum humidity	40%
Maximum humidity	100%

### Precipitation

Maximum Rainfall Rate	3.4 in/24 hr (86 mm/24 hr)
Maximum Snowfall Rate	6 in/24 hr (150 mm/24 hr)

Possible Snow Accumulation (not including snow drift accumulation due to winds)	12 in (305 mm)
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### Wind Velocity:

Continuous	52 mph (23 m/s)
Gusting	71 mph (32 m/s)

#### **2.5.4.1 Fordability**

With maximum wheel wear, the LRV shall operate without damage or equipment malfunction in water up to 2 in (51 mm) above the top of rail and at speeds up to 10 mph (16 km/h).

#### **2.5.4.2 Road Contamination**

The vehicle shall operate in the presence of calcium chloride (used as a snow melting salt), sand, dust, trash and leaf accumulation, and subway tunnel dust (up to 70% metallic) on the streets and rights of way in Sound Transit's service area. Vehicles shall suffer no long term damage from continuous exposure to the contaminants noted above.

#### **2.5.5 Wayside Power Supply**

Power will be supplied to the vehicle by an overhead contact system (OCS) that is primarily auto-tensioned simple catenary. In addition, the existing downtown tunnel section uses fixed termination single suspended contact wire with an aerial feeder system. The new tunnel will use

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fixed termination simple catenary, and the yards and shops will use fixed termination single contact wire.

Braking system performance, whether dynamic, friction, or a combination of these blended, shall be met regardless of the overhead contact system voltage, or its absence, from all possible combinations of climatic conditions.

The sources of the (OCS) voltage are dc transformer/rectifier substations, 6% regulation, 12-pulse rectification. The OCS voltage conditions are defined as follows:

Nominal:	1,500 Vdc
Maximum regeneration voltage:	1,800 Vdc
Maximum sustained:	1,900 Vdc
Minimum sustained:	900 Vdc

All vehicle equipment shall operate continuously over the range of 900 Vdc to 1,900 Vdc without damage, failure of the equipment to function as specified, or reduction of required service life.

Below line voltages of 1500 Vdc, however, propulsion performance may be reduced as defined elsewhere in the Specifications. Refer to the Propulsion and Braking Assumptions, and Acceleration sections, below.

Auxiliary equipment operated directly from the line voltage shall be rated for full performance at line voltages of 900 Vdc to 1,900 Vdc except for high voltage dc heating elements, if permitted, which shall be rated for full performance at line voltages of 1,500 Vdc and above.

Low voltage cut-out of systems shall be at or below 900 Vdc. High voltage cut-out shall be at or above 1,900 Vdc. The systems shall reset when the voltage decreases below 1,850 Vdc or higher voltage.

Vehicle equipment shall be impervious to damage on continuous overhead voltages from 0 to 1,900 Vdc.

## **2.6 Supply Voltages**

### **2.6.1 Low Voltage DC Power System**

A low voltage dc power system shall be provided and configured to supply nominal 28.5 Vdc power to all low voltage dc apparatus.

All equipment operating from the low voltage dc power system shall function normally, without failure or degradation in serviceable life, at voltages between 18 Vdc and 34 Vdc, at the equipment input terminals, for indefinite duration, and shall not be damaged by the continuous application of voltages between 0 and 34 Vdc.

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Where circuits are powered through trainlines, powered apparatus shall function satisfactorily in all vehicles, including the last vehicle of a four-vehicle train of LRVs, when the trainlines are powered from the lead vehicle's low-voltage dc power system, with minimum operating voltage as indicated above. Towed or otherwise disabled cars may have limited trainlined functionality, but at a minimum braking, lighting, communications and door operations will function properly. In a towed emergency consist, the lead vehicle's low-voltage dc power system can be considered to be nominal voltage rather than minimum.

Additional low voltage dc power system requirements are contained in Section 9.

### **2.6.2 Ac Power System**

A 208 Vac rms, 3-phase, 4-wire, 60 Hz power system shall be provided for all 3-phase ac loads. The ac power source shall also provide 120 Vac power to single-phase loads, as required or specified. Refer to Section 9 for additional requirements.

### **2.6.3 Abnormal Electrical Levels**

All equipment on the vehicle shall be self-protected from damage and improper operation due to:

- High voltage transients across the supply terminals of that equipment; and
- Long term over-voltage and under-voltage conditions resulting from equipment failure modes.

### **2.6.4 Transients and Abnormal Electrical Conditions**

The vehicle shall provide protection against transients and voltage surges typical of rail transit, and as specified in IEC 60850 and IEC 61287-1.

All equipment on the vehicle shall be protected from damage and not be subject to continued shutdown due to random interruptions of the OCS power due to isolation gaps, pantograph bounce, or other conditions.

## **2.7 Propulsion and Braking Performance**

The following establishes the performance required of the LRV, whether in a single vehicle consist or multiple-unit consist of up to and including four vehicles and of similar or dissimilar weights, as specified below.

### **2.7.1 Propulsion and Braking Assumptions**

The propulsion and braking equipment shall provide the performance specified below. The basis for performance calculations, designs and evaluation shall be as follows:

- All acceleration, braking and jerk rates shall be based on level tangent dry track in still air except when otherwise noted.

## *Design and Performance Criteria*

- Propulsion equipment shall provide the indicated acceleration performance at 1500 Vdc line voltage and higher, except where indicated otherwise.
- All requested acceleration rates and time-to-speeds shall be provided from AW0 to AW2. At weights above AW2, the acceleration rate may decrease by the ratio of AW2 to the actual weight.
- All requested braking rates shall be provided from AW0 to AW3. For weights above AW3, the rate may decrease by no less than the ratio of AW3 to the actual weight.
- Braking rates shall be independent of the line voltage and, once initiated, full dynamic braking capabilities shall be available without line voltage present.
- Dynamic braking shall provide 100% of the braking efforts for all car weights from AW0 to AW2. Above AW2 car weight, dynamic brake effort may be limited to no less than the dynamic braking power provided at AW2 car weight. For weights over AW2, the center truck and motor truck friction brakes shall supplement dynamic braking to provide the requested brake rates.
- Friction braking shall automatically supplement dynamic braking to achieve the requested rate in all cases where dynamic braking is providing less effort than necessary for the rate request.
- All specified performance capabilities shall be provided over the full range of the following, as specified elsewhere:
  - Wheel wear
  - Ambient temperatures
  - Low voltage power supply voltage
- The vehicle shall be capable of operating at speeds of 5 mph (8 km/h) or less continuously at AW2 on any portion of the Sound Transit system without overheating or damage to the vehicle, vehicle components or equipment. This requirement includes cycling the master controller to maintain desired the speed.

### **2.7.2 Acceleration**

The vehicle shall provide acceleration capabilities as follows:

- Instantaneous acceleration of 3.0 mphps (1.34 m/s<sup>2</sup>),  $\pm 5\%$ , from 0 to 20 mph (32 km/h) at master controller maximum power position,
- Below 1,500 Vdc the speed to which the initial acceleration rate is achieved may decrease proportional to line voltage.
- From a standing start, time to reach 25 mph (40 km/h) shall not exceed 10 s. Time to reach 50 mph (80 km/h) shall not exceed 35 s. These times are measured from the change in trainline signals at the propulsion equipment.

## *Design and Performance Criteria*

- The range of vehicle accelerations available to the operator shall be continuously variable between (no greater than) 0.3 mphps (0.13 m/s<sup>2</sup>) to the full acceleration as indicated above. Refer to Section 5 for Master Controller commands.
- When in the propulsion mode, the propulsion system shall linearly reduce the maximum line current as the line voltage decreases below 1,200 Vdc, with a setting of 100% at 1,200 Vdc and 40% at 900 Vdc. The set points and percentages shall be software adjustable so that the system can be fine-tuned when the cars are operated on any ST alignment.

### **2.7.3 Continuous and Balancing Speed**

The vehicle shall have sufficient tractive effort to achieve a minimum balancing speed of 60 mph (97 km/h) on level tangent track, over the specified range of wheel wear, at nominal line voltage, AW2 weight, and in still air. All vehicle equipment shall operate continuously at this balancing speed without damage or reduction in design life.

Minimum balancing speed at AW2 on a 5% uphill grade shall be at least 40 mph (64 km/h).

Actual operating speed shall be limited to 59 mph (95 km/h) by overspeed protection (refer to Section 14).

All vehicle equipment shall have sufficient safety margins to operate without damage, with fully worn wheels, at speeds no less than 65 mph (105 km/h).

### **2.7.4 Car Wash**

A car wash function shall be provided to regulate car speed when the cars are operated through the car wash. The speed regulation point shall be software adjustable over the range of 1 mph to 4 mph (1.6 km/h to 6.4 km/h). See Section 5.

### **2.7.5 Service Braking**

Service braking shall be provided by dynamic braking and disc braking. Dynamic braking shall be a combination of regenerative and rheostatic braking, with regenerative braking prioritized as appropriate for the specific overhead power receptivity condition. The system shall provide braking capability as follows:

- For a full service brake (FSB) request, at all vehicle weights up to AW2, the dynamic braking shall provide an instantaneous rate of 3.0 mphps (1.34 m/s<sup>2</sup>), +/-5%, for all speeds from at least 45 mph (72 km/h) down to the dynamic brake fade speed. For speeds from 59 mph (95 km/h) to no lower than 45 mph (72 km/h), the dynamic brake instantaneous rate may taper from a minimum of 2.0 mphps (0.89 m/s<sup>2</sup>), +/-5%, at 59 mph (95 km/h) to 3.0 mphps (1.34 m/s<sup>2</sup>), +/-5%, at 45 mph (72 km/h).
- For braking that is blended dynamic and friction, the instantaneous rates above shall apply, except that the tolerance may be increased to +/-10%.
- Dynamic brake efforts may start to fade at speeds no higher than 6 mph (9.7 km/h). Below that speed, disc brakes shall be proportionately blended in to provide the requested brake

rates down to zero speed. The transition from dynamic to friction braking shall be managed such that the tolerances above are maintained.

- In the event of dynamic brake failure on any given truck, the disc brakes on that truck, and the center truck as necessary, shall provide an average deceleration rate of 3.0 mphps (1.34 m/s<sup>2</sup>) ±15%. Average deceleration rate is defined as the change in vehicle speed divided by the elapsed time. The elapsed time (for calculation purposes) shall be defined as the time from 95% of the braking entry speed down to 2 mph (3.2 km/h), or to 5% above final speed in the event that a complete stop is not commanded. This deceleration rate shall be met from the speed at which the dynamic brake failure occurred until a complete stop. Instantaneous variations in deceleration rate of ±20% of the average rate will be allowed for the disc brake during any particular run to accommodate normal friction material non-linearities.
- When the dynamic brake system is inoperative on any truck or car, all vehicles in the train shall be automatically limited to a top speed of no less than 25 mph (40 km/h). Refer to this Section as well as Sections 5 and 10 for additional discussion of speed restrictions.
- The range of braking rates available to the operator shall be continuously variable between (no greater than) 0.3 mphps (0.13 m/s<sup>2</sup>) to full braking rate as indicated above. Refer to Section 5 for Master Controller commands.
- A Safety Brake (SB) rate of 2.0 mphps (0.89 m/s<sup>2</sup>) shall be available from 59 mph (95 km/h) to standstill for use by the ATP and Deadman Systems. The instantaneous blended brake tolerance shall be ±5%, and the average braking rate tolerance with one or more (per vehicle) dynamic brake failures shall be ±15%. Refer to this Section and Section 5.

### **2.7.6 Brake Blending**

The dynamic and disc brake systems shall be continuously blended to provide any specified braking rate throughout the operating speed range.

The control scheme shall maximize the use of dynamic braking, as defined above. Center truck disc brakes shall be used to supplement dynamic braking and motor truck friction braking only above vehicle weight AW2, or in the event of a dynamic brake failure.

During maximum brake applications, center truck disc brake effort shall be applied in proportion to vehicle weight at the center truck; however, the center truck maximum braking effort may be reduced below the nominal effort (based on proportional load) to decrease the probability of damage to the independent center truck wheels due to wheel slides, as long as the specified maximum brake rate is achieved. Refer to the Maximum Braking section, below.

Blending on all trucks shall provide for a smooth stop after dynamic brake fade.

Refer to Section 10 for a description of rheostatic and regenerative dynamic brake blending.

### **2.7.7 Braking Supervision**

Braking supervision will be provided as part of the Cab Signal equipment. Refer to Section 14.

### 2.7.8 Maximum Braking

Maximum braking (MXB) is considered a safety system, and all MXB circuits shall be arranged in a fail-safe manner. The MXB trainline circuit shall require both energization and continuity throughout the train to allow a permissive state. The maximum brake trainlines shall be treated as vital trainlines, with maximum isolation maintained from possible sources of false energization.

MXB shall be controlled by a four wire trainline. The controlling cab shall provide the positive and negative feeds to the trainlines through the Master Controller, ATP logic and the console MXB pushbutton switch. Commanding MXB shall cause the switches in both the positive and negative feeds to open, removing power to the MXB inputs. Other MXB switches in the train shall be provided in the positive and negative MXB loop trainline to cause all cars in the train to apply the maximum brake regardless of the switch location in the train.

Manual application of MXB shall be possible from the Master Controller and the console MXB push button switch. Automatic application of MXB shall be initiated by those events shown as automatic in Table 2-1 below.

MXB shall use the combination of load compensated dynamic brake and friction disc brake plus track brake and sanding to produce a high rate brake application. The MXB command shall override jerk limit. The friction brake system shall have the capability of producing the specified rate for at least one 55 mph (88 km/h) stop in case of dynamic brake failure.

An MXB command shall be irretrievable from the speed at which it is commanded down to the no motion detection speed. Sand shall be automatically applied until the no motion detection speed is achieved. The track brake command shall be interlocked with the no-motion signal so that MXB commanded track brakes are released when no motion is detected.

The spin/slide system shall function only when MXB is commanded by the master controller, and shall be cut out when the MXB is commanded by other means (see Table 2-1 below).

<b>Table 2-1 Maximum Braking</b>				
<b>MXB initiated by:</b>	<b>Manual/ Automatic</b>	<b>Spin Slide</b>	<b>Notes</b>	<b>Reference Section</b>
Master controller (MXB Position)	Manual	Yes	Provide auxiliary contacts to enable spin-slide	5.1.2.1.3
MXB pushbutton switch	Manual	No		5.3.4
Overspeed (ATP)	Automatic	No		14.2.2.1
Unintentional uncoupling	Automatic	No		4.3
Activation of more than one reverser switch at the same time	Automatic	No		

<b>Table 2-1 Maximum Braking</b>				
<b>MXB initiated by:</b>	<b>Manual/ Automatic</b>	<b>Spin Slide</b>	<b>Notes</b>	<b>Reference Section</b>
MXB trainline loss of energization or continuity	Automatic	No		

For brake entry speeds equal to or greater than 30 mph (48 km/h), the minimum MXB rate, at all weights up to AW3, shall meet or exceed the values calculated by the following equation:

$$R_{AVG}[\text{mphs}] = -0.02v [\text{mph}] + 5.6 \text{ (US)}$$

$$R_{AVG}[\text{m/s}^2] = -0.006v [\text{km/h}] + 2.5 \text{ (SI)}$$

Where:  $R_{AVG}$  is the average MXB rate, in mphs ( $\text{m/s}^2$ ) measured in the manner defined below; and  $v$  is the brake entry speed in mph (km/h).

For brake entry speeds greater than 15 mph (24 km/h) and less than 30 mph (48 km/h), the average MXB rate shall be a minimum of 5.0 mphs ( $2.23 \text{ m/s}^2$ ) and shall not exceed this rate by more than 30%.

For vehicle weights greater than AW3, the minimum MXB brake rate may decrease linearly from AW3 to AW4 down to a value determined by the ratio of AW3 to AW4 weight times the required AW3 rate. The maximum MXB rate shall not exceed the specified minimum average MXB rate by more than 30%.

Average MXB rate (RAV) is defined as brake entry speed divided by elapsed stopping time, averaged for two stops in each direction at approximately the same location. Brake entry speed is the vehicle speed at the time the MXB command trainlines are de-energized. Elapsed stopping time is measured from the time the MXB command trainlines are de-energized to the time the vehicle comes to a full stop.

For brake entry speeds of less than 15 mph (24 km/h), the instantaneous MXB rate after the rate has built up shall be a minimum of 5.0 mphs ( $2.24 \text{ m/s}^2$ ) and the maximum rate shall follow the characteristics of the magnetic track brake.

### 2.7.9 Wheel Spin/Slide Correction

A system shall be provided to detect and correct wheel spin and slide on each vehicle whether random or synchronous, on an individual truck basis, both in acceleration and braking. If independent control of center truck axles is provided for friction braking, slide control shall also be provided on this basis; regardless slide control shall be provided for the center truck whether independently controlled or controlled by a power truck. The spin/slide system shall be designed for safe operation such that a spin/slide system failure shall not prevent the application of braking at any level less than commanded, in any braking mode.

## *Design and Performance Criteria*

- The spin/slide system shall be functional under all acceleration and all dynamic and disc braking commands except for certain maximum brake applications, as shown in Table 2-1 above.
- The spin/slide system shall shorten stopping distance under adverse rail conditions and minimize damage to the wheel treads caused by wheel slide or spin.
- Spin/slide control algorithms shall provide both modified torque release for minor spins or slips, and full release for major spins or slides, with iterative control to reset the torque command level to the maximum sustainable level.
- The spin/slide system shall monitor the axle speeds of the motored axles and all wheels of the un-motored truck and shall detect slides or spins by evaluation of axle or wheel speed differences and acceleration/deceleration rate levels. Actual, analog speeds from each axle shall be directly provided to each spin/slide controller on the car in real time. Digitally processed speeds, such as those which may be distributed by a data bus, are not acceptable for this purpose. The system shall include a feature that shall modify the deceleration rate detection level during track brake applications.
- Spin/slide efficiency is defined as the average vehicle deceleration or acceleration rate expressed as a percentage of the rate which available adhesion is capable of supporting. The method by which the Contractor proposes to measure the available adhesion on any test run shall be submitted to Sound Transit for approval. The efficiency of the wheel spin/slide system at a coefficient of adhesion of 0.05 or greater shall be at least 85% in acceleration, and all braking modes including dynamic, blended, and 100% friction over the speed range between maximum speed and 3 mph (5 km/h).
- Sanding shall be applied automatically during correction of major spins and slides. Refer to Section 12.
- Operation of the spin/slide system shall not induce sustained acceleration or deceleration level oscillations at frequencies above 1.5 Hz.
- The wheel spin/slide correction system shall function properly with differences of up to 2 in (50 mm) in diameter among the wheels of a vehicle. Automatic wheel size adjustment shall be provided (see Section 10).
- A separate safety timing function shall be provided to trip and override the friction brake release on each truck after 3 s from slide detection if the braking effort on the truck remains below 25% of the commanded value for more than that time period. Minor slides shall time out after 10 s. The timer, if timed out, shall be reset by sensing coast or power modes. If not timed out the timer shall be reset by correction of the slide.

### **2.7.10 Jerk Limits**

In response to a step input command signal, the average rate of change of actual acceleration or deceleration, after any mode change dead time, shall be between 2.5 mph/s<sup>2</sup> and 3.0 mph/s<sup>2</sup> (1.1 m/s<sup>3</sup> to 1.3 m/s<sup>3</sup>). Where the command signal is changing at a rate that is less than the jerk rate, the system shall follow the command signal rate of change within specified accuracy limits. Jerk

limiting shall produce linear outputs, and shall be designed such that the maximum available braking rate shall not be reduced due to failure of the jerk limiting function.

- The jerk rate limits specified shall apply to all normal power and service braking applications and removals
- Release of power when traversing overhead primary power isolation gaps need not be jerk limited; however, reapplication of power must be jerk limited.
- Maximum brake applications shall not be jerk limited.
- For direct mode change between Power and Brake via master controller, jerk limiting of power removal shall be canceled when the master controller reaches the brake position. Friction disc brake release at speeds less than approximately 3 mph (5 km/h) shall not be jerk limited.
- Reapplication of braking effort following a reduction in effort due to slide control shall be jerk-limited.

### **2.7.11 Mode Change Dead Times**

The trainline controls and propulsion system (including dynamic brake) mode change dead time shall be less than 300 ms for the following direct mode changes:

- Power to Brake
- Power to Coast
- Coast to Brake
- Coast to Power
- Brake to Power - below 3 mph (5 km/h)

For the direct mode change Brake to Power, above 3 mph (5 km/h), the trainline controls and propulsion system mode change dead time shall be less than 400 ms. Removal of braking shall not be jerk limited; however, application of power shall be.

The trainline controls and friction brake system mode change dead time for all cases in the prior two paragraphs shall be less than 500 ms.

Mode change dead time shall be measured from the time that the source of the control trainline(s) change(s) state until the vehicle acceleration or deceleration reaches 90% of the previously commanded value, or 10% of the new commanded value, respectively, for mode changes to or from coast, and until the vehicle acceleration or deceleration reaches 10% of the new commanded value for mode changes between brake and power.

### **2.7.12 No-Motion Detection**

Apparatus shall be provided to detect all vehicle motions down to, and including, 1 mph (1.6 km/h). The speed detection system shall generate a safe signal, indicating that no-motion has been detected, for other vehicle systems that require such information.

## *Design and Performance Criteria*

The no-motion detection system shall monitor all propulsion speed sensors and be integrated into the propulsion electronic control unit.

No-motion detection shall be on a per vehicle basis and shall not be trainlined.

Refer to Section 5 for no-motion bypass requirements and other sections for various interfaces with the no-motion detection system.

Refer to this Section for safety design requirements.

### **2.7.13 Load Compensation**

A load measuring system shall be provided to maintain the acceleration and braking requirements of this Section. The system shall independently measure the loading on each of the three trucks. Propulsion and braking efforts shall be adjusted on a per truck basis to compensate for actual load. Each propulsion unit is to provide tractive effort to compensate for the load on its associated power truck and one half of the load on the center truck.

Failure of the load compensation system shall result in braking effort normally provided for AW0 vehicle weight on the affected truck.

### **2.7.14 Parking Brake**

The parking brake system shall be capable of holding a vehicle at all weights up to AW4 on a 7% grade indefinitely.

### **2.7.15 Duty Cycle Rating**

The vehicle shall be capable of continuous operation on the ST light rail alignment without exceeding the continuous rating of any equipment, under the following conditions:

- The vehicle shall be as described in the Specifications
- A constant AW3 load
- A dwell time of 20 s at each stop
- Acceleration and braking at maximum service rates
- Operation to and maintenance of maximum track speeds
- A 120 s layover at each end of the line

In addition, a train with an AW3 load shall be capable of pushing or towing another train of equal length with an AW3 load from the point of equipment failure to the next station, where passengers would be unloaded, and then continue with both trains at AW0 load to the end of the line, at reduced performance, without damage or reduction in equipment life. The point of failure shall be considered to be at the farthest location on the line from either end of the line such that the worst load is imposed on the equipment. The train will be dispatched to the nearest end of the line. The

train operating in this condition would be operated out of service with no passengers. Maximum speed will be reduced, by rule book, to not less than 25 mph (40 km/h).

If dynamic braking on a vehicle or truck becomes inoperative, the affected truck(s) shall be assumed to have inoperative propulsion systems, the vehicle and its train shall be limited to a speed restriction of 25 mph (40 km/h)  $\pm 1$  mph ( $\pm 1.6$  km/h) as described in Section 10, and the load shall be considered to be AW2. A vehicle with one failed propulsion system and an AW2 load shall be capable of continuous operation on the alignment at 25 mph without exceeding the continuous rating of any equipment under the conditions stated above.

### **2.7.16 Safety Brake**

When a Safety Brake (SB) application is requested or induced due to failure of the ATP system or the Master Controller Deadman function, the Master Controller electronics shall command a 2.0 mphps (0.89 m/s<sup>2</sup>) service brake application. Interface between devices shall be by a vital circuit that complies with the requirements of this Section.

## **2.8 Noise, Vibration, Ride Quality**

### **2.8.1 General**

Unless otherwise indicated, noise level (as defined by ANSI S1.4-1) is the weighted sound pressure level measured by the use of a metering characteristic and weighing A, B, or C as specified in ANSI S1.4-1. The unit of noise level is decibels (dB), and the reference pressure is 20  $\mu$ Pa.

Noise levels shall be measured in dB on the A scale (dBA) with slow meter response setting for stationary vehicle measurements, and fast meter response for moving vehicle measurements. A Type 1 sound level meter, in accordance with ANSI S1.4-1, shall be used. For the 1/3 octave band measurements, filters shall be causal infinite impulse (IIR) 6-pole filters conforming to Class 0 specifications for 1/3 octave band filters as defined in ANSI S1.11-1. For octave band measurements, filters in accordance with Class 0 specifications in ANSI S1.11-1 shall be used.

Under steady operating conditions, the root-mean-square averaging time shall be 1 s, corresponding to the SLOW meter response. The total measurement duration per event shall be for 2 min or the entire duration of the event, whichever is shorter. The reported noise levels shall be the maximum 5 s L<sup>eq</sup> during the train event.

Unless otherwise noted, specified noise limits shall be for continuously-operating equipment and shall not apply to equipment that operates occasionally, such as a circuit breaker, pneumatic pressure relief device, or air system drain valve.

### **2.8.2 Pure Tones**

The maximum allowable noise level shall be reduced by at least 3 dB if significant pure tones in the range from 250 Hz to 4,000 Hz are present in the noise. Pure tone noise shall be considered significant in this context if any one-third octave band sound pressure level is 5 dB, or more, higher than the arithmetic average of the two adjacent bands containing no pure tones.

### **2.8.3 Interior Noise**

Measurements of interior noise levels shall be taken in a fully equipped vehicle with no personnel on board other than the person performing the measurements, an observer, and the car operator for moving car tests. Measuring points shall be as follows:

- Forty in (1000 mm) below the geometric center of each return air grill
- Not less than 1 ft (305 mm) from the ceiling, end walls, or side walls
- Not less than 10 measurements at the height of the average seated passenger's ears at representative locations throughout the vehicle
- Not less than 10 measurements at the height of the average standing passenger's ears at representative locations throughout the vehicle
- One at the height of the average Operator's ears when seated in the cab seat

With the vehicle stationary with windows and doors closed, with all auxiliary equipment operating simultaneously under normal operating conditions, the interior noise level shall not exceed 68 dBA.

With the vehicle operating on the ST alignment (except in a tunnel or through an underpass) on non-corrugated rail, at any speed up to 55 mph (88 km/h), in any curve down to 82 ft (25 m) radius, and under any acceleration or deceleration condition, interior noise shall not exceed 75 dBA.

With the vehicle operating in the tunnel on non-corrugated rail, at any speed up to 55 mph (88 km/h) and under any acceleration or deceleration condition, interior noise shall not exceed 80 dBA. Assume a concrete lined tunnel with smooth reflective surfaces.

Noise generated by the Public Address System, measured 1 ft (305 mm) from any loudspeaker with the PA system energized and operating in a standby condition, and with any electrical system energized, shall not exceed 40 dBA.

Noise generated separately by any side door operation, measured with the fast meter response, 1 ft (305 mm) inboard from the doorway centerline at a height of 5 ft (1.5 m) above top of floor, shall not exceed 72 dBA.

Noise generated by airflow through the return air grill shall not exceed 72 dBA when measured 40 in (1000 mm) below the geometric center of each grill.

### **2.8.4 Wayside Noise Limits**

All measurements of exterior noise levels shall be made with the train on or operating on level, tangent track in an essentially free-field environment such as outdoors, away from any reflecting surfaces other than ballast, ties, newly ground welded rail, and the adjacent terrain. The measurement shall be taken at a distance of 50 ft (15 m) from the centerline of the track, 5 ft (1.5 m) above the ground. When taking noise measurement to comply with this section no physical barriers shall exist between the LRV and the measuring devices.

## Design and Performance Criteria

Average noise levels emanating from the vehicle shall not exceed the following levels with all auxiliary equipment operating simultaneously:

Test Condition	Meter Response	Noise Level
Vehicle stationary, empty	Slow	68 dBA
Vehicle empty, on tangent track accelerating from 40 mph (64 km/h) or in maximum dynamic braking or maximum friction braking from 40 mph (64 km/h) (whichever is worse). The vehicle shall be operated with wheels in new condition.	Fast	75 dBA
Two vehicles empty, on tangent track accelerating from 40 mph (64 km/h) or in maximum dynamic braking or maximum friction braking from 40 mph (64 km/h) (whichever is worse). The vehicle shall be operated with wheels in new condition.	Fast	78 dBA

The condition of the rail shall be documented with the noise test results. The rail roughness measurements shall be performed following ISO 3095 or BS EN 13231-2:2006.

### 2.8.5 Equipment Noise Prior to Installation on Vehicle

Noise levels produced by each truck's traction motors shall not exceed 90 dBA for each motor at 16 ft (4.9 m) from the center of the motor, in any direction, while operating at all speeds from zero to the equivalent of 55 mph (88 km/h) vehicle speed and at loads equivalent to the maximum tractive effort (motoring and braking) in either direction. The noise levels shall be corrected for the presence of pure tones as described in the Pure Tones section, above, and IEC 60349-2.

Noise levels produced by each propulsion gearbox and couplings shall not exceed 85 dBA at 16 ft (4.9 m) from the geometric center of the gearbox, in any direction, and with gears rotating in either direction at all speeds from zero to the equivalent of 55 mph (88 km/h) vehicle speed and at all loads up to the equivalent to maximum tractive effort (motoring and braking).

Noise produced by the individual operation of any undercar or roof mounted equipment which operates continuously or frequently (except traction motors and gear sets, above) shall not exceed 80 dBA at 16 ft (4.9 m) from the center of the equipment while it is operating under normal conditions and loads.

Noise levels produced by components prior to installation on the vehicle may exceed the levels specified in this section if the Contractor can demonstrate, by test, to Sound Transit's satisfaction, that all noise requirements for the completed car can be met.

### 2.8.6 Equipment Noise After Installation on Vehicle

Noise levels produced by individual operation of all undercar and roof mounted equipment and operating systems, except traction motors and gears, shall not exceed 67 dBA at 16 ft (4.9 m) from the vehicle centerline, on either side of the vehicle, on the horizontal plane passing through the shaft or equipment centerline while the equipment is operating at normal conditions with the

## *Design and Performance Criteria*

vehicle at rest. The equipment must be complete, installed, and all components of each system operating during test for noise levels.

Noise levels produced by the operating air conditioning equipment (in conjunction with the operating static inverter) shall not exceed 68 dBA anywhere inside the vehicle with doors closed. Measurements shall be taken at a minimum of 10 approved locations not less than 1 ft (305 mm) from the ceiling, floor, end walls, or side walls.

Noise levels produced by the individual operation of any undercar or roof mounted equipment which operates infrequently, and for less than 2 s, such as a circuit breaker or a pneumatic pressure relief device, shall not exceed 100 dBA measured from any point 16 ft (4.9 m) from the center of the equipment. The sound level reading shall be taken with the fast meter response.

### **2.8.7 Vibration Generation**

Equipment and auxiliaries mounted anywhere on the vehicle, car body, or trucks shall not cause vertical or horizontal vibrations anywhere on the vehicle floor, walls, ceiling panels and seat frames, at any speed from 0 to 55 mph (88 km/h) and for any acceleration or braking command except maximum braking, in excess of the following:

- Below 1.4 Hz: Maximum displacement (peak-to-peak) of 0.10 in (2.54 mm).
- 1.4 Hz to 20 Hz: Zero-to-Peak acceleration of 0.01 g (0.10 m/s<sup>2</sup>).
- Above 20 Hz: Zero-to-Peak velocity of 0.03 in/s (0.76 mm/s).

All traction motors shall be supported on resilient mountings which have at least 0.25 in (6.4 mm) static deflection with equivalent horizontal and vertical stiffness. The vibration of traction motors shall not exceed the limit specified in Section 10.

### **2.8.8 Vibration and Impact Loads**

All vehicle equipment shall operate without damage or degradation of performance when subjected to vibration and impacts encountered during normal service, and shall be compliant with and tested per IEC 61373, including all functional and durability requirements.

### **2.8.9 Ride Quality**

All panels and equipment mounted in the passenger area shall be free from resonance.

The ride quality shall be evaluated according to ISO 2631-4. The basic RMS vertical and lateral acceleration values shall not exceed 1.05 ft/s<sup>2</sup> (0.32 m/s<sup>2</sup>) and the vibration total value (root sum of squares summation) for each measurement point shall not exceed 1.64 ft/s<sup>2</sup> (0.5 m/s<sup>2</sup>) over the range of 1 Hz to 80 Hz for AW0 and AW3 load conditions and all normal vehicle acceleration, deceleration, and speed conditions. Frequency weighting W<sub>b</sub>, shall be used. Acceleration values outside this frequency range shall be subject to Sound Transit's review and approval. The vehicle shall be evaluated with new wheels on Class 3 or better tie, ballast track and direct fixation with non-corrugated welded rail.

## *Design and Performance Criteria*

Measurements shall be made with 1/3 octave band analysis.

If a single discrete frequency component determines the magnitude of vibration within a particular frequency band, then the limitation at that frequency shall apply.

Steady-state ride quality shall be measured with root-mean-square (RMS) responding instrumentation with integrating time or effective averaging time from 1 to 4 s. Averaged vibration level during any 10 s period shall not exceed the defined limitation.

The natural frequency associated with truck frame vertical motion between primary and secondary suspensions shall be separated from the natural frequency associated with carbody first vertical bending mode by at least 40% for minimal coupling between these modes.

### **2.8.10 Curving**

Low-speed (5 mph (8 km/h)) curving shall be modeled with an upward “cusp” on the inside rail, centered on a flat 82 ft (25 m) radius curve. The curve length shall not be less than 200 ft (60 m). The cusp shall have a 3 in (76 mm) amplitude with a distance equal to the truck wheelbase. The cases of new wheel/new rail and new wheel/worn rail shall be considered with appropriate cross-sectional profiles.

Report outputs and corresponding criteria as follows:

- Net Axle Lateral (NAL) force, as a check on track panel shift, shall be less than one-half the static vertical axle load for AW0 and AW3.
- Single wheel Longitudinal/Vertical (L/V) force, measuring the resistance to wheel climb derailment, shall not exceed the Nadal limit for minimum design flange angle and a wheel/rail coefficient of friction of 0.5.
- Truck side L/V, a measure of rail rollover potential, shall be less than 0.6.
- The minimum vertical wheel force, to prevent wheel unloading, shall be greater than 10% of the static wheel load.

### **2.8.11 Truck Stability**

The Contractor shall analyze vehicle stability in tangent tracks at speeds up to 110% of maximum revenue service speed. The analysis shall be based on measurements performed inside the truck using transducers mounted in lateral directions. The transducers shall be mounted on a truck frame to measure lateral acceleration at a longitudinal location as close as practicable to an axle's centerline. The output of lateral accelerations from transducers on the truck frame shall be reported to indicate if truck hunting occurred. Hunting shall be defined as six or more consecutive oscillations where truck frame lateral accelerations exceed 0.8g (7.8 m/s<sup>2</sup>) peak-to-peak. Hunting shall not occur up to maximum revenue service speed. Tangent track segments in the model shall be at least 2,000 ft (610 m) long. The four cases of new wheel/new rail, new wheel/worn rail, worn wheel/new rail, and worn wheel/worn rail profiles shall be analyzed to determine the worst condition.

### 2.8.12 Truck and Component Vibration

Root-mean-square vibration acceleration in the vertical direction at any 1/3 octave band from 5 Hz to 20 Hz, at any speed between 25 and 30 mph (40 and 48 km/h) inclusive, and at any vehicle load from AW0 to AW4, shall not exceed the following:

- Gear unit, at any point: 0.02 g (0.196 m/s<sup>2</sup>) rms
- Truck frame near axle bearing: 0.015 g (0.147 m/s<sup>2</sup>) rms

The measurements shall be performed using transducers mounted vertically on the gear unit and on the truck frame near the axle bearing. The measurements shall be conducted on tangent tracks with standard RE115 rail with resilient direct fixation. One-third octave band filters shall be causal infinite impulse response (IIR) 6-pole filters conforming to Class 0 specifications for 1/3 octave band filters as defined in ANSI S1.11-1. Measurement duration shall be of minimum length of 20 s in either train direction.

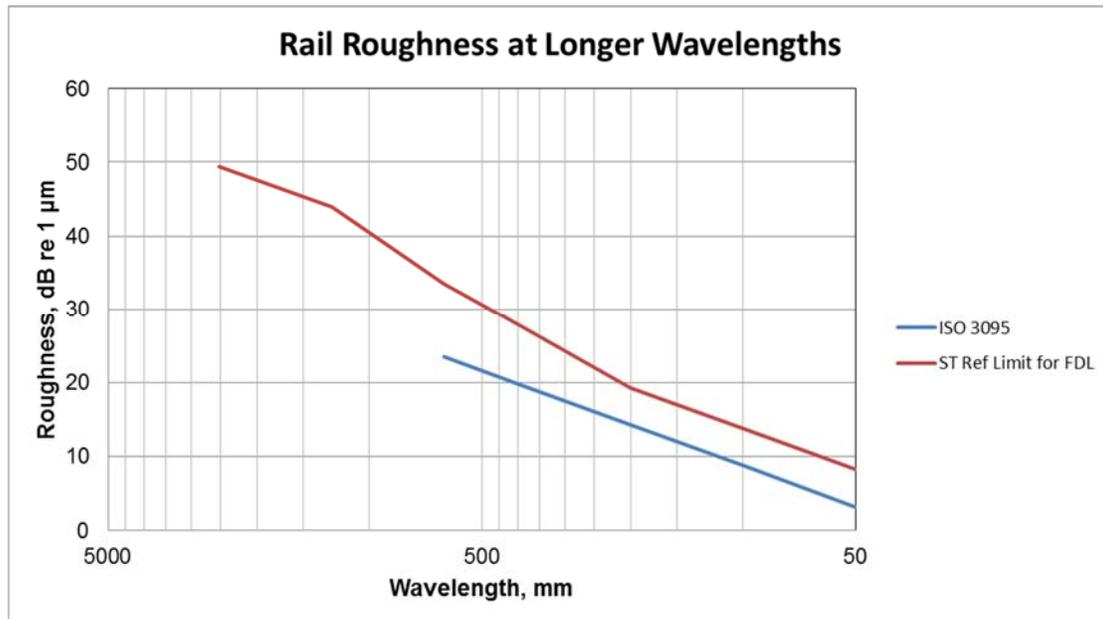
### 2.8.13 Ground Borne Vibration

Ground borne vibration levels from trains measured on the wayside are a function of the forces generated by the trains at the interface of the wheel and rail, and the efficiency with which energy is transmitted through the ground. The vibration forces generated by trains are largely independent of the ground characteristics and characterized by the Force Density Level (FDL). FDL is a function of the vehicle design, train speed, condition of the wheel surface, condition of the rail surface, and track fixation characteristics.

The Sound Transit system is subject to vibration limits, and the LRV must be designed such that the system continues to meet those limits, detailed in Table 2-2 below. The Sound Transit limit for rail roughness level, based on tests performed following ISO 3095 procedures, is shown as the red curve in Figure 2-1 and corresponds to the vibration limit specified in Table 2-2. Fundamentally, the ST2 LRV design must produce no more vibration than the existing ST1 vehicles as characterized by the FDL at 30 mph for direct fixation tracks in this specification. Vehicle design aspects that tend to limit wayside vibration include low unsprung mass and a relatively low primary suspension resonance frequency (8 to 10 Hz).

<b>Frequency, Hz</b>	<b>FDL Limit, dB re 1 lb/(ft)<sup>1/2</sup></b>
5	25
6.3	25
8	29
10	29

12.5	25
16	25
20	25
25	20
31.5	20
40	27
50	27
63	27
80	27
100	27
125	27
160	27



**Figure 2-1: Sound Transit’s Reference Rail Roughness Limits for the FDL test**

Test methods and elements to incorporate into the test procedures are provided in Section 16. Appendices A and B of the specification provide more detailed information on the vibration testing performed on the existing vehicle fleet.

Verification of compliance with this requirement must be done as early as possible. Failure to meet this requirement will prohibit shipment of additional vehicles until a redesign has been implemented on the first vehicle and verified to be compliant with the FDL limit.

## 2.9 Electromagnetic Interference and Compatibility

### 2.9.1 General

The Contractor shall design and construct the vehicle such that its equipment does not electrically interfere with the safe and proper operation of the vehicle itself or any wayside equipment, including equipment or systems external to the LRT system, both for normal operation and under those failure conditions which could in any way affect the vehicle’s output EMI spectrum. Of particular concern is the requirement that the LRV not interfere with the safe and proper operation of the planned Sound Transit signal system, TWC, communications system and the University of Washington’s monitoring of perturbations in the earth’s magnetic field.

## **2.9.2 Signal System**

The audio frequency cab signal system, including both Automatic Train Protection (ATP) and Train-to-Wayside Communications (TWC) systems, is described in Section 14. The Contractor shall cooperate and coordinate with the Wayside Construction Contractors on Vehicle/Signal interface issues, including EMC issues.

## **2.9.3 Sound Transit Communications System**

The Sound Transit communications system will include a multi-channel two-way radio system, on-board intercom, station announcement, PA system, and a TWC system as part of the communication system. Reference Sections 13 and 14.

## **2.9.4 University of Washington Monitoring of Magnetic Fields**

The Sound Transit light rail alignment passes under the University of Washington (UW) campus where they are monitoring minute changes in the earth's magnetic field. When the ST1 LRV operated in the vicinity of the UW, it caused perturbations in the magnetic field impacting the measurement. Sound Transit and the UW have an agreement that allows train operation in the area as long as the perturbations are limited to 0.795 mG (79.5 nT) measured at 40m.

To determine compliance with this requirement, it is essential that the ST2 vehicle is tested in the same location and under the same conditions used to establish this limit. For additional detail refer to test requirements in Section 16. Appendices C and D of this Specification provide further reference detail on the magnetic perturbation tests performed on the existing fleet.

Verification of compliance with this requirement must be done as early as possible. Failure to meet this requirement will prohibit shipment of additional vehicles until a redesign has been implemented on the first vehicle and verified to be compliant with the magnetic perturbation limit.

## **2.9.5 Control and Test Plans**

The Contractor shall submit electromagnetic interference (EMI) and electromagnetic compatibility (EMC) control and test plans to Sound Transit for review and approval 90 days after NTP or 30 days prior to issuing purchase specifications for any carborne apparatus, whichever comes first. (CDRL 2-11) The approved version of these plans shall be included in every such purchase specification.

The plans shall ensure that proper emphasis will be placed on the control of interference, interface design, and FCC requirements from the earliest stages of vehicle design. The EMI and EMC control and test plans shall describe the Contractor's approach to ensure that the specified EMC and EMI requirements are met. The Contractor's EMI and EMC control and test plans shall include a listing of car-borne EMI sources, a listing of car-borne and wayside equipment potentially susceptible to this interference, vehicle and system failure conditions which could impact the vehicle's EMI signature, proposed techniques and methods for resolution of potential EMC problems, test techniques, etc. Sound Transit approval of the Contractor's EMI/EMC documents does not relieve the Contractor from the requirement to provide equipment that functions safely and properly in Sound Transit's transit system environment.

## *Design and Performance Criteria*

To contain EMI emissions as effectively as possible, the suppression of transients shall be at the source of the transient.

The following design requirements shall be included in the EMI control plan and EMC program:

- All magnet valves, relay and contactor coils, and other inductive devices, shall have free-wheeling diode or metal-oxide varistor transient suppression. Other means of suppression or the absence of suppression for performance reasons shall require the approval of Sound Transit prior to use.
- The number of suppression device types shall be kept to a minimum.
- Equipment design, wiring techniques, and enclosures shall shield equipment from any effects resulting from the operation of a Sound Transit hand-held transceiver when the transceiver is within 18 in (460 mm) of the enclosure.
- Equipment design, wiring techniques, and enclosures shall shield equipment from any effects resulting from the operation of cellular telephones, including when the telephones are operated within the vehicle and on the passenger platforms.
- Equipment design, wiring techniques, and enclosures shall shield systems to prevent the car and its systems from causing undesired effects to external equipment and systems, with particular emphasis being placed on safe operation with the Sound Transit signal and communications systems. Operational sensitivities of the Sound Transit signal and communications systems shall be confirmed by the Contractor and interference free operation based on design goals and test confirmation shall both be requirements of this program.
- The capacitance and inductance of the OCS and running rails, taken in combination with the characteristics of the vehicle propulsion and auxiliary input filters, shall be taken into consideration when determining the vehicle EMI spectrum. Changes in the wayside capacitance and inductance as a function of the vehicle distance from electrical substations shall so be considered.

### **2.9.6 Methods and Equipment**

The Contractor shall employ design techniques, construction methods, and whatever equipment is required to prevent interference caused by internal sources from affecting the proper operation of vehicle and external systems. In addition to coordinating frequencies, EMI levels, and susceptibility levels the Contractor shall provide necessary on-board grounding, balancing, filtering, shielding, modulating techniques, and isolation to meet the requirements of this Section and to reduce the undesirable effects of interference to acceptable levels. Electrostatic and magnetic shielding methods shall be employed to minimize the effect of stray signals and transient voltages on interconnecting cables. Interconnecting power and signal cables shall be physically separated. Trainlines shall be located and arranged to minimize voltage induction into trainline circuits due to propulsion system, auxiliary power, and overhead contact system current transients.

### **2.9.7 Emission Limits**

To help avoid undesirable effects upon external equipment or other installations along the right-of-way caused by on-board vehicle subsystems, including the Sound Transit ATP and TWC systems, each vehicle shall, as a minimum, comply with the electromagnetic emission limits specified below. Compliance with these limits, however, does not relieve the Contractor from the responsibility for providing a vehicle whose EMI spectrum successfully integrates with the specified electrical environment, including the vehicle, signal and other wayside systems and installations.

### **2.9.8 Radiated Emission Limits**

Radiated emissions, as measured by the procedures from "Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-11", shall conform to the following limits:

- From 0.01 MHz to 30 MHz, the maximum permissible interference limit follows a straight line from 120 dB above 1  $\mu\text{V}/\text{m}/\text{MHz}$  bandwidth at 0.1 MHz to 83 dB above 1  $\mu\text{V}/\text{m}/\text{MHz}$  bandwidth at 30 MHz.
- From 30 MHz to 88 MHz, the maximum permissible interference limit shall be 58 dB above 1  $\mu\text{V}/\text{m}/\text{MHz}$  bandwidth.
- From 88 MHz to 3,000 MHz, the maximum permissible interference limit shall be 68 dB above 1  $\mu\text{V}/\text{m}/\text{MHz}$  bandwidth.

These limits shall not be exceeded when measured at a distance of 100 ft (30 m) from the track centerline.

### **2.9.9 Conductive Emission Limits**

Conductive emissions, as measured by the procedures of "Conductive Interference in Rapid Transit Signaling Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-6, Method RT/CE02A, Conductive Emission Test, Vehicle", shall have a current limit (amperes rms) defined as follows:

- From 10 Hz to 320 Hz, 10 A maximum.
- Above 320 Hz, the emissions limit then follows a smooth curve through 10 A at 320 Hz, 0.05 A at 2.34 kHz (Cab Signal carrier frequency), 0.016 A at 4 kHz and 0.0046 A at 7 kHz.

Sound Transit will consider allowing higher currents at some frequencies, provided that the currents are limited in the track circuit and communication system passbands to values that will not cause interference with the operation of the signal and communications systems, or any other susceptible wayside systems. The specific values shall be based upon Contractor demonstrating that the higher values do not interfere under the worst case wayside and vehicle combinations, and shall be developed as part of the EMI/EMC control plan required by this Section.

The limits above shall be individually met by each power equipment apparatus as well as during the simultaneous operation of all equipment.

### **2.9.10 Inductive Emission Limits**

The inductive emissions, as measured by the procedures of "Inductive Interference in Rapid Transit Signaling Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-8, method RT/IEO1A", shall be limited to a maximum of 20 mV, rms, rail-to-rail, at all frequencies between 20 Hz and 20 kHz. This condition shall be met by each individual power equipment as well as the simultaneous operation of all equipment.

Sound Transit will consider allowing higher rail-to-rail voltages at some frequencies, provided that the currents are limited in the track circuit and communication system passbands to values that will not cause interference with the operation of the signal and communications system, or any other susceptible wayside systems. The specific values shall be based upon Contractor demonstrating that the higher values do not interfere under the worst case wayside and vehicle combinations, and shall be developed as part of the EMI/EMC control plan required by this Section.

### **2.9.11 Conducted Disturbances**

The Contractor shall formulate a set of criteria governing both generation and tolerance of electrical disturbances on conductors between assemblies. The criteria shall distinguish the basic types of circuits present on the vehicle and shall define a suitable comprehensive classification of disturbances that could be present in each type of circuit, including both high voltage and low voltage transients. The criteria shall ensure that each connected assembly will be able to tolerate the disturbances introduced simultaneously by all of the other assemblies to which it could be connected. The criteria shall include any required modification of the limits described above on conducted interference into the overhead contact system and running rails, with levels selected to prevent interference with signal and communication systems which use those circuits for their means of operation and communication. These criteria shall be a part of the EMI/EMC control plan.

### **2.9.12 Inductive Interference**

The Contractor shall formulate a set of criteria governing generation and tolerance of magnetically coupled disturbances on or between assemblies. The criteria shall identify the basic types of circuits present on the vehicle and shall define a suitable comprehensive classification of disturbances that could be present in each type of circuit. The criteria shall ensure that each connected assembly will be able to tolerate the disturbances introduced simultaneously by all other assemblies to which it is magnetically coupled. The criteria shall include any required modifications to the limits described above on the inductive interference into the OCS and running rails, with levels selected to prevent interference with signal and communications systems which use these circuits for their means of operation and communication. These criteria shall be a part of the EMI/EMC control plan.

### **2.9.13 Magnetic Perturbation**

The car builder shall prepare a plan that describes how the car body structure and materials used in manufacturing of the vehicle will be designed to minimize magnetic perturbations to ensure compliance with the requirement.

## **2.10 Samples and Renderings**

### **2.10.1 General**

The Contractor shall furnish the following samples and vehicle renderings to facilitate physical design refinement between the Contractor and Sound Transit

### **2.10.2 Samples**

Samples of all interior materials, fixtures, passenger and operator's seats, decorations, and signs shall be furnished during the vehicle design period for Sound Transit's evaluation and approval. Material samples shall be submitted by the Contractor for quality, color, and finish evaluation by Sound Transit, and shall be 10 in by 10 in (250 mm by 250 mm) in size to permit meaningful review. Three sets of all samples, except seats, shall be provided. The samples, except seats, are to be delivered during the program review meetings described in Section 19. (CDRL 2-12) Seat Samples, one of each type of seat, shall be delivered to the Sound Transit project office location in Seattle. (CDRL 2-13)

An interior finish schedule, giving actual final material samples identified with the manufacturer's name and ordering reference for each material, shall be furnished before delivery of the first vehicle. (CDRL 2-14)

### **2.10.3 Vehicle Renderings**

The Contractor shall furnish a color, three-dimensional, artistic vehicle rendering (in the form of a drawing) for public relations purposes. Contractor shall furnish three copies 11 in x 17 in, and an electronic version. (CDRL 2-15)

The Contractor shall also furnish a rendering detailing the vehicle's interface with the ADA tactile pathways and waiting areas on the existing platform as shown in figure 2-9 Platform Interface 2, demonstrating that the vehicle's doorways properly align with the ADA waiting areas. (CDRL 2-34)

The renderings shall be delivered to Sound Transit no later than 60 days after NTP.

## **2.11 Service Proven Design**

Vehicle, system, and subsystem designs shall be service proven, unless otherwise approved by Sound Transit. Sound Transit will assess the definition of "service proven" according to the risk associated with each particular design. For systems and subsystems, a service proven design will meet all the following criteria:

## *Design and Performance Criteria*

- Used in revenue rail operation for at least 2 years
- Used in revenue rail operation for at least 1 million vehicle miles (1.6 million km) with at least 50,000 miles (80,000 km) per vehicle
- Has a minimum fleet size of 20 vehicles
- Has achieved an MDBTD consistent with the requirements in the Specifications

For a complete car, a service proven design shall meet the following criteria:

- Used in revenue rail operation or operational testing for at least 1 year
- Has a minimum operating fleet size of 12 cars

To establish a design's service proven history, the Contractor shall submit specific details of the application history, certified by current users of the equipment. Equipment that does not meet the above criteria may be proposed for Sound Transit approval if the proposed equipment can be demonstrated by the Contractor to meet the specified reliability requirements and the Contractor has successfully supplied fleets of similar but high floor equipment which otherwise complies with the above requirements. (CDRL 2-16)

The Contractor may offer, for approval, a design that is basically unchanged from a service proven design, but which must be varied slightly in design or manufacture to meet Sound Transit requirements. The Contractor shall show, in detail, what has been changed in the equipment and why such changes will not adversely affect operation in the Seattle environment.

## **2.12 Reliability**

### **2.12.1 General**

Each component, assembly, subsystem, and system element shall be designed in a manner such that it will perform its function under the specified design operating conditions without failure for the durations specified. The Contractor shall submit a reliability analysis which defines the Mean Distance Between Component Failure (MDBCF) and Mean Distance in miles Between Train Delays (MDBTD) for its vehicle design, considering all failure modes for each component, assembly, subsystem, and system element. The combination shall result in realization of a vehicle MDBTD of 25,000 mi (40,000 km) in accordance with this Section and the Reliability and Failure Analyses section, below.

For this analysis, vehicle system reliability calculations shall be based on single vehicle operation with an average speed of 25 mph (40 km/h) and an average of 80,000 mi (129,000 km) per vehicle year.

A Train Delay is defined as an incident causing a revenue train to be:

- More than five min late at its terminus
- Canceled either at its original terminal or enroute

## *Design and Performance Criteria*

- Rerouted or turned back

The MDBCFC of a component is expressed as the total operating distance,  $d$ , accumulated by the total population of identical components, divided by the number of relevant failures,  $F$ , occurring within the population of identical items used in the same application during distance  $d$ . It is given by the following equation:

$$\text{MDBCFC} = d/F$$

The MTBCFC (Mean Time Between Component Failures) of an item is the ratio of the total operating time,  $t$ , accumulated by the total population of relevant failures,  $F$ , occurring within the population of those components during time,  $t$ . It is expressed by the following equation:

$$\text{MTBCFC} = t/F$$

Conversion between MDBCFC and MTBCFC can be done by multiplying or dividing by the average speed identified as 25 mph (40 km/h).

A relevant failure of an item is defined as an independent failure that results in an unscheduled corrective maintenance action of any subsystem or vehicle component. Relevant failures shall include intermittent, software and unverified failures which may require power cycling or rebooting. They will exclude consumable items except for those not achieving their design reliability. Additional failures to be excluded include the following:

- Secondary failures (A failure occurrence in equipment of another subsystem due to the primary failure) only if the failure can be traced back to the primary component.
- A failure due to Sound Transit not performing the recommended preventive maintenance actions.
- Failures due to vandalism, physical mistreatment at a human interface, or foreign object damage during operation
- Failures due to an accident
- Failures due to operating or weather conditions outside the requirements of the Specifications

The time, place or type of service in which the car was being operated at the time of a failure shall not be of any consequence, unless determined otherwise by Sound Transit.

### **2.12.1.1 Component Reliability Requirements**

The following are reliability requirements for the systems and components of the vehicle, assuming routine maintenance is performed in accordance with the approved maintenance manuals:

System	MDBCF	
	(mi)	(km)
Propulsion System	100,000	160,000
Friction Brake System	100,000	160,000
Communications, except Radio	200,000	320,000
Cab Signal System	200,000	320,000
TWC System	200,000	320,000
Car body & Appointments	500,000	800,000
Side Doors & Controls	85,000	136,000
Lighting (except light bulbs)	500,000	800,000
General Electrical Apparatus	100,000	160,000
HVAC Equipment & Controls	150,000	240,000
Couplers & Draft Gear	350,000	560,000
Trucks & Suspension	250,000	400,000
Traction Gear Unit	500,000	800,000

The system component MDBCF shall be calculated as a cumulative value over the time of the reliability demonstration period.

### 2.12.2 Reliability and Failure Analyses

The Contractor shall submit documented verification of product history and experience which demonstrates that the specified MDBTD and MDBCF requirements will be achievable. (CDRL 2-17) The Contractor shall perform analyses to identify weaknesses in system hardware and software design whenever these details are not established by historical records of equipment operation. The analyses shall provide input to system designs for theoretical circuit behavior, random component failures, electrical interference, systematic component failures, and software errors in software-based logic. The reliability predictions shall be identified through the use of MIL-HDBK-217 or certified field failure data. Reliability analyses shall be updated on a quarterly basis throughout vehicle design development. (CDRL 2-18)

### 2.12.3 Reliability Program

The Contractor's Reliability Program Plan shall be submitted 60 days after NTP for Sound Transit review and approval, and shall contain the following information, as a minimum: (CDRL 2-19)

- Reliability program objectives
- Reliability program schedule, which identifies specific tasks, with start and completion dates, and explains how these tasks are coordinated and integrated with major program milestones for design, manufacturing, and testing
- Methodology to be used in reliability analyses to predict compliance with the reliability requirements specified in the other subsections, above, of this Reliability section

## *Design and Performance Criteria*

- Organization of personnel responsible for managing the reliability program
- Controls for activities of subcontractors and equipment suppliers, to ensure their compliance with reliability program methods and objectives
- Reliability demonstration testing plans for verification of compliance with reliability requirements
- The Contractor's process for identifying deviations from the specified reliability requirements, and the process for modifying the design of those discrepant systems and/or components in order to attain the required reliability. This necessarily includes interface protocols between the Contractor and its subcontractors, this to resolve reliability problems in purchased systems and components.
- Reliability progress reporting, which details implementation of the approved reliability program, shall be submitted to Sound Transit on a monthly basis, beginning 90 days after NTP (CDRL 2-20)

### **2.13 Maintainability**

#### **2.13.1 General**

The vehicle design shall incorporate standards which minimize Mean Time To Repair (MTTR) and maintenance costs throughout its intended useful life. The Contractor shall develop a maintainability program for the vehicle, including corrective and preventive maintenance, which shall provide for:

- Enhancement of vehicle availability
- Minimization of maintenance costs

The maintainability design for the Sound Transit vehicle shall result in an overall MTTR of 1.8 man-hr. This shall be the weighted average of the MTTR of the key system elements as listed below. Diagnostic time shall be included in MTTR.

<b>System Element</b>	<b>MTTR (man-hr)</b>
Propulsion System	2.0
Friction Brake System	2.0
Communications, except radio	1.0
Side Doors & Controls	0.8
Lighting	0.5
General Electrical Apparatus	1.5
HVAC Equipment and Controls	2.0
Couplers & Draft Gear	2.25
Cab Signal System	1.0

<b>System Element</b>	<b>MTTR (man-hr)</b>
Trucks & Suspension	1.6
Train-To-Wayside Communication	1.0
Car body & Appointments	2.1
Side window replacement *	3.0
Passenger Seat Cushion and Back	0.25

\* To include removal of old window glass, installation and sealing of new window glass, and for car to be ready to operate through car wash without damage to window and associated materials.

### **2.13.2 Maintainability Program Plan**

The Contractor's maintainability program shall include a detailed plan outlining all schedules and activities for vehicle preventive maintenance. The Maintainability Program Plan shall be developed in accordance with current Sound Transit maintenance practices and MIL-HDBK-470A. This plan, along with the outline of the proposed maintenance manuals and associated drawings, shall be submitted to Sound Transit for review and approval within 120 days after NTP (CDRL 2-21) (Refer to Section 18.). The plan shall outline each maintenance task, time schedules, recommended tools, personnel, and skill levels required. These recommendations shall be based upon those of the Contractor and of the equipment suppliers. The weighted average of the component MTTR shall illustrate compliance with the overall MTTR requirements. This plan shall be coordinated with the maintenance manuals and shall be consistent with same.

### **2.13.3 Maintainability Demonstration**

As part of the training program for maintenance personnel, all servicing and preventive maintenance shall be demonstrated. In-service troubleshooting, use of diagnostic programs via portable test units, change-out of components, corrective maintenance, and use of special tools shall be demonstrated where special emphasis, instruction, or proficiency is needed. Vehicle “rescue” movement under disabling conditions shall also be demonstrated. The Contractor shall submit a Maintainability Demonstration Plan 90 days before delivery of the first vehicle. (CDRL 2-22) As part of this demonstration, compliance with the MTTR requirements in this Section shall be demonstrated.

### **2.13.4 Preventive Maintenance Plan**

The Contractor shall develop a detailed Preventive Maintenance Plan based upon the ease of maintenance concepts and maintainability requirements established in the Specifications. It shall be submitted within 90 days of NTP to Sound Transit for review and approval (CDRL 2-23). Preventive maintenance is defined as the implementation of those maintenance tasks performed to minimize the possibility of future equipment failure, reduce or minimize wear rates, replace consumable parts, and satisfy warranty requirements.

## Design and Performance Criteria

Vehicle reliability and maintainability design shall be sufficiently robust such that the total of preventive maintenance tasks, as defined in the maintenance manual, shall be no more frequent or take more time than the following schedule for each vehicle:

Operating Interval		Preventive Maintenance
Miles	(km)	Man-Hours
Daily Checks and Inspections		0.06
Weekly		0.50
5,000	(8,000)	10
15,000	(24,000)	20
30,000	(48,280)	60
60,000	(96,560)	120
120,000	(193,121)	240
300,000	(482,803)	600
480,000	(772,485)	960
600,000	(965,606)	1200
960,000	(1,544,970)	1920

The preventative maintenance schedule for each vehicle shall commence on its acceptance. Prior to acceptance, maintenance shall be the responsibility of the Contractor. All work orders, including equipment serial number tracking, shall be provided to ST maintenance on a daily basis.

Scheduled activities during the 5000 mile cycle shall be limited to inspection, filter cleaning or replacement, and replacement of approved consumables.

### 2.13.5 Maintainability Design Criteria

To achieve the maintainability objectives outlined in this Section, the following shall be required in the design for maintainability:

- Systematic fault isolation procedures shall be developed for inclusion in the maintenance manuals.
- A Monitoring and Diagnostics System (MDS) shall be provided, as required by Section 9, to store, process, and permit cab access to maintenance and fault data from vehicle systems. All control and microprocessor-driven systems on the vehicle shall be connected to the MDS via two-way data communications.
- Built-in test points and test connectors shall be provided and marked. These are to be used with standard test equipment, the MDS, and the diagnostic test equipment described in Section 18.

## *Design and Performance Criteria*

- A system of status and failure indicators shall be provided and integrated with the MDS. The Contractor shall develop a list of indicators and other features of the vehicle MDS for Sound Transit review and approval. (CDRL 2-24)
- All test points, fault indicators, modules, wire junctions, pipes, tubes, and wires shall be identified by name plates, color coding, number coding, or other means as approved by Sound Transit, to assist the maintenance personnel.
- All systems and components serviced as part of inspection or periodic preventive maintenance shall be readily accessible for service and inspection. This will be confirmed during the First Article Inspections of components, systems and the completed vehicle. Removal or physical movement of components unrelated to the specific maintenance tasks shall be unnecessary.
- The relative accessibility of components, measured as time-to-gain access, shall be logically related to their frequency of maintenance, inspection or repair.
- Access panels and openings shall be sufficient in quantity, size, and placement to permit ready access from normal work locations. Doors or cover panels shall be hinged, contain a hold-open device or shall be easily removable if they cannot swing fully open.
- Standard and commercially available components and hardware shall be used wherever suitable for the task and when conforming to this document.
- Unless otherwise specified, captive, quarter-turn fasteners shall be used on covers and access panels where periodic maintenance and inspection is to be performed. These fasteners shall not require the use of special tools except where necessary to prevent vandalism and unauthorized access.
- Major components shall be designed for removal by provision of handles, lifting eyes, lugs, and/or pads.
- The requirement for special tools and fixtures for maintenance shall be subject to Sound Transit approval.
- Assemblies or components that are functionally interchangeable shall be physically interchangeable. Modules or plug-in assemblies that are not functionally interchangeable shall not be physically interchangeable and shall be shaped or keyed to prevent incorrect application.

### **2.13.6 Adjustments**

The need for adjustments shall be avoided. To the greatest extent possible, Contractor shall use adaptive circuitry and mechanical design techniques to accommodate for loss of tolerance and wear such that systems are self-adjusting, and the need for external adjustment is minimized or eliminated.

If adjustment points cannot be avoided, they shall be readily accessible, adequately identified, and self-locking to prevent inadvertent adjustment or drift. All such adjustments shall be subject to

approval. The Contractor shall provide a list of adjustment points in the maintenance manuals and initial settings in the Vehicle History Book.

#### **2.13.6.1 Electrical Adjustments**

Provisions for electrical adjustments shall be approved prior to being included in a circuit. Stable components, tight tolerances, adaptable circuitry and drift and temperature compensation techniques shall be used wherever possible in order to avoid adjustments. Adjustments using select-in-test components are preferred over variable components. Where adjustable components are approved, they shall be sealed to preserve the adjustment and to identify calibrated assemblies. Sealing materials shall be non-caustic, durable, breakable for readjustment, and shall provide visual indication when broken.

Performance adjustments shall be provided, however, as described in Sections 10 and 12.

#### **2.13.6.2 Mechanical Adjustments**

Mechanical adjustments will be allowed only to compensate for a device's manufacturing tolerances and wear. Self-adjusting, adaptable designs, both mechanical and electrical, shall be used to compensate for mechanical wear. Once adjusted, like assemblies shall be interchangeable without further adjustment. Mechanical adjustments shall occur in fixed, discrete steps using serration, notches or pins to ensure positive adjustment retention. Mechanical adjustments shall include positive locking devices.

#### **2.13.6.3 Software Adjustments**

Adjustments to be made by stored parameters in software shall reside in non-volatile memory. The location and scaling of all adjustment parameters shall be clear to service personnel. Parameter values shall be in decimal notation and expressed in customary units. Password or similar security provisions shall be made to prevent unauthorized parameter changes. Parameter adjustment features shall not allow adjustment beyond safe and reasonable limits.

### **2.14 System Safety**

#### **2.14.1 General**

The vehicle shall be designed and constructed to be safe to passengers, persons nearby, Sound Transit employees, and the environment both under normal operating conditions, and in the event of equipment failure.

The Contractor shall ensure that all risks resulting from failures or mishaps are identified, evaluated, and mitigated to a level acceptable to Sound Transit.

#### **2.14.2 System Safety Program Plan**

Contractor shall develop, implement, and maintain a comprehensive System Safety Program Plan (SSPP) based on the guidelines and requirements in U.S. Department of Transportation, Federal

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Transit Administration, document - DOT-FTA-MA-26-5005-00-01, and the requirements of the Specifications.

The SSPP shall identify all hazards related to the vehicle. Design requirements and management controls shall prioritize the elimination of hazards and reduction of risk to levels acceptable to Sound Transit. The SSPP shall be developed and submitted within 90 days after NTP and shall be continuously maintained throughout design, manufacturing and commissioning of the vehicles.

Safety requirements defined in this Section and elsewhere in the Specifications shall be incorporated into the SSPP and the vehicle design.

The SSPP shall document the methods and procedures used to identify, document, and mitigate hazards during all phases of vehicle design, construction, and commissioning. It shall include sample documents and the format for reports, analyses, and any other documents the Contractor will use in the program. The SSPP shall be submitted to Sound Transit for review and approval (CDRL 2-25).

The Contractor is not responsible for the safety or analysis of Sound Transit Furnished Equipment (STFE). The Contractor is responsible for including the interfacing of this equipment to the vehicle in the SSPP. STFE shall be analyzed using a “black box” approach where all inputs and outputs may fail in any state. It is the Contractor's responsibility to integrate the STFE into the overall vehicle design in a manner such that the vehicle is protected against single-point failures.

### **2.14.3 General Safety Design Requirements**

The following general safety design requirements shall be incorporated into the design of all vehicle systems affecting safety:

- All safety-critical applications shall be designed to be fail-safe.
- Only components with high reliability and predictable failure modes, and which have been proven in conditions similar to the projected service, shall be utilized.
- All devices not guaranteed fail-safe shall be assumed capable of failing in permissive modes.
- All electronic circuits shall be assumed capable of failing in permissive modes.
- Software which performs safety critical functions shall be considered to fail in a permissive, undetected mode and must be provided with independent checking and self-test capability to ensure safety.
- Systems shall be based on closed circuit principles in which energized circuits result in permissive conditions, while interrupted or de-energized circuits result in restrictive conditions.
- All vital circuits not wholly within the system apparatus enclosure shall be double-wire, double-break, with the exception of connections to non-vital circuits, which may be single-wire, single-break.

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- Any component or wire becoming grounded shall not cause a permissive condition. Safety circuits shall be kept free of any combination of grounds that will permit a flow of current equal to, or in excess of, 50% of the release value of any safety device in the circuit.
- Circuit impedances, signal encoding, shielding, layout, and isolation shall be selected to reduce the effects of interference to the extent that safety is maintained under all conditions.
- Commands that result in permissive conditions shall be propagated by no less than two independent signals, both of which must be present before the permissive condition can occur. The lack of either signal shall be interpreted as a restrictive command.
- Systems controlled by variable level signals or Pulse Width Modulated (PWM) signals shall be arranged such that zero signal level results in the most restrictive condition. At least one enabling signal, however, independent from the variable control signal, shall be present before the control signal can modulate the system to a more permissive level.
- Systems controlled by digital transmission of commands or data shall utilize methods such as data redundancy or multiple transmission of messages in diverse forms to ensure the accurate reception of such signals. Digital message transmission reliability protocols shall be built into the transmission of such messages to ensure that they represent current commands or data, and that they are received with full message integrity. Failure to receive such a message in a timely manner, or with indications of corrupt data, shall default the function to the most restrictive condition.
- Circuit breakers and fuses shall be guaranteed by the manufacturer to successfully interrupt rated currents. Circuit breakers and fuses shall be sized such that the maximum circuit fault currents and operating voltages do not exceed the manufacturer's recommendation for fault currents and operating voltages.
- Systems that rely on structural integrity for safety shall have sufficient safety factors such that failures are not possible within the life of the vehicle under all possible normal conditions.
- Systems and devices subject to wear shall not wear to permissive states within a period no less than three times the overhaul period under the worst-case combination of duty cycle, environment, and all other influences. Such systems and devices shall be clearly indicated as SAFETY CRITICAL in the maintenance manuals.
- Mechanical systems that apply force to achieve safe states shall not depend upon the application of fluid pressure or electrical energy, unless specifically approved.
- All locks, catches, and similar devices affecting safety shall be either self-engaging without application of power, or, if engaged by application of power, shall remain fully and safely engaged in the absence of power.
- All systems shall function safely under all combinations of supply voltages, fluid pressures, shock, vibration, dirt accumulation, and the Sound Transit environment.

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- All safety related systems, and devices within those systems, shall be clearly identified as **SAFETY CRITICAL** in all operation and maintenance manuals, procedures, and training materials.

The Contractor shall distribute this Subsection to all suppliers for inclusion in their designs.

### **2.14.4 Failure-Induced Hazards**

Vehicle equipment and systems shall be designed and constructed to revert to safe modes under failure conditions. The Contractor shall employ high quality components, proven systems, redundancy, checking devices, and other techniques to accomplish this goal.

Vehicle systems whose failure could result in hazards of Category I or II severity shall conform to both of the following design principals, and shall be validated per Unit Qualification Test.

- The failure of a single device shall not result in a permissive condition, and
- An undetected failure of any device shall not permit a subsequent device failure to result in a permissive condition.

The term ‘failure’ includes both the initial device failure and all consequential device failures caused by the initial failure.

The term “device” includes any component, subsystem, or system, whether electrical or mechanical, structural, pneumatic or hydraulic.

The terms “restrictive” and “permissive” relate to potential system responses that result in either a more safe or less safe condition, respectively, such as the following:

- Stop versus proceed
- A lower speed versus a higher speed
- Close doors versus open doors
- Deceleration versus acceleration
- Brakes applied versus brakes released
- Actuation of alarm versus no actuation of alarm

Systems shall conform to the safety design principals by one or both of the following methods:

- The utilization of fail-safe devices, that is, devices with known, guaranteed-by-the-manufacturer failure modes, such as signal grade relays, combined in circuits in such a way that the requirements of this Section are met
- Independent channels with independent checking of each channel. All channels shall indicate a permissive state in order for the controlled system to achieve a permissive state. Failure in any channel shall not affect any other channel, or force the system into a permissive state, unless other actions are required by other parts of the Specifications. Differences in state between channels monitoring the same variable shall be alarmed and shall force a restrictive state on the system.

Failures in equipment which result in an indication of danger, whether or not actual danger exists, shall be considered to have occurred in a safe manner. Conversely, a failure which results in an indication of safety when a dangerous condition may exist shall not be considered safe.

#### **2.14.5 Friction Brake System**

The friction brake system shall consist of three completely independent systems, with one system for each truck. Each system is permitted to have independent permissive failure modes. Refer to Section 12 for friction brake control details.

As part of the analysis of the maximum brake system, the Contractor shall include a table summarizing the effect of the failure of any one braking subsystem, i.e., power truck dynamic, power truck friction, center truck friction, and track brake, on the total deceleration rate and stopping distance of the vehicle. The table shall include the actual braking effort of the individual braking subsystem and the percentage of total vehicle braking effort.

#### **2.14.6 Fire and Life Safety**

All vehicle components, subsystems, and systems shall be designed for the prevention of fire; protection of the public, employees, and emergency response personnel from injury due to fire, smoke, explosion, or panic due to these occurrences; and protection of system elements from damage by fire or explosion.

Design shall provide for equipment to be located outside of the passenger compartment, whenever practical, unless specified otherwise, to isolate potential ignition sources from combustible materials. The articulation, floor, sides, and roof shall be designed to retard propagation of an underfloor and/or roof fire to the vehicle interior. Fire-stops shall be provided at floor and roof penetrations. Enclosures for control and other critical equipment shall be located to provide protection against environmental contamination and mechanical damage.

#### **2.14.7 Safety under Normal Operating and Maintenance Conditions**

The vehicle shall present a safe, hazard-free environment to passengers, operators, and Sound Transit maintainers.

Passengers and operators shall not be exposed to tripping hazards, sharp points and edges, lethal or injurious voltages, toxic materials, abrupt or unexpected accelerations, or similar hazards. Location, illumination levels, colors, graphics, and surface finishes shall be selected to enhance visibility of step edges, windscreens, controls, and other objects with which the passengers and operators must interface.

Normal and emergency equipment and controls which the passengers or operators may operate shall be clearly identified, and where required, operating procedures shall be presented in both printed and graphic formats.

Maintenance manuals, procedures, and training shall indicate the proper handling, storage, and disposal of hazardous materials. Exposure of maintenance personnel to lethal or high voltages shall be reduced through compartmentalization, interlocks, and similar measures. All equipment shall

be free from sharp points and edges. All equipment containing hazardous materials, lethal or injurious voltages, or other risks shall be clearly labeled on both the outside and inside of the equipment.

Maintenance, operating, training, and other manuals shall clearly identify all hazardous materials and equipment. All maintenance procedures involving hazards shall contain clear identification of the hazard and instructions to reduce or eliminate the hazards during the procedure.

#### **2.14.8 Human Error and Other External Influences**

All systems shall minimize unsafe conditions resulting from human error. No sequence of operations, or the simultaneous activation of any controls, shall result in unsafe conditions. Where conflicting commands, such as simultaneous power and brake, are requested, the more restrictive shall result.

Maintenance of safety-related equipment shall be arranged such that the effects of errors are minimized. Methods such as limitation of adjustment ranges, unalterable software, non-interchangeable parts, and visible wear indicators (where approved by ST) shall be employed.

#### **2.14.9 Systems Hazard Analysis (SHA)**

The Contractor shall identify, eliminate and/or control hazards by performing a Systems Hazard Analysis in accordance with “Hazard Analysis Guidelines for Transit Projects” - U.S. Department of Transportation, Federal Transit Administration document DOT-FTA-MA-26-5005-00-01 (CDRL 2-26).

In addition to those hazards identified by the Contractor, the following hazards shall be included in the listings and shall be considered hazards severity Category I or II:

- Maximum brake fails to apply when requested
- Service brakes fail to apply when requested
- Propulsion fails to cease when requested
- No-motion detection system indicates no-motion when vehicle is moving
- Door opens spontaneously when not commanded
- Door opens on the wrong side of the vehicle
- Door closes on person's limb and indicates door closed and locked to control system
- Door interlocks erroneously indicate door is closed and locked
- Vehicle system responds in a permissive manner to a restrictive ATS command
- Indication of uncoupled when not uncoupled
- Indication of being coupled when not coupled

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- Excessive currents or overheated equipment cause fire
- Vehicle moves in wrong direction
- Vehicle speed and track curvature combine in such a manner as to cause a train to derail or a vehicle to overturn;
- Onboard equipment causing EMI affecting wayside signaling system or other onboard systems;
- Wayside equipment causing EMI affecting wayside signaling system through vehicle or onboard systems;
- ATP fails to detect overspeed;
- ATP system component failure;
- ATP fails to enforce Brake Assurance; and
- Use of material that is hazardous to Sound Transit or contract personnel, passengers or the environment.

### **2.14.9.1 Failure Modes, Effects and Criticality Analyses**

The Contractor shall summarize test procedures and perform a Failure Modes, Effects and Criticality Analysis (FMECA) (CDRL 2-27). The FMECA shall be developed in accordance with MIL-STD 1629A. The FMECA shall provide a systematic, comprehensive, and bottom-up evaluation that analyzes the effects of potential component failures in a system, as installed, from design data.

### **2.14.9.2 Sneak Circuit Analysis**

The Contractor shall submit test procedures and perform a sneak circuit analysis in all trainline control circuits, where wiring and/or signal path errors can lead directly to hazard effects without additional mitigation. (CDRL 2-28).

### **2.14.9.3 Operating and Support Hazard Analysis**

The Contractor shall submit test procedures and a perform Operating and Support Hazard Analysis (O&SHA) (CDRL 2-29). The analysis shall evaluate the operating and maintenance procedures to ensure that, when followed, the procedures do not result in hazards.

The Contractor shall submit Safety Data Sheets (SDS) for all material recommended for use on the vehicles that are subject to the Workplace Hazardous Materials Information System (WHMIS).

The Contractor shall ensure that warnings, as required to mitigate identified hazards associated with the SDSs, are included in the Operations and Maintenance manuals.

The Contractor shall work cooperatively to ensure maintenance and operational procedures are compliant with the Sound Transit's Occupational Health and Safety (OHS) Programs.

Specifically, the Contractor shall ensure that all parties verify that required mitigations are in place to prevent/address hazards. The Contractor shall make recommendations regarding the OHS programs in order to mitigate hazards related to the vehicle service and maintenance. These recommendations shall be identified in the O&SHA analysis.

#### **2.14.10 Fire Hazard Analysis**

The entire vehicle and its components, subsystems, and systems shall comply with the requirements of Section 17. Measures shall be adopted to minimize injury due to fire, smoke, explosion, or panic due to fire. Measures shall also be adopted to protect equipment from damage by fire or explosion. The Contractor shall submit for approval a Fire Hazard Analysis (CDRL 2-30), documenting all design and test efforts taken to comply with the requirements of the Specifications.

#### **2.14.11 Safety Tests**

Any test used to mitigate a hazard (proves correct assembly/functionality) shall be designated as a safety related test. The Contractor shall submit such test procedures, data, and results for acceptance by Sound Transit (CDRL 2-31).

#### **2.14.12 Safety Verification**

Prior to shipment of the first vehicle a Safety Compliance Assessment (SCA) shall be completed, which SCA shall incorporate all components of the SHA. It shall be organized in the same format as the PHA and clearly demonstrate that all requirements identified in the PHA have been completed. All items and documents identified as requirements for the safety verification of individual events shall be included, preferably as appendices. This document shall be submitted for approval by Sound Transit. (CDRL 2-32)

#### **2.14.13 Safety Certification Support**

The Federal Transit Administration (FTA) requires a certification program to address safety and security of funded transportation projects. Sound Transit will implement a safety certification process in compliance with FTA regulations, as deemed appropriate for this project, to safety certify the vehicles delivered under this contract. The Contractor shall:

- Comply with and support the requirements of the Safety Certification process.
- Participate in the Safety Certification process and furnish supporting documentation in a format acceptable to Sound Transit to facilitate required audits of the Safety Certification documentation, as required, by the Department of Transportation and/or the FTA and Sound Transit.

The Conditional Acceptance and final determination of the readiness of the delivered vehicles for revenue service is contingent upon the completion of the Safety Certification.

## **2.15 Codes and Regulations**

All equipment shall comply with applicable codes, standards, and regulations cited below and elsewhere in the Specifications. Where conflicts exist between standards, the more restrictive, as determined by Sound Transit, shall apply. Application of these codes and standards shall be as modified by the Specifications.

All equipment shall comply with applicable local, state, and federal rules and regulations. These include, but are not limited to, the following:

- Recommended Fire Safety Practices for Rail Transit Materials Selection.
- 36 CFR, Part 1192: Americans With Disabilities Act (ADA), Accessibility Guidelines for Transportation Vehicles.
- 49 CFR 27, 37, and 38: Transportation for Individuals with Disabilities (U.S. Dept. of Transportation)
- 49 CFR, Parts 200 to 399: Chapter II - Federal Railroad Administration. (U.S. Dept. of Transportation).
- NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems.
- Military Standard, MIL-STD-882: Standard Practice For System Safety. (U.S. Dept. of Defense).

Deviations from, and substitutions of, specified standards shall be made only if previously approved by Sound Transit. Contractor shall submit a detailed comparison of the alternative criteria, the rationale for the alternative, and whether the proposed code or standard meets or exceeds the existing standard. (CDRL 2-33)

## **2.16 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 2-1 Bicycle stowage arrangement (Section 2.2.4)
- 2-2 Vehicle numbering locations (Section 2.2.5)
- 2-3 Dynamic envelope study (Section 2.3.5.2)
- 2-4 Platform interface study (Section 2.3.5.3)
- 2-5 Vehicle weight, passenger load calculations, and weight unbalance report (Section 2.4.1)
- 2-6 Estimated total vehicle weight report (Section 2.4.3)

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- 2-7 Subsystem weight report form (Section 2.4.3)
- 2-8 Wheel to rail interface study plan (Section 2.5.3.1)
- 2-9 Wheel to rail interface study report (Section 2.5.3.1)
- 2-10 Evaluation of local climatic conditions (2.5.4)
- 2-11 EMC control and test plans (Section 2.9.5)
- 2-12 Samples, except seats (Section 2.10.2)
- 2-13 Seat samples (Section 2.10.2)
- 2-14 Interior finish schedule (Section 2.10.2)
- 2-15 Vehicle renderings (Section 2.10.3)
- 2-16 Service history report (Section 2.11)
- 2-17 Verification of product history (Section 2.12.2)
- 2-18 Reliability analysis (Section 2.12.2)
- 2-19 Reliability program plan (Section 2.12.3)
- 2-20 Reliability progress reports (Section 2.12.3))
- 2-21 Maintainability program plan (Section 2.13.2)
- 2-22 Maintainability demonstration plan (Section 2.13.3)
- 2-23 Preventive maintenance plan (Section 2.13.4)
- 2-24 List of indicators and features of self-diagnostic system (Section 2.13.5)
- 2-25 System safety program plan (Section 2.14.2)
- 2-26 Systems hazard analysis (Section 2.14.9)
- 2-27 Failure, Modes and Effects Criticality Analysis (FMECA) (Section 2.14.9.1)
- 2-28 Sneak circuit analysis (Section 2.14.9.2)
- 2-29 Operating & support hazard analysis (2.14.9.3)
- 2-30 Fire hazard analysis (Section 2.14.10)
- 2-31 Safety test procedures, data and results (Section 2.14.11)

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- 2-32 Safety compliance assessment (Section 2.14.12)
- 2-33 Detailed comparison of alternative criteria for deviation requests from, and substitutions of, specified standards and confirmation of meeting or exceeding specified standard (Section 2.15)
- 2-34 Rendering demonstrating doorway alignment with platform ADA tactile waiting areas (Section 2.10.3)

### **2.17 Cited References**

The following standards or references were cited in this Section at the referenced location:

ANSI S1.4-1	Electroacoustics - Sound Level Meters - Part 1: Specifications (Section 2.8.1)
ANSI S1.11-1	Electroacoustics - Octave-Band and Fractional-Octave-Band Filters: Specifications (Section 2.8.1, 2.8.12)
DOT-FTA-MA-26-5005-00-01	Hazard Analysis Guidelines for Transit Projects” - U.S. “Department of Transportation, Federal Transit Administration (Section 2.14.9)
FTA	Recommended Fire Safety Practices for Rail Transit Materials Selection (Section 2.15)
IEC 60349-2	Electric Traction – Rotating Electrical Machines for Rail and Road Vehicles – Part 2: Electronic Converter-Fed Alternating Current Motors (Section 2.8.5)
IEC 61373	Railway Applications – Rolling Stock Equipment – Shock and Vibration Tests (Section 2.8.8)
ISO 2631	Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration (Section 2.8.9)
ISO 3095	Acoustics -- Railway applications -- Measurement of noise emitted by railbound vehicles (Section 2.8.4)
MIL-STD-882	Standard Practice For System Safety (Sections 2.14.1, 2.14.2, 2.14.3, 2.14.4, 2.15)
NFPA 130	Standard for Fixed Guideway Transit and Passenger Rail Systems (Section 2.15)
UMTA-MA-06-0153-85-6	Conductive Interference in Rapid Transit Signaling Systems, Volume II: Suggested Test Procedures (Section 2.9.8)

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UMTA-MA-06-0153-85-8	Inductive Interference in Rapid Transit Signaling Systems, Volume II: Suggested Test Procedures (Section 2.9.9)
UMTA-MA-06-0153-85-11	Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures (2.9.7)
36 CFR 1192	Americans With Disabilities Act (ADA), Accessibility Guidelines for Transportation Vehicles (Section 2.15)
49 CFR 27, 37, & 38	Transportation for Individuals with Disabilities (Section 2.15)
49 CFR 200 to 399	Chapter II - Federal Railroad Administration. (U.S. Dept. of Transportation) (Section 2.15)

Figure 2-4: General Arrangement

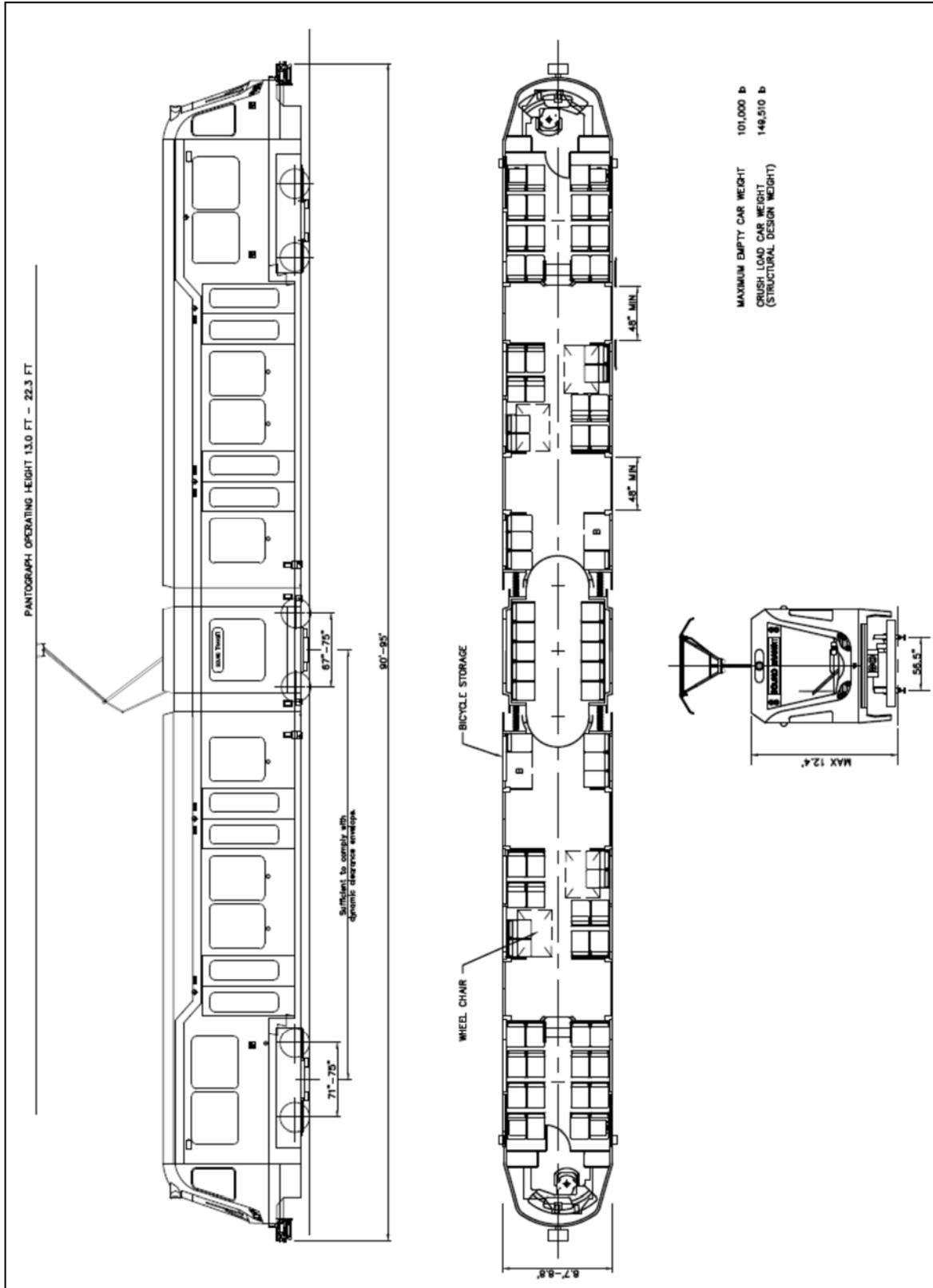
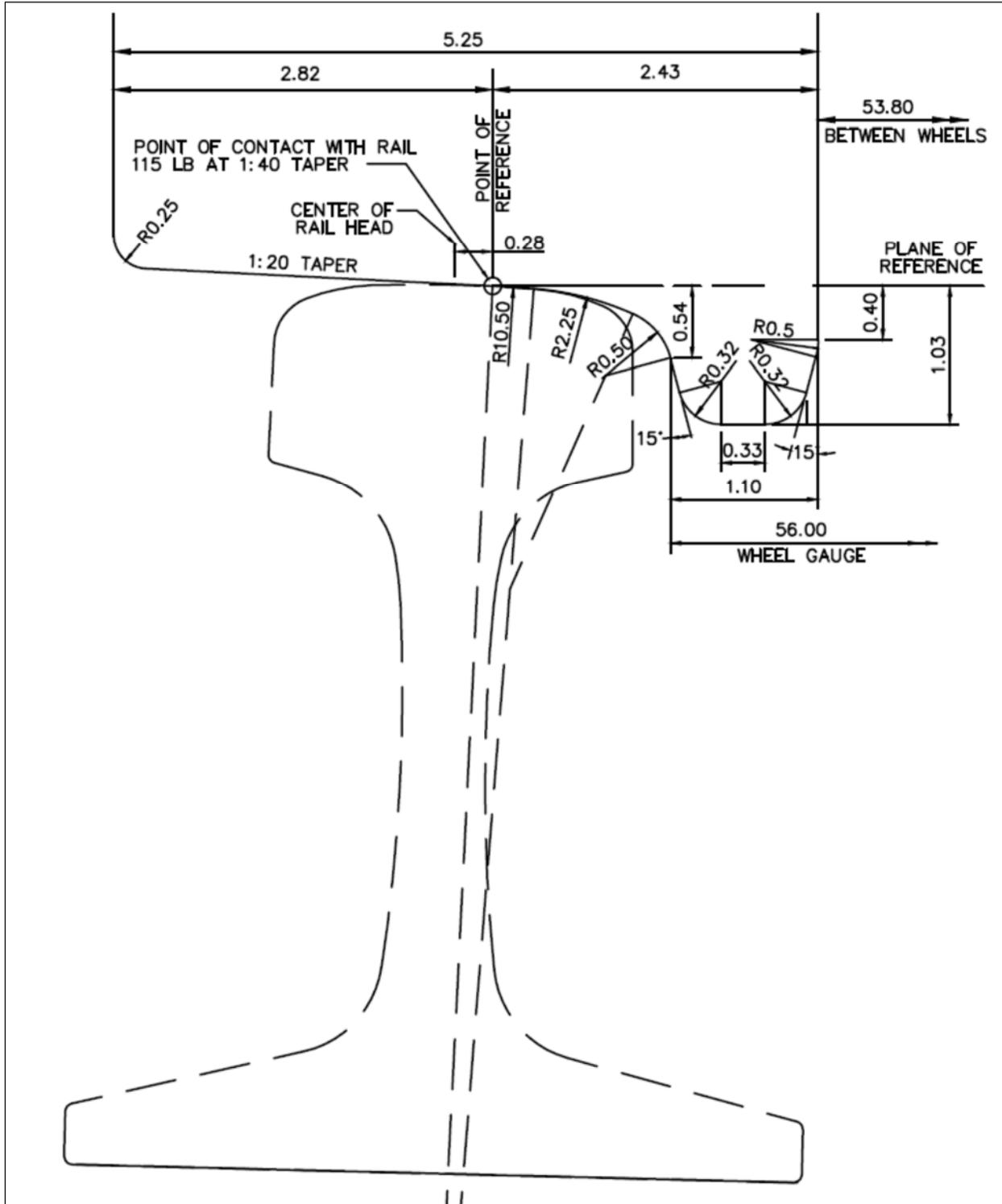
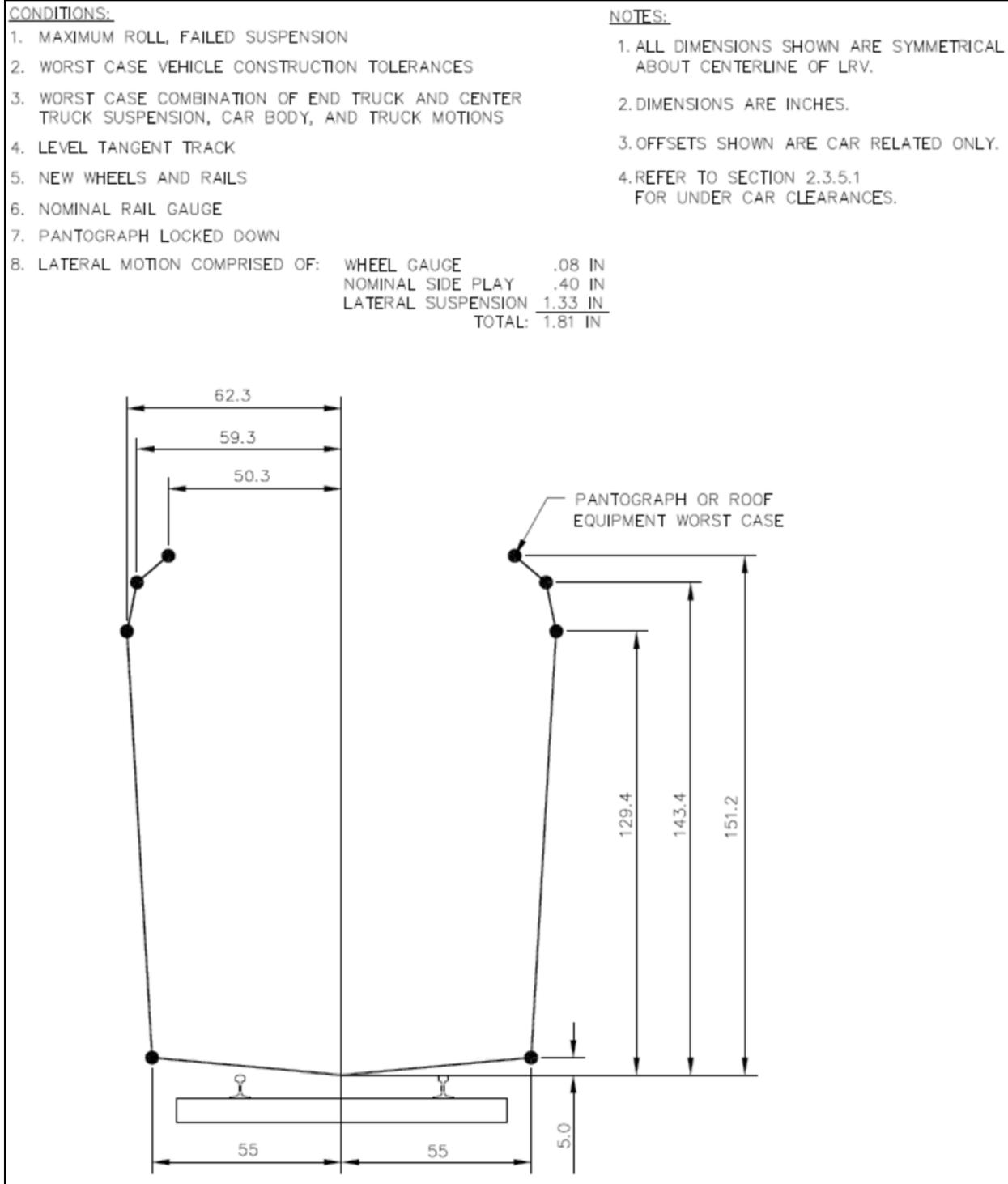


Figure 2-5: Wheel Profile



**Figure 2-6: Vehicle Dynamic Envelope**



**Figure 2-7: Maximum Curve Offset**

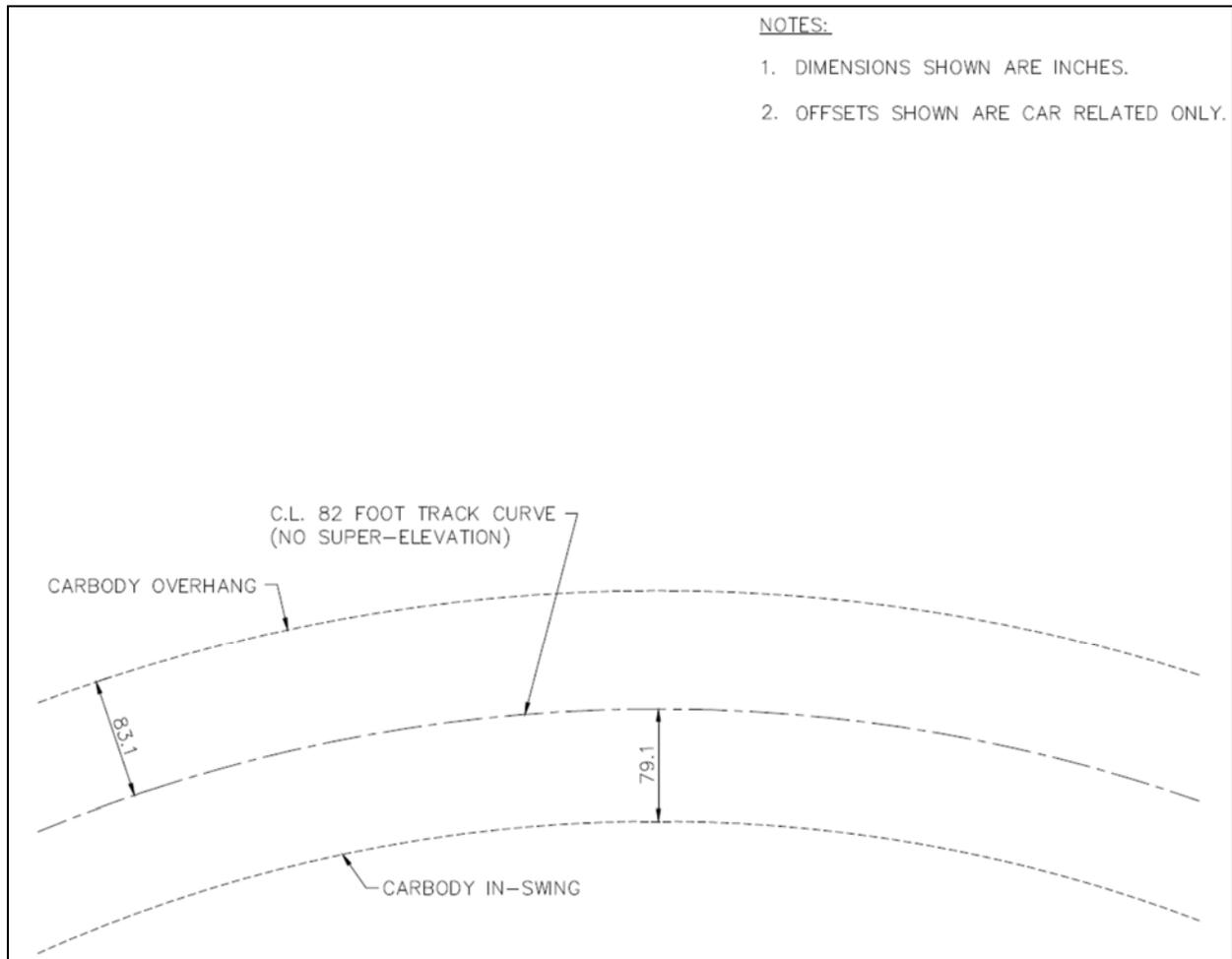
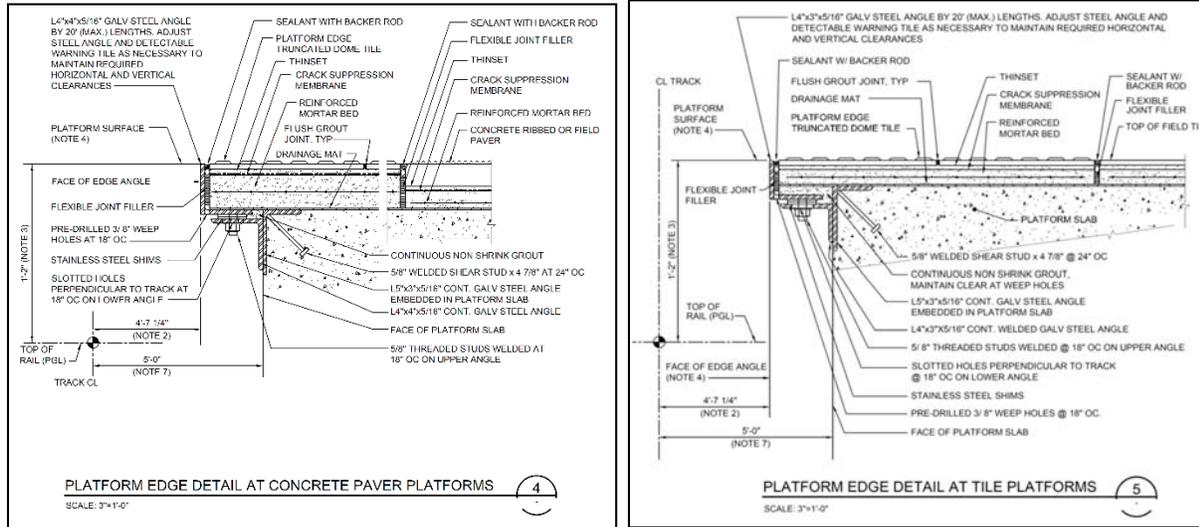


Figure 2-8: Platform Interface 1



Notes referenced in above details:

2. **HORIZONTAL TOLERANCE:**  
SEPARATION BETWEEN FACE OF PLATFORM EDGE ANGLE AND INSTALLED TRACK CENTERLINE SHALL NOT VARY MORE THAN PLUS 1/4-INCH OR MINUS 0 INCHES FROM THE INDICATED DIMENSION.
3. **VERTICAL TOLERANCE:**  
SEPARATION BETWEEN PLATFORM SURFACE AND THE ACTUAL INSTALLED TOP OF RAIL ELEVATIONS (PROFILE GRADE LINE) SHALL NOT VARY MORE THAN PLUS 0 INCHES OR MINUS 3/8 INCH FROM THE INDICATED DIMENSION.
4. ALONG THE LENGTH OF PLATFORM FACE AND AT THE PLATFORM SURFACE, RATE OF CHANGE VARIATIONS SHALL BE LIMITED TO 1/8-INCH IN 15 FEET.
5. TOLERANCE OF TRUNCATED DOME TILE TO THE TOP OF PLATFORM EDGE ANGLE SHALL NOT VARY MORE THAN PLUS 1/16 INCH OR MINUS 0 INCHES.
6. THE SURFACE OF THE PLATFORM SLAB TO RECEIVE MORTAR BED FOR CONCRETE OR TILE UNIT PAVERS SHALL NOT VARY MORE THAN PLUS OR MINUS 1/4-INCH FROM SPOT ELEVATIONS INDICATED OR MORE THAN 1/4-INCH IN ANY 10-FOOT LENGTH.
7. THE VERTICAL FACE OF THE PLATFORM SLAB BENEATH THE PLATFORM EDGE ANGLE SHALL NOT VARY MORE THAN PLUS OR MINUS 1/4 INCH FROM THE INDICATED TRACK CENTERLINE OFFSET OR MORE THAN 1/8-INCH IN ANY 15-FOOT LENGTH.

Figure 2-9: Platform Interface 2

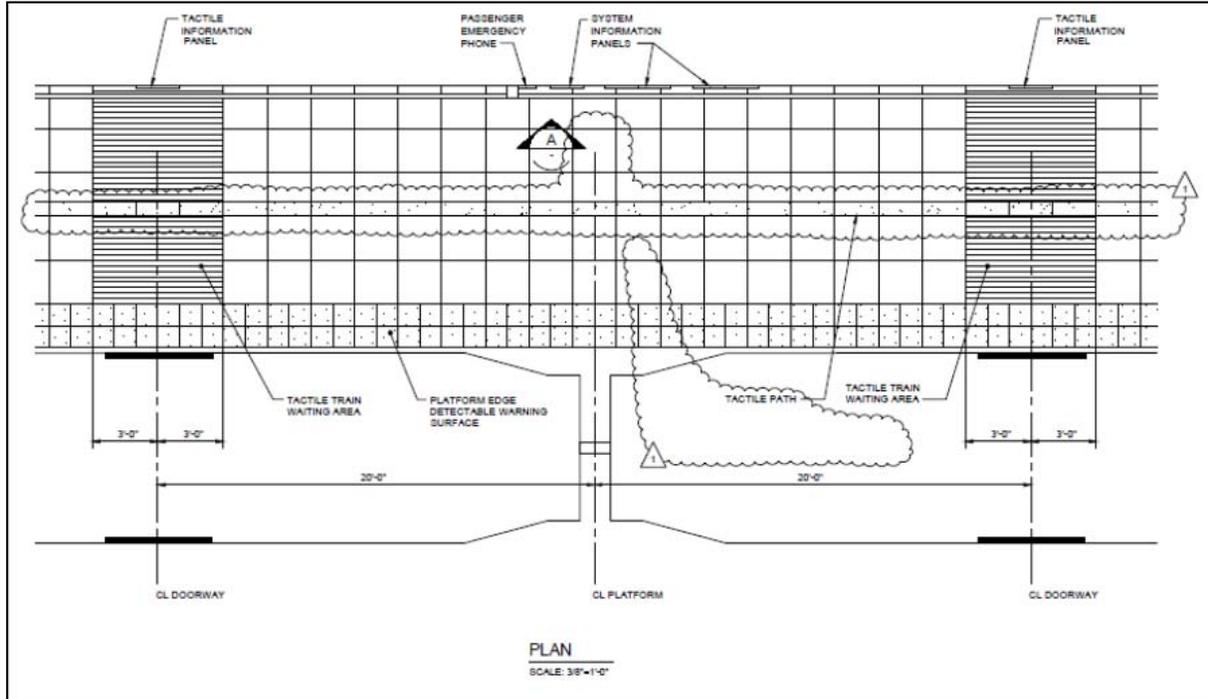


Figure 2-10: Door Center-Lines and Jack Support Locations

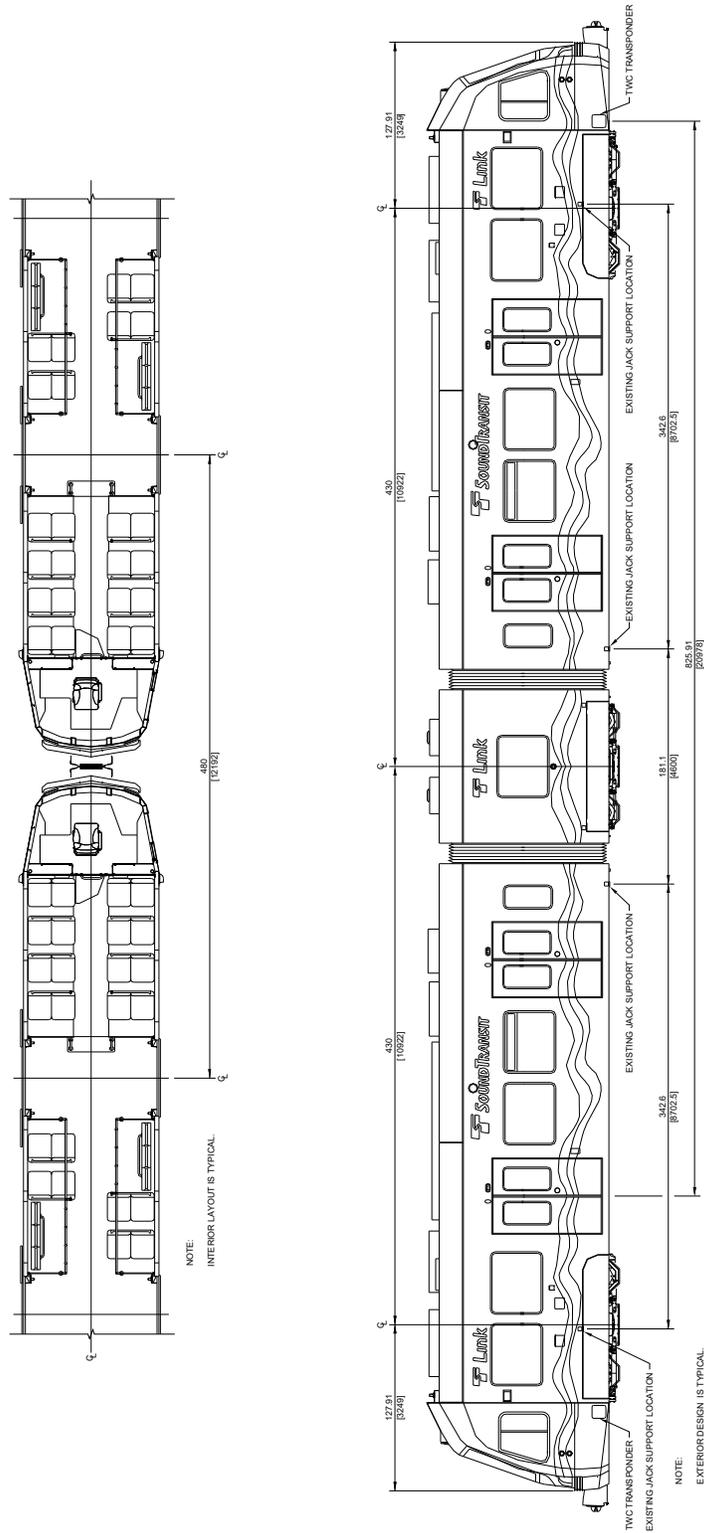
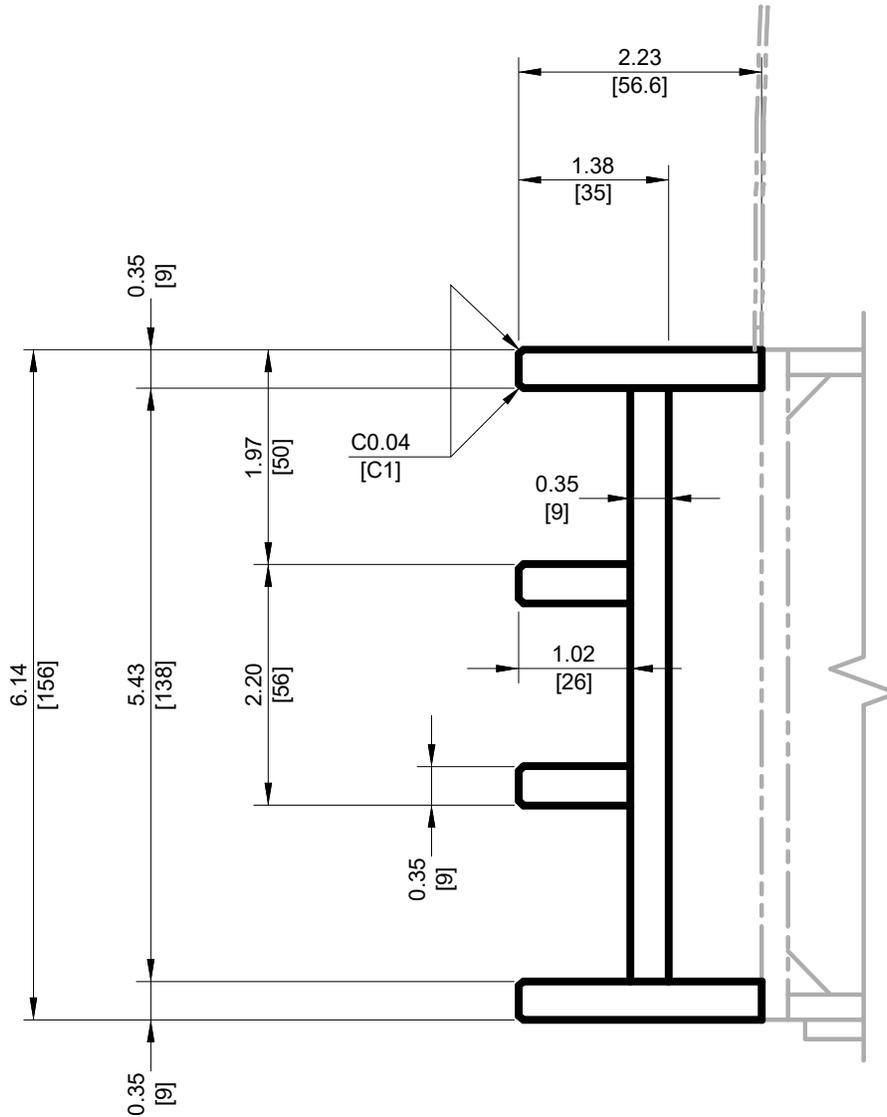


Figure 2-11: ST1 Anticlimber Detail



END OF SECTION 2

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 3  
CAR BODY**

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## **SECTION 3: CAR BODY**

### **3.1 General**

The car body shall consist of two main body sections joined by articulations to a short center section. The main portion of the main body sections and the center section shall be low floor. All three sections shall be semi-permanently coupled together to form a single operating vehicle. Each vehicle shall have eight door openings, with four openings per side. Door openings on one side shall be directly opposite those on the other side. All door openings shall be located in low floor area. The passenger door openings closest to the cab end shall be located to line up with the existing tactile “Train Waiting Area” on the station platforms as described in Section 2 and shown on Figure 2-9, Platform Interface 2. The passenger door openings closest to the cab end shall be located to line up with shop maintenance platforms.

Refer to Figure 2-4, General Arrangement, for the general arrangement of the vehicle and Figure 2-8 and 2-9 for the platform interface.

Each body section shall be designed as described in this Section 3 below, as applicable. Portions of the roof, side frame, and underframe shall be designed to form a girder to carry the shear and bending loads resulting from the specified loads. In the selection of the type and thickness of material to be used, the Contractor's design shall maximize strength and reliability, minimize weight, and produce the desired appearance.

The car body and attached equipment shall be designed to provide clearances for the truck and track profiles as specified in Sections 2 and 11, except for any stops attached to the car body for limiting truck movement.

The structural design shall be based on the specified loads, factors of safety, and deflections. The finished car body shall be proof-tested to verify the design analysis. Refer to Section 16.

Exterior appearance shall be as approved by Sound Transit; refer to Section 15. The front end shall permit the use of a wide curved window to maximize operator field of view and to enhance appearance.

No control equipment except coupler, TWC (Transponder) and friction brake control equipment shall be permitted below the floor between the motor truck and the anticlimber. Trainline junction boxes, coupler control boxes, and friction control equipment enclosures shall be formed of or be protected by main structural elements. Control equipment shall be protected against damage caused by track debris and automobile accidents.

The car body structure, including end underframe with attached anticlimber, end frames, and articulation assemblies, assembled with couplers and trucks shall be arranged to minimize the propensity to telescope in the event of collision with a highway vehicle or another LRV. Alternatively, the Contractor may propose carbody structure design based on Crash Energy Management (CEM) approach per Section 3.14 below, provided the Contractor can successfully demonstrate benefits of the proposed CEM design over the conventional design on the existing fleet, in the event of a collision with the existing vehicles. The Contractor will be required to

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provide a detailed crashworthiness analyses and the validating physical test, described in Section 16, to demonstrate crashworthiness compatibility with the current LRV fleet.

Interfaces to wayside equipment for lifting, hoisting, and re-railing shall align with existing in-floor car lifting apparatus located at the Sound Transit maintenance facilities and shall be as approved by Sound Transit. A wayside interface design report containing dimensional load information for lifting and jacking locations shall be submitted to Sound Transit for review and approval. (CDRL 3-1)

Tie down points shall be incorporated into the car in order to secure the vehicle for shipment on a flat car and for body straightening after an accident.

### **3.1.1 Exterior Flatness Before Finishing**

Prior to the application of fillers to the body, all raw exterior surfaces shall be free of ripples and buckles. Maximum allowable variation from a straight line or the designed curved line shall be as follows:

- All exterior side, ends, and roof surfaces not hidden by covers or shrouds:
  - 3/32 inches (2.4 mm) (peak to valley) in 36 inches (914 mm) measured in any direction.
- Exterior surfaces hidden by covers and shrouds:
  - 5/16 inches (7.9 mm) (peak to valley) in 36 inches (914 mm) measured in any direction.

### **3.2 Materials**

All materials used in car body construction shall be in accordance with the requirements of Section 17.

The car body shall be constructed of welded HSLA steel or approved equal except as noted below. The end underframe unit shall be constructed in accordance with this Section. The use of polyurethane insulation or asbestos is prohibited. Refer to Section 17 for painting requirements and restrictions.

### **3.3 Construction Methods**

The car body structure shall be assembled by welding, using connections designed in accordance with AWS D1.1/D1.1M, or approved equivalent standards (refer to Section 17).

All welding shall conform to the requirements of Section 17. Where the car body structure must be assembled with mechanical fasteners, the fasteners shall be high-strength lock bolts (refer to Section 17).

Uniform construction and assembly methods shall permit interchangeability of like subsystems, equipment and components. The Contractor shall verify that this requirement has been met through the Contractor's Quality Assurance program (refer to Section 19). All weld and bolt patterns shall be identical on all cars.

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Where dissimilar metals are joined they shall be protected against electrolytic corrosion (refer to Section 17).

Bolts or welding may be used to join secondary structure or for attaching brackets and equipment to primary structure in subassembly. Otherwise, attachments that are not part of the car body structure shall be attached to the structure with mechanical fasteners. Lock-bolts shall be set with power tools. All holes for mechanical fasteners shall be clean and free of burrs and will not be oversized. Refer to Section 17 for joining and fastening requirements.

Adequate drainage shall be provided in all body structure members. Enclosed structural cavities shall be vented to prevent condensate buildup. Any enclosed structural cavities of steel members shall be treated with a rustproofing coating as specified in Section 17.

### **3.3.1 Structural Connections**

Rivets or bolts used in combination with welds, or bonds, in a connection shall not be considered as sharing the load with the welds. When used in a connection, welds, or bonds, shall be designed to carry the entire load across the connection.

Connections between structural members of the car body shall be made so that the design strength of the connection exceeds the ultimate load carrying capacity of the weakest member joined. This requirement applies to connections among primary car body structural members in and around the passenger compartment and cab under the actions of the specified emergency load cases. The emergency load cases include the end-compression loads, end-frame post loads, side loads, rollover loads, and truck connection design load. For connections consisting of a primary structural member that resists the specified emergency load conditions, the ultimate strength of the weaker member is obtained by overloading the member at the point of application of the load for the corresponding emergency load case.

Refer to Section 17, Special Requirements for Structural Fasteners section, for bolted connection requirements. Equivalent metric standards may be proposed for Sound Transit approval. Clamping force friction shall be ignored in the design and analysis of mechanically fastened connection (refer to Section 17). No visible fastener heads shall be permitted.

Self-tapping screws are not allowed. There shall be no tapped holes in the car body structure.

Intermittent fillet welds on tension members, or in areas that experience fatigue, are prohibited. Plug or slot welds on tension members, or in areas that experience fatigue, are prohibited. Intermittent groove welds are prohibited. Stud welding to car body structure is prohibited; however, stud welding to non-load carrying members and secondary structure is permitted.

Where used, shims shall be permanently attached to the car body structure.

### **3.3.2 Camber and Deflection**

Under the combined weight of the completed main body section and a proportional passenger load of AW4, the side sill shall not deflect more than 0.35 in (8.9 mm) from the datum line drawn from the transverse center line of the car body bolster at the motor truck through the transverse center line

of the articulation joint. All equipment, including side doors, shall operate satisfactorily and shall not bind due to the deflection caused by variations of load from AW0 to AW4. The maximum difference between the camber of each side sill shall not exceed 1/8 in (3.2 mm).

### **3.4 Underframe**

#### **3.4.1 End Underframe**

The end underframe shall consist of the draft sill, body bolster, end sill, anticlimber, collision and corner posts and stubs for connecting to the underframe sills.

The end underframe shall be made of HSLA steel and assembled by arc welding in accordance with Section 17, using AWS prequalified, complete-joint penetration, groovewelded joints, as defined by AWS D1.1/D1.1M, wherever primary loads are carried across the joint in tension or compression. AWS prequalified, partial joint penetration, groove welded joints, as defined by AWS D1.1/D1.1M, may be used where primary loads are carried in shear along the length of the weld. Fillet welds may be used in joints that do not carry primary loads. Stainless steel may be used in the end underframe, as subject to approval by Sound Transit. (CDRL 3-2)

If heat treatment is required for stress relief or to attain the required strength level, the assemblies shall be heat-treated after welding.

The end underframe shall be designed so that:

- Flanges and webs at any location where load bearing members intersect are continuous;
- In case of excessive impact, failure shall be caused by progressive buckling or crushing of structural elements beginning in the region outboard of the coupler anchor, rather than by shearing of structural elements or by failure of connections between elements (refer to this Section below); and
- The vehicle can be lifted by jacking beneath the longitudinal centerline of the anticlimber.

##### **3.4.1.1 Draft Sill**

The draft sill shall extend longitudinally from the end sill to the body bolster, and shall include the coupler support structure. It shall be designed to transmit the specified longitudinal loadings from the anticlimber and coupler into the body bolster. The side sills may carry some of the longitudinal load. The design shall be such that there is a critical section (the section which fails first) immediately outboard of the coupler support structure.

##### **3.4.1.2 Body Bolster**

The body bolsters shall be designed to transmit the specified vertical and horizontal loads from the motor trucks into the car body, and to transmit buff and draft loads from the draft sill into the side sills. The design shall provide clearance for all truck positions, strength of truck attachment, and accessibility for truck maintenance and removal. The car body bolster shall be deemed as part of the car body.

### **3.4.1.3 End Sill**

The end sill at each end of each main body section shall be designed to transmit the required anticlimber loadings into the draft sill and side sills without exceeding the yield strength of the end sill structure. The end sill shall also be capable of transmitting the loads from the collision and corner posts into the draft sill and side sills, without failure, when the posts are loaded to their ultimate strength.

### **3.4.1.4 Anticlimber**

An anticlimber shall extend laterally over the full width of the vehicle front-end frame and shall be welded to the end sill or other car structure protruding beyond the end sill, as long as crashworthiness and strength requirements are met. The anticlimber shall be shaped as a curve with a constant radius from the coupler pivot, so as to keep the gap between cars uniform in any position of adjacent cars. If a collision occurs the anticlimber shall be designed to engage the anticlimber of an opposing vehicle under the worst horizontal and vertical track curves, and resist climbing forces between vehicles. The anticlimbers shall be designed so that they will interact with the Sound Transit ST1 vehicle in the event of a collision between an ST1 and ST2 vehicle. Refer to Figure 2-11, ST1 Anticlimber Detail.

A jack pad shall be provided under the center of each anticlimber; refer to this Section.

### **3.4.2 Articulation End Underframe**

The underframe at each articulation end shall consist of a transverse beam at the body end and such other transverse and longitudinal beams and attaching arms as necessary to transmit the internal longitudinal, transverse, vertical and torsional loads within the specified allowable stresses.

### **3.4.3 Side Sills and Body Sills**

Side sills shall form the lower longitudinal corner of the car body structure and shall resist the combined vertical and longitudinal loads resulting from the design loads. Longitudinal or body sills located inboard of the side sills may be used, if necessary, to carry longitudinal loads through the underframe. The side and body sills shall, together with the draft sill, be designed so that, when longitudinal loadings exceed the specified values, any failure of the car body will begin in the side sills and draft sill outboard of the coupler support structure rather than in the region between the coupler support structure and the articulation end underframe or in the center car section. Refer to this Section.

### **3.4.4 Sub-Floor Panels**

A stainless steel sub-floor (floor pans) shall be provided below the floor beams throughout the length of the car. The sub-floor panels shall not be less than 0.020 in (0.5 mm) thick. The sub-floor shall be welded to the bottom flanges of the floor beams and to the draft sills, end sills, side sills, and body bolsters. Riveting of the floor pans will be allowed only if riveting and sealing of the pan is service proven to last for the life of the vehicle. All seams and edges shall be watertight. The space between the floor and subfloor shall be filled with insulation as required by Section 15. If clearances prohibit the application of the subfloor panel at particular locations, or require less than

normal separation between the subfloor and floor panels, alternative designs which provide the specified thermal and acoustic insulation requirements and fire-barrier properties may be proposed for Sound Transit review and approval. (CDRL 3-3)

### **3.4.5 Equipment Supports**

Equipment weighing more than 25 lb (11.3 kg) shall not be supported solely by bolts in tension or shear, but instead shall rest on top of, or be supported by, mounting brackets, or structural members of the underframe or roof structure and be secured by bolts. No equipment shall be supported by bolts in holes tapped in the car structure.

Equipment supported on resilient mounts shall be provided with safety straps or other safety devices for support in case of mount failure.

Refer to this Section for additional requirements.

## **3.5 Floor Construction**

### **3.5.1 General**

The floor shall be constructed so that all applicable noise, vibration, strength, and fire endurance rating requirements are met. Refer to Section 2 for noise and vibration requirements, Section 3 for strength requirements, and Section 17 for fire endurance rating requirements. The floor design shall be tested to meet the fire endurance rating requirements prior to the Contractor's procurement of production material.

The Contractor shall, immediately after installation, provide a protective mat or hardboard sheeting over the entire floor to prevent damage from workers, equipment, tools, or material during the balance of construction of each car shell. Floor finished design shall not promote any tripping hazard to any point along the surface.

### **3.5.2 Floor Panels**

The floor, including the cab floor, shall be constructed of composite panels, as detailed in this Section. Floor panels shall be constructed of minimum 0.75 in (19 mm) thick composite panels faced on the entire top and bottom surface with 0.1 in (2.5 mm) minimum thickness, bi-axial fiberglass fabric impregnated with a Phenolic thermosetting resin. Other designs of the composite floor panels may be considered by Sound Transit. Where the floor panels are supported no more than 36 inches (914 mm) apart, the skin thickness may be 0.055 in (1.4 mm) minimum. The fiberglass reinforced Phenolic skins shall be permanently bonded to an end-grain balsa core through a compression molding process, co-curing the wet Phenolic resin impregnated skins directly against the balsa core.

The panels shall extend from the sidewalls to the aisle. The shiplap transverse joints shall be located over structural members. There shall not be any joints in the top or bottom face skins of the panel. The panels shall be insulated from the metallic structure by an elastomeric tape. All exposed edges of the panels, including interior holes, cutouts for ducts and conduits, and joints between panels shall have a dense phenolic syntactic composite edge machined smooth and free of sharp edges and

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burrs. The floor material shall be non-vermin supporting and shall not rot, corrode or absorb water. The passenger compartment floor shall be flat and level throughout and shall not exhibit visible buckles, delamination or waviness.

No transverse joints shall be used in the intermediate level entranceways. Transverse supports shall be spaced no more than 42 inches (1067 mm) apart.

The floor panels shall be attached to the floor structure using approved flat head stainless steel fasteners in countersunk holes in the upper floor panels. Reinforcements and steel tapping plates for above floor attachments (other than the seat pedestals) shall be provided in the car structure.

Alternative methods for attaching the floor panels to the floor structure may be proposed to Sound Transit for review and approval during the design review period. (CDRL 3-4)

### **3.5.3 Floor Beams**

Transverse beams shall be provided to transmit vertical floor loads to the side sills. The floor panels shall be attached to the floor beams, end sills, side sills, body sills (if used), and body bolsters, depending upon location.

### **3.5.4 Steps**

Steps shall be provided in the center aisle of the floor of main body sections between the high and low floors. The stairs shall be as wide as the center aisle. Risers shall be of equal heights. Risers and treads shall be dimensioned as described in Section 2.

The steps, stair side walls, and the bulkheads between the high and low floor shall meet the same fire endurance requirements as the floor and shall be made of stainless steel. The top surface of the steps shall be covered with ribbed rubber sheet with appropriate step edge nosing as described in Section 15.

## **3.6 Front End Frame**

The front end frame shall consist of corner posts at the juncture of the front end and side frame; stub collision posts located at the approximate third points of the end frame width, but in any case not more than 36 in (914 mm) apart; an end structural shelf or transverse beam just below the bottom of the windshield; and sheet metal sheathing connected to the structural framing members.

The front-end frame shall be capable of resisting, without failure, normal operating loads and the specified collision and jacking loads. The front-end frame shall also be designed to support the windshield in accordance with the requirements contained in Section 15.

### **3.6.1 Collision Posts**

The collision posts shall be continuous through the end sill, extending from the bottom of the end sill to the structural shelf immediately below the windshield. They shall be connected to the structural shelf and to the top and bottom surfaces of the end sill to develop the full strength of the posts.

If reinforcement is used to provide the horizontal shear value required by this Section, such reinforcement shall have full value from the underframe top surface to the structural shelf. The reinforcement shall also continue downward with the post section so that both are welded securely to the bottom plate of the end sill.

### **3.6.2 Corner Posts**

The corner posts shall extend the full height from the underside of the end underframe to the roof rail. They shall be connected to the top and bottom of the end sill, to the roof rail and structural shelf to develop the full strength of the posts. They shall be reinforced below the structural shelf, if required, to resist the specified loadings of this Section. The area properties of the reinforcement shall be continuous from the bottom of the end sill to the top of the structural shelf.

### **3.6.3 Structural Shelf**

The structural shelf shall be a horizontal transverse beam in the front-end frame just below the windshield. It shall extend from corner post to corner post and be connected to the corner posts and collision posts. The structural shelf shall be designed to resist the load specified in this Section.

### **3.7 Articulation End Frame**

The articulation end frame shall consist of corner posts, framing posts, a header, and sheathing. It shall be designed to resist the specified vertical, transverse, and torsional loads.

### **3.8 Roof**

#### **3.8.1 Roof Structure**

The roof assembly shall be constructed of carlines, purlines, and roof sheathing covering the entire roof area. Framing members and structural wells shall be provided for the support of roof-mounted equipment. Equipment wells shall have adequate drainage for the worst case environmental conditions described in Section 2 (refer to Section 15 for further drainage requirements). The roof assembly and penetrations shall be constructed so that the specified fire endurance requirements are met (refer to Section 17). The roof design shall be tested to meet the fire endurance rating requirements prior to the Contractor's procurement of production material. Roof structure shall be constructed with a positive camber at AW0 condition in transverse direction, so that there will be no low spot where water may accumulate. The use of sealant over welds is not permitted.

#### **3.8.2 Roof Equipment Supports**

To support roof-mounted equipment, stainless steel brackets shall be welded to the roof on or at carlines and purlines, not on unsupported roof sheets, during subassembly. The roof equipment shall be bolted to these brackets. Refer to this Section for additional equipment mounting requirements. Through-roof mechanical fasteners shall not be used.

A roof access stair system shall be incorporated into the roof design such that each step does not exceed 7 inches from the shop mezzanine to the roof sheathing. Steps shall incorporate a non-slip design and shall be located one each side diagonally opposed on each end of the LRV.

### **3.8.3 Roof Openings**

The roof shall be framed and reinforced around openings for air inlets, piping, and wiring. All reinforcement shall be welded steel. Reinforcements on the roof shall be made watertight by welding.

### **3.9 Side Frame**

Side frames shall consist of window posts, doorposts, longitudinal roof rails, longitudinal window top rail and belt rail members, sheathing, appropriate stub (cripple) posts and internal skin stiffening members.

Full-height structural posts shall be located at the sides of all door and window openings and elsewhere as required. Full-height structural posts shall be continuous between the side sill and the roof rail. Where horizontal rails are interrupted by posts, gussets shall be used to reinforce connections to effectively make the rails continuous. Adequate side frame posts or stub posts extending between the side sills and the belt rails shall be provided to transmit vertical load from the body bolster ends, crossbearer ends, and jacking pads into the side frame sheathing.

Steel side sheets shall be welded to the outside of the side frame framing members. Side sheets may be stiffened by corrugations or similar sections on the inside face of the side sheet. The sides shall meet the minimum smoothness requirements specified in this Section.

### **3.10 Car Body Center Section and Articulations**

The car body center section, mounted on its truck, shall provide attachment and support for the "A" and "B" car body sections. The car body center section shall be considered an integral part of the vehicle. The articulation frame shall be fabricated from HSLA or made of cast steel in accordance with the material and workmanship requirements of Section 17.

#### **3.10.1 Design**

The car body center section shall have no doors and shall be designed to maximize ease of passenger access from one main car body section to the other main car body section. The width of the car body center section shall be the same width of the adjacent car body sections the car body center section floor shall be level with the low car body section floors, and shall not present a tripping hazard under any operating condition. Alternative floor arrangements, such as a floor level ramped to match the low floor level, may be proposed for Sound Transit review and approval (CDRL 3-5).

The articulation interior and exterior surfaces shall be arranged to prevent injuries to passengers and operating personnel. Openings, sliding surfaces, spaces, or edges, which could endanger passengers, cause finger snags or pinch points to passengers, either inside, or outside, under any condition up to maximum vertical and horizontal movement, shall not be allowed.

The articulation design must permit the "A" and "B" car body sections and the center car body section to rotate freely with respect to each other, externally and internally, about the transverse (horizontal) and vertical axes while maintaining torsional rigidity about the longitudinal axis.

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Rotational rigidity shall also be provided between the center car body section and one main car body section around the transverse (horizontal) axis. Other methods may be proposed, for Sound Transit review and approval, which constrain the angular displacement around the transverse axes to be divided between the two articulations. (CDRL 3-6)

The center car body section and its attachment to the adjacent car body sections shall meet all applicable car body static strength requirements. It shall have sufficient strength to resist dynamic buffing loads at least as great as the adjacent car body sections, so that in a collision, the articulations or the center car body section will not be the first structure to fail. The articulation joint and its attachment shall provide anti-climbing and anti-telescoping protection as required by this Section.

The articulations and the center car body section shall provide all necessary passages for cabling, ducting, and piping which must pass across the car body sections.

Articulation bellows on interior sidewalls and ceiling shall be covered by interior lining material for noise control, as specified in Section 15. Interior noise and temperature requirements shall be met in the articulations and the center car body section.

The articulations and center car body section shall be constructed to resist fire and smoke penetration from the vehicle exterior. The articulation bellows shall comply with Section 17 flammability and smoke emission requirements.

The exposed parts of the articulations and center car body section, including the bellows, shall be designed to resist vandalism, including painting, marking, and penetration or slashing with sharp objects.

For details of the attachment of the center car body section to the center truck, refer to Section 11.

### **3.10.2 Appearance**

There shall be a hard exterior sheathing or soft bellows at the articulations to protect and mask from view the articulation mechanisms and seals.

### **3.10.3 Noise**

Vertical or horizontal rotation of the articulation and truck attachment to car body interface shall not cause rubbing, squealing, squeaking, or other noises.

## **3.11 Jack Pads, Jack Sockets, and Hoisting**

The jacking and hoisting arrangement shall be compatible with current Sound Transit equipment and designed such that for maintenance or re-railing:

- The vehicle can be jacked or hoisted as a unit.

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- Either end body section can be jacked or hoisted at one end while supported at the articulation joint at the other end. The end body section shall be able to be lifted high enough to remove the end truck without damage to any portion of the vehicle.
- Each car body section can be jacked or hoisted independently while remaining connected at the articulation for re-railing purposes.
- Either end body section can be jacked or hoisted individually with four jacks or hoists.

Refer to this Section for jacking pad load requirements.

Jack sockets shall be provided in the sidewalls above each jack pad to permit the vehicle body to be lifted when it is too low to permit lifting at the jack pads. Additional jack pads shall be provided on the center car body section if required by the design to permit the center car body section to be lifted. The fully assembled vehicle shall be capable of being lifted with the number of jacks appropriate for the body design. The bottom of all jack pads shall have a non-skid surface to transmit horizontal loading between the jack pad and the jack head. The Contractor shall design and provide jack socket adapters to permit jacks to be used to lift the vehicle (refer to special tools requirements in Section 18).

Diagonal jacking of a car body section with trucks and adjacent articulation and car body sections attached as described in the diagonal jacking test in Section 16 shall not cause any structural or cosmetic damage, affect subsequent door operation, or cause degradation of the watertightness of a finished car, including glazing installation. Refer to this Section.

Trucks shall be retained with the body during jacking or hoisting unless intentionally disconnected as described in Section 11.

### **3.12 Skirts and Roof Shrouds**

Skirts shall be provided along the lower perimeter of the vehicle as described in Section 15. Roof shrouds shall be provided as described in Section 15.

### **3.13 Structural Design Loads**

#### **3.13.1 Allowable Stress at Operating Vertical Loads**

The completely equipped car body shall be designed to carry the maximum loading of car weight AW3, less truck weight, distributed uniformly along the vehicle, with stresses not exceeding 50% of the guaranteed minimum yield strength, or 50% of the inelastic buckling strength, whichever is less. Stresses shall not exceed 65% of guaranteed minimum yield strength at AW4, or 65% of the inelastic buckling strength, whichever is less. Static weld stress shall not exceed the values of table titled “Allowable Stresses in Nontubular Connection Welds” in AWS D1.1/D1.1M, where “same as base metal” is taken as the limits in the preceding sentence. The vertical load shall be distributed as specified in Section 16. Sound Transit may consider alternate designs on a case-by-case basis during the design reviews, for areas proven not to be fatigue critical.

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For all areas of car body structure, including base material and structural connections, the static stress at the car weight AW2 load shall be less than the mean stress that determines the allowable fatigue endurance limit.

The fatigue stress range shall be computed by multiplying the static stress at the car weight AW2 load by the dynamic factor (fatigue load range). For welded connections, this stress range shall be less than the allowable fatigue endurance limit at 10 million cycles obtained from AAR MSRP C-II, Section 7, or the threshold stress range,  $F_{th}$  for AWS D1.1/D1.1M. The Contractor shall use allowable fatigue stresses from its own tests for:

- Joint designs not covered by AAR MSRP C-II, Section 7 or AWS D1.1/D1.1M;
- Joint designs covered by AAR MSRP C-II, Section 7 or AWS D1.1/D1.1M if the Contractor's allowable stresses are more conservative than AAR and AWS allowables; and
- The dynamic factor shall be determined by the Contractor but shall not be less than  $\pm 20\%$ .

### **3.13.2 End Sill Compression Load**

Under an end compression load required by ASME RT-1, or the maximum end compression load determined by the crush energy analysis described in this Section, whichever is greater, applied longitudinally at the anticlimbers of a car body at AW0 and loaded to AW4, the following conditions shall be met:

- There shall be no permanent deformation in any structural members, including sheathing, at 8 mph (8 km/h), defined as Zone 1 in ASME RT-1;
- Deformation at higher speeds shall not exceed the values listed in ASME RT-1 for Zones 2 at 15 mph (24 km/h) and Zone 3 at 25 mph (40 km/h);
- At no point inboard of the coupler anchor shall the margin of safety be less than the lowest margin of safety outboard of the coupler anchor; and
- The lowest margin of safety inboard of the coupler anchor shall not be in any part of the articulation or the yoke arms that attach the car body sections to the articulation.

### **3.13.3 Coupler Compression Load**

Under an end compression load equal to 133% of the release force of the coupler energy absorption device (refer to Section 4), applied longitudinally at the coupler pivot of a car body at AW0 and loaded to AW4, there shall be no permanent deformation in any structural members, including sheathing.

### **3.13.4 Collision Post, Anti-Telescoping Load above Floor**

The capacity of each collision post when loaded inward in a horizontal plane 15 in (380 mm) above the top of the end underframe and within 15 degrees on either side of the longitudinal axis of the vehicle shall be a minimum of 45,000 lbf (200 kN) with no yielding of any car body structure (with the specified load applied to one or both posts at the same time). The posts and supporting structure

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in the underframe and end frame shall be designed so that when the post is overloaded, the initial failure shall begin as bending or buckling in the post. Both the connections of the posts to the supporting structure, and the supporting structure itself, shall support the posts at their ultimate capacity.

Yielding of the end underframe shall occur outboard of the coupler anchor before yielding or buckling of any underframe structure inboard of the coupler anchor.

### **3.13.5 Collision Post, Anti-Telescoping Load at Floor**

The minimum ultimate shear strength of each collision post shall be 135,000 lbf (600.5 kN) when the load is applied at a point even with the top of the underframe to which the post is attached. The shear strength of the collision post shall be based on the area of its web only. The web area is the depth of the member, in the direction parallel to the longitudinal axis of the car, multiplied by the web thickness. This shear strength shall be carried to the bottom of the end underframe.

### **3.13.6 Structural Shelf**

The structural shelf shall support a longitudinal load of 15,000 lbf (66.7 kN) applied anywhere along its span, without permanent deformation of any part of the car structure. It shall also support the upper reactions of the collision posts.

### **3.13.7 Corner Post, Horizontal Load**

The capacity of each end corner post, under an inward horizontal load in any direction from longitudinal to transverse, applied 15 in (380 mm) above the top of the end underframe, shall be 15,000 lbf (66.7 kN) with no yielding of any car body structure. The connections of the posts to the supporting structure, and the supporting structure itself, shall be strong enough to develop the bending capacity of the posts. If the posts are designed to support more than 15,000 lbf (66.7 kN), then the supporting structure must be strong enough to support the increased bending capacity of the posts; the posts shall fail before the supporting structure fails.

### **3.13.8 Corner Post, Shear Load**

The ultimate horizontal shear strength of each end corner post, in any direction from longitudinal to transverse, at the level of the top of the end underframe, shall be 55,000 lbf (245 kN). The shear strength shall be carried to the bottom of the end underframe.

### **3.13.9 Anticlimber Loads**

The anticlimber shall withstand a  $\pm 40,000$  lbf (178 kN) vertical load combined with a 100,000 lbf (445 kN) longitudinal, compressive load applied at the car body centerline with no yielding of any car body structure. One rib less than the total shall be used in determining the strength of the anticlimber.

The anticlimber shall be designed to maintain vertical load capacity as the anticlimber crushes longitudinally.

### **3.13.10 Articulation Joint Anticlimbing Loads**

The articulation joint shall withstand a  $\pm 40,000$  lbf (178 kN) vertical load combined with a 100,000 lbf (445 kN) longitudinal, compressive load without permanent deformation of any car body structure.

### **3.13.11 Floor Load**

The following conditions shall be met for a fully equipped vehicle with car weight AW4 passenger loading, uniformly distributed:

The floor panels shall not deflect more than 1/250 of the shortest span between supports, up to a maximum of 0.17 in (4.3 mm).

The floor beams shall not deflect more than 1/250 of the span between supports.

The maximum stress in the floor beams shall be less than 65% of the critical inelastic buckling stress or 65% of the yield strength of the material, whichever is less.

### **3.13.12 Roof Load**

All parts of the roof structure and sheets, auxiliary roof, equipment covers, roof walkway, screens, and other guards shall have sufficient strength to separately withstand, without permanent deformation, the loads imposed by a mechanical car washer and three concentrated loads of 300 lbf (1330 N) each distributed over a 12 in by 12 in (305 mm by 305 mm) area, spaced 30 in (760 mm) apart, such as might be applied by maintenance personnel working on the roof and carrying tools and equipment. The roof shall also support roof-mounted equipment, the loads imposed by normal operating conditions, the specified collision and jacking loads, and snow and ice loads as described in Section 2.

### **3.13.13 Side Load**

Any 8 ft (2.44 m) length of side sill and supporting structure shall be strong enough to resist a transverse inward load of 40,000 lbf (178 kN), evenly distributed over the height and 8 ft (2.44 m) length of the side sill, without yielding or buckling. Any 8 ft (2.44 m) length of belt rail and supporting structure shall be strong enough to resist an inward transverse load of 10,000 lbf (44.5 kN), evenly distributed over the height and 8 ft (2.44 m) length of the belt rail. The allowable stress shall be the lesser of yield or the critical inelastic buckling stress, except that for the purposes of calculating stress to show compliance with these requirements, local yielding of the side skin adjacent to the side sill and belt rail will be allowed.

### **3.13.14 Car Body Torsional Loads**

Under the loads imposed by the diagonal jacking test of Section 16, the maximum stresses anywhere in the car shall not exceed 90% of the guaranteed minimum material yield strength.

### **3.13.15 Jacking Loads**

The car body jack pads, jack sockets and supporting structure shall be capable of supporting, with a load factor of 2, an empty car (AW0 condition) including trucks under the jacking configuration of this Section in combination with a horizontal load of 10% of the vertical load applied to the bottom of the jack pad or socket in any direction. With the above loading, there shall be no permanent deformation.

The car body jacking pads, jacking sockets and supporting structure shall be capable of supporting, with a load factor of 1.5, an empty car (AW0 condition) with trucks under the load imposed by the diagonal jacking test of Section 16 without permanent deformation.

The contractor shall analyze to confirm the minimum number of jacking points that can support the vehicle. See Figure 3-1 at the end of this section.

The stress analysis shall include an analysis of the jack pads, jack sockets, their connections to the car body, and the immediate supporting car structure.

The same load factors as above shall apply for hoisting.

The car body at AW0, with truck attached, shall be capable of being lifted under the jacking configurations of this Section without permanent deformation of any car body structure.

### **3.13.16 Steps**

The steps shall be designed to support two people per tread with a load factor of 2. The resulting stresses in any part of the step assembly shall not exceed the yield strength of the material.

### **3.13.17 Equipment Loads**

The load factor for the design of all underfloor, roof and interior equipment, any portion of the equipment, equipment boxes, equipment hangers, standby supports, safety hangers and the car body supporting structure shall be 5 in the longitudinal direction, 3 in the vertical direction, and 2 in the lateral direction. The design load shall be equal to the weight of the item multiplied by the appropriate load factor. These loadings shall be applied separately; each such loading may develop the ultimate load-carrying capacity of the member under consideration.

Equipment within an equipment box need not meet the above criteria provided it can be shown that the equipment will not penetrate the walls of the equipment box when exposed to these load levels. The equipment box shall conform to these load criteria with the equipment in the after impact arrangement in addition to its normal arrangement.

All supports shall be designed to be fatigue resistant for the life of the car.

Fastenings shall be designed so that in no case will the strength of a fastener or the shearing of the fasteners through the base material be the limit of the carrying capacity of a member. Bolts used to support equipment shall not be less than 3/8 in (10 mm) diameter. Refer to Section 17.

### **3.13.18 Truck Loads**

The trucks shall be locked to the car body such that they remain attached to the car when raised unless first intentionally detached. When the vehicle is raised off the track, the car body, truck, and car body connection to the truck shall resist a vertical load equal to two times the full weight of the truck without yielding. Refer to Section 11.

The car body, truck, and the car body connection to the truck shall be capable of resisting an ultimate horizontal load of 90,000 lbf (400,000 N) in any direction applied to any point on the truck through the center of rotation. The required resistance to a 90,000 lbf (400,000 N) horizontal load shall be available at any possible position of the truck in its vertical suspension travel, including the condition of the car raised off the track with the truck hanging from the car, and shall not depend upon external vertical loading nor upon the bolster anchor rods, if used.

### **3.13.19 Natural Frequency**

The natural frequency of the car body under a car weight AW4 passenger load and supported at the articulation yokes and at the bolsters shall not be less than 2.5 times the natural frequency of the truck secondary suspension. The natural frequency shall be calculated in free/hinged mode, for the bolster and articulated ends respectively.

## **3.14 Crashworthiness**

### **3.14.1 General**

The car body shall be designed to maximize energy-absorbing capability within the specified strength parameters and as described in this Section. In the event of a collision occurring on level, tangent track between two trains with mating anticlimbers locked together, deformation of the structure shall commence at the extreme ends and progress toward the coupler anchor (when couplers are extended), with all of the end structural members retaining their attachments to one another and to the roof and floor structures.

### **3.14.2 Energy Absorbing Design**

If a CEM design is proposed, crashworthiness and energy absorbing design shall comply with the requirements of ASME RT-1 and the requirements of this Section, whichever is greater.

Energy absorption devices shall adequately absorb and transmit the energy during collision when the couplers are extended and not extended/stored.

The acceleration of the vehicles involved shall not exceed a maximum of 10 g at any time after a closing speed of 15 mph (24 km/hr) collision of two vehicles on level, tangent track, and crush of car body structure shall be limited to the zone outboard of the coupler anchor.

## *Car Body*

In order to assess the energy-absorbing properties of the structure, a crush energy analysis of the vehicle shall be performed. The analysis shall be based on the assumptions that:

- One vehicle impacts an identical vehicle on level, tangent track such that couplers (when extended) and anticlimbers engage;
- The impacting vehicle is traveling at 15 mph (24 km/hr) with brakes applied in emergency; and
- The impacted vehicle is stationary with brakes applied in full service.

The analysis shall show the following:

- Compression load developed by the longitudinal underframe members designed for crushing;
- Buckling strength of the longitudinal members under the calculated compressive load;
- The progressive buckling and bending of the car body end structure;
- The accumulation of energy during crushing, i.e., force versus distance;
- The vehicle structure inboard of the coupler anchor does not fail while the end is crushing;
- Deformation of the carbody shell during collision shall be such that the areas occupied by the operator and passengers are adequately protected;
- Underframe mounted equipment and underframe structural members other than those designed for energy absorption shall not provide any portion of, or interfere with, the crushing; and
- Acceleration of any vehicle does not exceed a maximum of 10 g, and the maximum vehicle crush is limited to the portion of the structures outboard the coupler anchors, or 5 ft (1.5 m).

A crashworthiness analysis report shall be prepared and submitted for approval as described in this Section. This report shall include the same reference information (drawing numbers, material properties, references for formulas, buckling coefficients, etc.) as required in the Stress Analysis Report described in this Section. Compression tests in lieu of analysis may be performed on the various structural elements to show the energy absorbed by the element during crushing.

### **3.15 Stress Analysis**

#### **3.15.1 General**

The Contractor shall submit a stress analysis of the car body structure and all equipment supports for equipment weighing over 200 lbs (91 kg). The car body structure includes all components discussed in this Section. The equipment support stress analysis report shall be submitted to Sound Transit not later than 60 calendar days prior to commencing manufacture of any car body structural parts. (CDRL 3-7) Stress analyses for supports for items weighing less than 200 lbs (91 kg) may be requested for review at the discretion of Sound Transit.

## *Car Body*

The stress analysis shall be used to design the car structure to meet the requirements of this Specification and to obtain the lightest-weight car consistent with requirements. Structural tests shall be performed in accordance with Section 16 to confirm the accuracy of the analysis. The report shall be sufficiently complete and the analysis sufficiently accurate for Sound Transit to use the report to design repairs during the life of the vehicles.

The stress analysis shall show the calculated stresses, allowable stresses, and margins of safety for all elements for all specified loading conditions. The stress analysis shall include calculations of stresses in joints, joint elements, and other important elements.

The approved stress analysis shall be a prerequisite for approval of the structural test procedures and structural drawings required by this Specification, and shall be used as an aid in determining strain gage locations for use during the tests.

During the design and manufacture of the cars, the input to the stress analysis shall be updated to reflect the as-built configuration of the structure.

The initial stress analysis will require temporary assumptions as to configuration and weights; also manufacturing and other considerations may require design changes. As these changes are made, the stress analysis shall be revised and submitted for review. The final submitted and approved stress analysis shall be for the car in the as-built configuration.

Critical connections that cannot be adequately analyzed shall be prototyped and tested to demonstrate compliance with the requirements of the design and the Specification.

The elastic stability of plates, webs and flanges shall be calculated for members subject to compression and shear.

If stainless steel is used, the variation in the stainless steel compression modulus with stress shall be considered in calculating compressive stability of stainless steel members.

For any portion of the proposed design that is based on a service-proven vehicle, the Contractor may provide data from previous tests, historical data from operations, or stress analyses as required to satisfy the corresponding portion of these requirements.

### **3.15.2 Definitions**

#### Permanent Deformation

A member shall be considered as having developed permanent deformation if one of the following conditions is met:

- The minimum yield strength as published by ASTM for the specified material and grade is exceeded;
- For materials or grades not covered by an ASTM specification, the minimum yield strength as guaranteed by the manufacturer is exceeded; or

## *Car Body*

- The material has buckled or deformed and will not return to its original shape or position after the load is released.

For materials without a specific yield point, the 0.2 percent offset method shall be used to determine yield strength.

### Ultimate Load Carrying Capacity

The ultimate load carrying capacity of a member is the maximum load that the member can support before it separates at its ultimate strength or completely fails as a column.

### Margin of Safety

Margin of safety (MS) is defined as follows:

$$MS = \frac{\text{Allowable Stress}}{\text{Calculated Stress}} - 1$$

The calculated stress shall include the applicable load factors. MS shall be a minimum value, but a positive number.

### Load Factor

Load factor is defined as a number by which the actual or specified load is multiplied in computing the calculated stress. The load factor shall include all applicable safety factors.

### **3.15.3 Buckling Analysis**

The buckling strength of major members shall be calculated. Any member in any of the analyses with a calculated compressive stress equal to, or greater than, 35% of material yield strength shall be included.

### **3.15.4 Elastic Stress Analysis Submittals**

#### **3.15.4.1 Car Body Stress Analysis and Tests Plan**

A Car Body Stress Analysis and Tests Plan shall be submitted not later than 30 days after NTP (CDRL 3-8). It shall be discussed during the first design review meeting. The Plan shall be a working document that is updated as the body design develops. Whenever the Plan for the analysis and testing of the car body is revised, it shall be updated and resubmitted, but not more often than monthly. Each revision shall be accompanied by detailed revision notes that explain each change and indicate where changes were made in the report as a result of the change.

The Car Body Stress Analysis and Tests Plan shall include an outline of the procedure the car builder will use to analyze and test the design of the car body. It shall also include the following:

- Listing of load conditions to be used during analysis and test, with load magnitudes, supports and points of application;

## *Car Body*

- Description of the analysis to be used for each load condition;
- Structural sketch of the car body, showing sheathing thickness and all framing member locations and shapes, and the indicating materials and thicknesses of each. Methods of joining shall be defined;
- Diagrams of load applications and supports;
- Table of material properties;
- Description of the major assumptions; and
- Description of how analysis results will be correlated with test results, as required in this Section.

The Car Body Stress Analysis and Tests Plan must be approved prior to approval of the Stress Analysis Report required by this Section. The Plan shall be a volume of the Analysis Report.

The Plan shall follow the general requirements of the report in this Section.

### **3.15.4.2 Stress Analysis Report**

A stress analysis report shall be prepared and submitted not later than 60 days prior to commencing manufacture of any car body structural parts (CDRL 3-9). The report shall demonstrate that the structure satisfies the requirements of the carbuilder's design and the Specifications. The report shall be organized and in sufficient detail so that the Sound Transit reviewer can readily follow the theory and its application to this car.

The Contractor shall certify that the analysis and calculations have been reviewed and checked before the report is submitted to Sound Transit.

If a cited reference is not readily available to Sound Transit, the Contractor shall provide the reference or copies of the pertinent pages. In addition to the pages that show the cited formula or data, the pages that show the development and interpretation of the formula or data must be included.

All references shall be in the English language. If an English reference cannot be found, an English translation shall be provided. Both the original and the translation shall be included in the report.

In addition to the body of the analysis, the stress analysis report shall include, at a minimum all of the following:

- A Table of Contents.
- The algebraic statement of all formulas and equations before the related calculations are performed. With the statement all terms shall be defined, and the values and units to be applied to these terms stated.
- Units shall be given with all quantities.

## *Car Body*

- References for all formulas, calculation procedures, buckling coefficients, material strengths, fatigue strengths, and other physical and mechanical properties must be cited where these items appear in the stress analysis.
- Each page of manual analysis shall be numbered, dated, and initialed by the analyst and the checker, and marked for revision level. In addition, in the event of a revision, the revision letter shall be included with revision date and initials of the analyst and checker. Each page of computer-generated analysis shall as a minimum be numbered, dated, and marked for revision level.
- The approved structural sketch (see this Section).
- Diagrams displaying, for each load case, loads applied externally to the car body and points of support.
- An analysis showing compliance with each design load and condition, as required by this Section.
- Detailed calculations of stresses with Margins of Safety (MS) in all structural framing members and sheathing, with a summary of the results.
- A table showing locations where the MS is less than 0.20 along with the design or operating conditions (loads) which cause the stresses.

Particular reference in the stress analysis shall be made to, but not limited to the following:

- Side sill
- Body sills (if used)
- End sill
- Anticlimber
- Draft sills
- Coupler supports
- Side frame rails
- Side frame posts
- Transverse and longitudinal sections at doorways
- Body bolster
- Floor and floor beams
- Collision posts
- Corner posts
- Structural shelf

## *Car Body*

- Articulation end frame
- Roof structure
- Equipment supports
- Connections between structural elements

The analysis shall include the following, as a minimum:

- A tabulation or diagram of calculated deflections of the car body under full vertical loading and under combined vertical and compression loads specified in this Section.
- Analysis of all critical and highly loaded connections, as required in this Section, showing the joint is stronger than the weakest member being joined.
- Analysis of the strength of the connection of the trucks to the car body, including calculated vertical and horizontal connection capacities.
- Analyses of the car body structure under the torsional loading resulting from diagonal jacking described in this Section, and under torsional loadings resulting from anticipated normal operations.
- A tabulation of the Contractor's selection of allowable fatigue stresses, with sources, and assumed applied fatigue stress ranges for structural members and connections that are critical in fatigue.
- A table showing the engineering properties of each grade and temper of each material used in the car structure. This table shall include the material designation, yield strength, ultimate strength, elongation, Young's modulus for tension, and compression and shear elastic moduli. In each case, minimum-guaranteed values from the specifications for the corresponding grade and heat treatment of the material shall be used. Materials, grades and tempers not used in the car body construction shall not be included in the tables.
- A table showing geometric properties, such as area and section moduli.
- Table(s) showing the minimum static and fatigue strengths of single and multiple spot welds. Values shall be given for each material, temper, weld size, and thickness combination used in the car body. The source of the data shall be provided.

If tests are conducted to provide the necessary data, the entire test report shall be submitted. This report shall show the test procedure, raw data as well as reduced data, and summary. Each revision shall be accompanied by detailed revision notes that explain each change and indicate where changes were made in the report as a result of the change.

### **3.15.4.3 Finite Element Analysis (FEA)**

As part of the stress analysis, a linear-static finite element analysis (FEA) of the complete car body shall be performed. The Finite Element Analysis Report shall be submitted not later than 60 days prior to commencing manufacture of any car body structural parts (CDRL 3-10). The FEA shall be a recognized computer program such as NASTRAN, ANSYS, ABAQUS, or approved equal. The

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purpose of the car body FEA along with other analysis types, shall be to show that the car body design meets the requirements of this Section.

The Contractor shall submit for Sound Transit review and receive approval of the finite element model prior to performing the analysis (CDRL 3-11). The finite element model report shall be submitted not later than three months after NTP. The element mesh, all assumptions, and a complete printed copy of the input file which includes input data, such as loads, boundary conditions, area properties and material properties, shall be included as part of the preliminary submittal and again as part of the complete analysis. A key to all symbols and colors shall be included. Boundary reaction forces shall be included. Each revision shall be accompanied by detailed revision notes that explain each change and indicate where changes were made in the report as a result of the change.

Each load condition submittal thereafter shall include diagrams of areas of mesh refinement, all assumptions, all input data, reaction forces, and a table to show static equilibrium.

Wherever required to be submitted, the input and output shall have each page numbered, and columns of data shall be clearly labeled on each page using terms, symbols, abbreviations, and units defined in the analysis report.

At the discretion of Sound Transit, FE models and results shall be reviewed during live interactive sessions three weeks after each submittal. At these sessions, Sound Transit shall have full access to the FE model input, output and use of the software on the computer used for the analysis.

Color plots shall be prepared showing the following:

- Deflections in all three axes separately plotted and imposed over the deflected shape;
- Von Mises, or other approved failure criteria depending on the material;
- Maximum and minimum principal stresses;
- Direction of maximum and minimum principal stresses; and
- Meshing accuracy index.

All plots shall show the maximum and minimum values and all values that are greater than 80% of the specified maximum value. Each drawing shall include a triad showing the direction of the global axes. Plots at high magnification shall be keyed to a plot showing the structure to an extent sufficient to orient the high-magnification plots. There shall be a sufficient number of plots for each load case to see the stresses in all areas of the car body with special attention given to those components listed in this Section. All areas with an MS less than 2.0 shall be shown in detail.

The FEA input and output data shall also be submitted on electronic media as approved by Sound Transit. Submittal of the input file is required with the model, and at any time the file is changed, but not more often than monthly. (CDRL 3-12)

Each revision shall be accompanied by detailed revision notes that explain each change and indicate where changes were made in the report as a result of the change. Criteria for final approval of the

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stress analysis shall include the Contractor's submittal of the fully configured input data files as required by this paragraph.

Upon completion of the final design, the FE model and analysis report shall be updated to represent the final configuration of the structure.

### **3.15.4.4 Validation of Linear Elastic Analysis**

For each test required by Section 16, the car body structural test results shall be compared with the corresponding stress analysis results. This information shall be tabulated and submitted with the car body structural test reports for each test. Refer to Section 16.

The tables shall compare strains measured (stresses calculated) from the test strain gauge readings with analytical strains (stresses) from the FEA. The test procedure shall include a list of gauges to be used for the comparison, which shall not be less than half of the total number of strain gauges used during the test. The test procedure tables shall include the gauge number, element number, location and predicted strain (stress). The test procedure shall also include plots of the FE mesh with all gauge locations indicated and dimensioned. The tables shall include the test strain (stress) value, the analytical strain (stress) value, the percent difference between the two values, and a space for annotation.

The percent difference between the two values shall be within the following specified tolerance: for 75% of the compared values, test and analytical results shall agree within 15%.

If the analysis results do not agree with the test results within the above-specified tolerance, the builder shall revise the stress analyses, update the FE model, and re-run all FE analyses. This process shall be repeated until agreement of results is within the specified tolerance. All manual analyses using data from the FEA shall be recalculated using the corrected values. The stress analysis report shall be revised and re-submitted. All results from re-analysis shall meet Specification requirements, and, if they do not, the design shall be corrected.

For any of the remaining 25% of the compared values where the analytical values disagree with the test value by more than 15%, and the test value is equal to or greater than 35% of the yield strength of the material, a detailed explanation of the reasons for the excessive variance shall be included in the car body test report. This explanation may include supporting manual calculations.

Approval of the car body test report shall depend, in part, on the adequacy of the analyses of excessive variance between analytical and test stress values.

### **3.15.5 Crashworthiness Analysis Report**

#### **3.15.5.1 General**

If the CEM design is proposed, a crashworthiness analysis report shall be prepared and submitted such that the approval is granted prior to commencing manufacture of structural parts. (CDRL 3-13) The report shall show that all structural members and the car body satisfy the crashworthiness requirements of the Specification including component level crash energy design verification tests. The report shall demonstrate that the crushing of the car body is stable. The report shall include

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animations of the time-dependent, large-deflection analysis compatible with one of the current commonly available video formats. The animation shall contain sufficient detail, view directions, and magnifications to review the behavior and stability of energy absorption elements, frangible elements, non-crushable structure inboard of the crush zones, and the car body as a whole.

The report shall be organized and in sufficient detail so that the Sound Transit reviewer can readily follow the theory and its application to this car.

The report shall include a description of the model in sufficient detail to show that the model is appropriate for this application. This shall include, as a minimum, descriptions of the elements and restraints, and the conditions of the simulation. It shall also include the output of the simulation to show that relevant Specification requirements have been met, including force-displacement plots, force-time plots, energy plots, velocity plots, deceleration plots, etc.

For non-crushable structure inboard the crush zones, locations where the MS is less than 0.20 shall be shown in a table with a discussion of the results. There shall be no permanent deformation in this area of the structure.

References for all formulas, calculation procedures, buckling coefficients, material strengths, and other physical and mechanical properties must be cited where these items appear in the report. If a cited reference is not readily available to Sound Transit, the Contractor shall provide the reference or copies of the pertinent pages. In addition to the pages that show the cited formula or data, the pages that show the development and interpretation of the formula or data must be included. All references shall be in the English language. If an English reference cannot be found, an English translation shall be provided. Both the original and the translation shall be included in the report.

If tests are conducted to provide necessary data, the entire test report shall be submitted. Such reports shall include the test procedure, raw data as well as reduced data, and a summary.

At the discretion of Sound Transit, all models and results shall be reviewed during live interactive sessions three weeks after each submittal. At these sessions, Sound Transit shall have full access to the model input, output and use of the software on a computer. Access shall be provided to view the crushing simulation on the computer.

### **3.15.5.2 Crashworthiness Analysis Validation**

Whenever crash tests are conducted, the report shall contain the results of a comparison of analytical and test results. Refer to Section 16. The analysis shall be in substantial agreement with the test results. Criteria for agreement shall be included in the Stress Analysis Plan.

### **3.16 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 3-1 Interfaces to wayside design report (Section 3.1)

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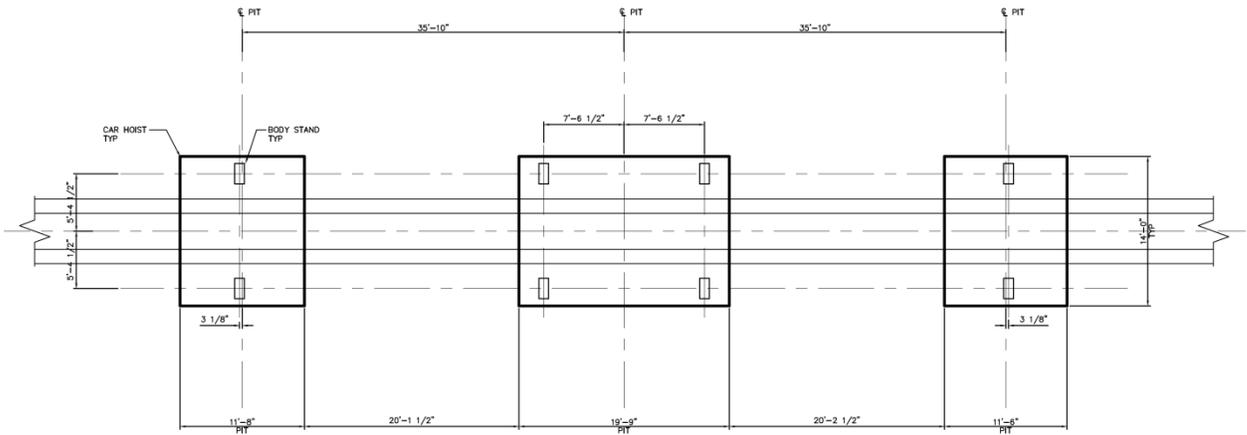
- 3-2 Use of stainless steel in end underframe (Section 3.4.1)
- 3-3 Alternative sub-floor designs for specific locations, if required (Section 3.4.4)
- 3-4 Alternative floor panel attachment methods, if required (Section 3.5.2)
- 3-5 Alternative floor arrangements, if required (Section 3.10.1)
- 3-6 Alternative articulation methods, if required (Section 3.10.1)
- 3-7 Equipment support stress analysis report (Section 3.15.1)
- 3-8 Car Body Stress Analysis and Tests Plan(Section 3.15.4.1)
- 3-9 Stress Analysis Report (Section 3.15.4.2)
- 3-10 Finite Element Analysis Report (Section 3.15.4.3)
- 3-11 Finite Element Model Report (Section 3.15.4.3)
- 3-12 FEA input and output data on electronic media (Section 3.15.4.3)
- 3-13 Crashworthiness Analysis Report (Section 3.15.5.1)

### **3.17 Cited References**

The following standards or references were cited in this Section at the referenced location:

AAR MSRP C II	AAR, Manual of Standards and Recommended Practices, Section C, Part II, Design, Fabrication and Construction of Freight Cars (Section 3.13.1)
ASME RT-1	Safety Standard for Structural Requirements for Light Rail Vehicles (Sections 3.1, 3.13.2, 3.14.2)
AWS D1.1/D1.1M	Structural Welding Code – Steel (Sections 3.3, 3.4.1, 3.13.1)
SAE J429	Mechanical and Material Requirements for Externally Threaded Fasteners (Section 3.3.1)
SAE J995	Mechanical and Material Requirements for Steel Nuts (Section 3.3.1)

3.18 Figures



**Figure 3-1: Macton-In Floor Vehicle Hoist System**

**END OF SECTION 3**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 4  
COUPLING SYSTEM**

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## **SECTION 4: COUPLING SYSTEM**

### **4.1 General**

Each end of the vehicle shall be equipped with a manually foldable, self-centering, fully automatic, mechanical, electrical, and pneumatic coupler and associated draft gear system. The folded coupler shall be stowed behind a hinged, raising, front hood.

The coupler system shall permit operation of up to four cars in a train under normal conditions. This system shall provide electric and pneumatic trainline connections to enable any one car to control all other cars in a train. Coupler equipment and controls shall provide, at a minimum, for the following functions:

- Manual deployment from and stowage to the folded position;
- Automatic coupling;
- Operator-activated uncoupling;
- Operator-activated electrical isolation;
- Manual mechanical uncoupling; and
- Manual isolation and reconnection for the electrical portion, which will override the normal automatic electrical functions.

The coupler and draft gear shall be strong enough to allow, under emergency conditions, a four car train with an AW4 passenger load operating at degraded dynamic performance, to push or tow an inoperable train of up to four cars with an AW4 passenger load, without damage to the coupler over all grades and curves on the system as defined in Section 2.

The couplers shall be mechanically compatible with the existing fleet such that it shall be possible to mechanically couple ST2 and ST1 vehicles for dead-car towing operation, with the electric head(s) retracted and isolated as described in the Electric Isolation section, below.

### **4.2 Mechanical Coupler**

#### **4.2.1 General Requirements**

The mechanical coupler shall be a hook or latch type slack-free tightlock design having a flat contact face and guide pins, which is cantilevered from the draft gear. Designs that utilize a slide or radial bar for support of the coupler head shall not be permitted. The coupler assembly shall be of cast steel and/or fabricated from steel. The coupler shall include hinges and latches to permit it to be folded and stored when not being used. A latch shall be provided to hold the folded assembly in place when stowed under the car. Another latch shall be provided to release the center hinge. Release handles for the latches shall extend forward so that they can be operated from a standing position after the hinged front hood is raised.

Lubrication provisions shall be made in the coupler, draft gear, and anchorage. All bearing and wear surfaces of the coupler assembly, hinges and latches, and its attachment shall be provided with shims, replaceable bushings, plates, or other means to compensate for wear. All alignment surfaces of the coupler assembly shall use replaceable, hardened steel bushings. All hardware, other than castings and weldments, shall be of corrosion-proof materials. All weldments shall be painted for corrosion protection.

#### **4.2.2 Geometric Requirements**

The coupler system shall permit trains to operate over all track profiles of Sound Transit's system and the maintenance yards, including the worst-case combination of the following conditions without damage to the coupler, other equipment, or the vehicle structure:

- Right-of-way constraints described in Section 2;
- Any possible train consist up to and including the eight-car consist, as described in the General section, above; and
- Variations between adjacent cars in a train resulting from uneven loading, full wheel wear, maximum suspension travel, and suspension failure.

Lateral stops shall be provided to positively limit coupler swing and prevent damage to the car body structure, skirt, and other equipment in the event of a derailment or other unusual occurrence. The strength of the stop shall be sufficient to meet the more restrictive of the following conditions:

- To withstand the impact loading of the coupler moving freely from one stop to the other under the action of lateral acceleration, applied at the car's center of gravity, sufficient to cause the car to overturn, with a factor of safety of two; and
- The strength of each lateral stop shall not be less than three times the weight of a complete coupler, including the draft gear assembly.

The stops shall be designed to fail before the structure to which they are attached. The stops shall be bolted to the car structure to facilitate replacement after accident damage. The gathering range of the coupler and the centering and leveling device tolerances shall be sufficient for two cars with correctly adjusted couplers to automatically couple on level tangent track under the worst case combination of permitted wear and car displacement. In no case shall the coupler gathering range be less than 4.75 in (120 mm) in either horizontal direction or 3.0 in (76 mm) in either vertical direction, from the center position. The Contractor shall submit a geometric and clearance analysis report on the coupler and vehicle to confirm compliance with the requirements of this Section. (CDRL 4-1)

#### **4.2.3 Strength Requirements**

The coupler assembly shall be capable of withstanding a buff or draft load of not less than 133% of the release value of the energy absorption device, as described below, with no permanent deformation. The anchorage, its attachment to the car underframe, and the underframe shall withstand any loads which can be transmitted to them by the coupler, without sustaining damage.

The coupler system shall be capable of withstanding the pushing and towing requirements of the General section, above.

All parts of the coupler on which it is possible for a person to stand shall be capable of withstanding, without permanent deformation, a 400 lbf (1780 N) vertical load. There shall be no exposed hardware that can be damaged by a person standing on the coupler.

The Contractor shall submit a strength analysis report on the coupler and vehicle to confirm compliance with the requirements of this Section. (CDRL 4-2)

#### **4.2.4 Energy Absorption**

Because of the requirement to provide a folding coupler, the energy absorption function shall be split between a regenerative, self-restoring, hydrostatic or gas/hydraulic-type of energy absorption element that shall be incorporated into the back shaft of the coupler assembly and a crushable element in the forward portion. It shall have a breakaway feature to prevent damage to the vehicle floor and carbody coupler anchor in the event of a high-speed impact. Compression of the rear element shall not occur below a 3.0 mph (4.8 km/h) coupling speed. Compression of the front crushable element shall occur above a 5.0 mph (8.0 km/h) coupling speed. The travel length of the energy absorbing elements and coupler head shall be a minimum of 12 in (305 mm) from release to the point of engagement of the mating anticlimbers, and shall have at least 1 in (25 mm) in additional travel to permit the anticlimbers to fully engage. The average force during the complete travel length shall be the release force value described below. The instantaneous force shall not deviate from this value by more than +/-10%. When deformation occurs, the coupler head, electric portions, draft gear, coupler pivot, coupler anchorage, and other coupler equipment shall not be damaged. Removal and replacement of the crushable element shall require only standard maintenance shop tools and minimum labor.

Upon a buff force of 75,000 lbf (334 kN) minimum, or higher force, as required to accommodate coupling speed requirements below, the energy absorbing elements shall automatically and sequentially begin to release (engage), the coupler head shall move back, and the anti-climbers shall mate and transfer the buff load to the car body structure. Under this condition, the coupler head shall remain positively attached to the draft gear for both draft and buff loading conditions. The coupler system shall be capable of withstanding coupling one car with another car at speeds up to 8.0 mph (12.9 km/h) with permanent deformation or crushing of only the front energy absorption mechanism. The car builder shall provide, for approval, an analysis which determines the release (engagement) forces for the energy absorbing devices, based on the requirements above. (CDRL 4-3)

#### **4.2.5 Self-Centering**

Each coupler shall be provided with a non-powered self-centering device, which shall retain the unconnected coupler head within the gathering range, to permit automatic coupling on level tangent track. When coupled, the centering device shall not prevent coupler movement necessary for normal operation. The centering device shall be designed to allow the coupler to be manually positioned for coupling on curved track.

#### **4.2.6 Draft Gear and Anchorage**

The draft gear and anchorage shall be of strength sufficient to permit pushing or towing in accordance with the requirements of the General section, above. The draft gear shall have rubber cushioning in both buff and draft. The draft gear deflection shall not exceed 2.5 in (63 mm) prior to the start of deformation or crushing of the energy-absorbing device.

The coupler and draft gear assembly shall be supported from the coupler anchor point to maintain the specified coupler height above top of rail. The supporting device shall provide a method for vertical height adjustment of the coupler head to compensate for wear.

The Contractor shall submit a strength analysis report on the draft gear and anchorage to confirm compliance with the requirements of this Section. (CDRL 4-4)

#### **4.3 General Requirements**

Each coupler assembly shall be provided with an electrical coupler head or heads and electrical head retracting mechanism, capable of making all necessary low voltage electrical connections between adjacent vehicles to permit normal control of all vehicles in a train from the controlling cab. The electrical portion of the coupling equipment shall perform the following functions (refer to the Electric Isolation and Electric Uncoupling sections, below):

- Sense the uncoupled state and control the car relays needed to establish the adjacent car end as a train end;
- Sense the coupled state and control the car relays to establish the car end as a middle, or coupled end;
- Provide means, through the use of cab mounted controls, by which all trainlines can be broken and reconnected, electrically isolating and re-trainlining cars which are mechanically coupled together;
- Provide means of manual isolation and reconnection of the electric trainlines; and
- Sense an unintentional uncoupling through the use of a loop circuit and apply maximum brakes in the train.

Coupler relay panels shall be provided at each end of the car to function with retracting electric heads, to provide the necessary coupler interface and switching requirements.

The electrical coupler head or heads shall be mounted on the top or sides of the mechanical portion. The electric coupler shall be provided with a minimum of 10% spare contacts, including one gold set wired with a shielded-twisted pair cable.

The assignment of trainlines and control lines to coupler pins shall consider safety, so that shorted adjacent pins do not cause unsafe vehicle conditions. The Contractor shall perform a safety analysis of the pin assignments and include it in the electric coupler design analysis report required by the next paragraph.

The Contractor shall submit a design analysis report on the electrical coupler to confirm compliance with the requirements of this Section. (CDRL 4-5)

#### **4.3.1 Coupler Face Contact**

Provide pin and sleeve type, silver-plated or gold-plated contacts held in a non-conductive insulating block. Select contact materials appropriate for current levels and long term signal integrity. Unless otherwise approved, use gold plated contacts for network signals.

Provide dedicated, shielded, 4-pin contact assemblies for Ethernet connections, with electrical characteristics as required for the highest trainline data transmission rates. Provide similar dedicated network connectors for other network protocols, if approved. See Section 9.

Each contact shall have a minimum capacity of 150% of the normal maximum current to which it will be subjected. Contacts shall have a minimum service life of 50,000 coupling cycles and minimum 12,000 coupling cycles with a forced misalignment.

#### **4.3.2 Contact Block**

The contact tips shall be replaceable by removal through the front of the coupler block without disassembly of the coupler or its wiring.

The electrical coupler contact block shall be of a non-hygroscopic material, of adequate strength to withstand, without damage, mechanical forces imposed by normal revenue service operation. The insulation shall meet the insulation testing requirements of Section 16 for wiring insulation resistance and applied high potential from pin to pin and from pin to car body ground.

The block design shall maximize creepage distance between adjacent contacts and between the contacts and any metal part connected to the car body. Where creepage paths involve surfaces not readily accessible for cleaning, the minimum distance shall be 0.75 in (19 mm). Assignment of trainline functions to contacts shall minimize the hazards presented by creepage between adjacent contacts.

An elastomeric gasket shall be attached to the perimeter of the electric coupler contact block. When the electrical heads mate during coupling, the gasket material shall form a seal to protect the contacts. This gasket shall also form a weather-resistant seal with the electrical head cover when it is in the closed position.

The contact block and the entire electric head shall be removable for repairs or replacement.

#### **4.3.3 Coupler Contact Connection**

Connections to the back of the electrical coupler contacts shall be designed to prevent interference between adjacent connections and shall be accessible for maintenance. Connections shall be by means of a compression-type ring terminal connection secured to the back of the contacts with stainless steel nuts or machine screws that comply with the requirements for fasteners in Section 17, or other method approved by Sound Transit. Cable entry to the electrical coupler head shall be by a watertight bushing.

Connections from the electrical coupler head to the car body mounted trainline junction box shall be by means of flexible multiple conductor cables with locking-type multi-pin waterproof connectors at both ends meeting the requirements for cable connectors of Section 17. Sufficient conductors shall be provided to wire all coupler contacts, including spares, back to the junction box. The method of connection and support shall minimize stress in all operating and stowed positions, and shall prevent chafing of the cables. The connection shall permit removal and replacement of the complete electrical coupler head without disturbing the mechanical portion of the coupler.

#### **4.3.4 Electric Coupler Cover**

Each electric coupler shall be provided with a weather-resistant cover which shall protect the coupler contacts from dirt, dust, and water when it is closed. The cover shall be automatically opened when the electric heads mate during coupling and shall close as the electric heads separate during uncoupling or electrical isolation. The cover shall not be damaged by maintenance personnel using it as a step.

#### **4.3.5 Electric Isolation**

The coupler shall be capable of electric isolation. Electric isolation shall be accomplished by electric head retraction.

Sensing switches shall be provided to indicate the position of the electric head. Relays shall provide the necessary trainline loop functions.

### **4.4 Pneumatic Coupling**

#### **4.4.1 General Requirements**

The pneumatic coupler shall be capable of making automatically all necessary connections for trainlining the main reservoirs in a train. The air connections shall be guided effectively to provide free movement without locking or binding. The hoses shall be so arranged as to be free of stress in all operating positions and to prevent chafing.

Pneumatic trainlines shall be automatically isolated on uncoupling and also shall be capable of being isolated manually by cut-out cocks at each end of the vehicle. The cut-out cocks shall be located inboard of the hoses, so as to be able to isolate hoses.

### **4.5 Coupler Operation**

#### **4.5.1 Deployment**

The operator (or assistant) shall manually unlatch the hinged front hood and raise it to uncover the coupler. The operator shall then pull the handles to release the latch to allow the coupler to be swung out and the two sections to be latched together. Spring forces shall help the person center the coupler.

Stowage shall consist of disabling the automatic centering device, unlatching the hinge, folding the coupler, and moving it under the car until it is in the stowed position, held by an automatic latch. The hinged front hood shall be lowered down until it automatically latches in place.

Safety of personnel is of primary concern to Sound Transit. Under no conditions shall personnel need to place hands, or other body parts, in such a manner as to become trapped.

#### **4.5.2 Automatic Coupling**

When contact with a second coupler is made, the couplers shall automatically couple mechanically and pneumatically. Electrical coupling shall be controlled by the operator by using a 3 position “Electric Coupler” rotary switch to electrically Couple or Uncouple.

#### **4.5.3 Electric Uncoupling**

The uncoupling operation shall be electrically controlled from an adjacent cab console. The uncoupling control shall be interlocked so that activation of the uncoupling control is restricted to a powered cab console with the car speed below the no-motion detection point of the no-motion detection system. The couplers shall be controllable only from the cab control panels adjacent to the point of separation. Coupler control shall not be trainlined.

The uncoupling sequence shall be as follows:

- The Key Switch of a cab console adjacent to the coupler where the uncoupling is to occur shall be placed in an ON position.
- The UNCOUPLE pushbutton on the upper control panel in the active cab shall be depressed. This shall cause the electric heads on both of the coupled cars to move to the isolated position. Then mechanical uncoupling shall be initiated. Once this sequence is begun it shall continue to the fully uncoupled state even if the UNCOUPLE button is released. It shall not be necessary to operate the car in forward, to buff the couplers, to achieve mechanical uncoupling.
- Place the reverser in REVERSE and back away from the opposing, uncoupled portion of the train.
- Electrical isolation shall be possible without mechanically uncoupling by placing the NORMAL/ISOLATE switch on the cab upper control panel in ISOLATE. The electric heads shall then proceed to operate as in the second bullet above. It shall not be necessary to return the NORMAL/ISOLATE switch to NORMAL in order to mechanically uncouple from the UNCOUPLE pushbutton.

#### **4.5.4 Manual Operation Requirements**

Secure and conveniently located devices shall be provided to permit the operation of the mechanical coupler (uncouple only) and retracting electric heads (isolate and reconnect) without the use of tools in the event of power loss or control failure. Sufficient mechanical advantage shall be provided to allow Sound Transit's personnel to manually operate these devices in an

emergency using a force of 60 lbf (267 N) or less. Device(s) shall be easily located when stowed, by application of high visibility material to device location or device itself.

All functions shall be independent and be capable of being operated in any sequence or combination.

#### **4.6 Hinged Front Hood**

Hinged, raising, manually operated front hoods shall be provided to close off the ends of the vehicle when uncoupled. When open to permit coupling, the hood shall be held above the anticlimber with a detent to prevent rattling or other relative motion as the vehicle is operated.

A spring loaded hinge mechanism shall be provided to hold the hood in both the closed and open positions. The maximum force to shift the hood between positions shall be 36 lb (160 N). In addition, a mechanical latching device shall be provided to hold the hood in the closed position.

The hood shall be constructed of HSLA steel, stainless steel, or FRP, and shall be finished and painted to the same standards as the rest of the exterior. Hoods shall be subject to approval as part of the exterior finishing scheme.

Hoods shall meet the same impact, strength, and finish requirements as the other end exterior surfaces.

If the configuration of the hood is such that it obstructs the illumination from the headlights in the open position, secondary lights shall be provided as specified in Section 8.

The Contractor shall submit a design report on the hinged front hood to confirm compliance with the requirements of this Section. (CDRL 4-6)

#### **4.7 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 4-1 Coupler geometric and clearance analysis report (Section 4.2.2)
- 4-2 Coupler strength analysis report (Section 4.2.3)
- 4-3 Coupler energy absorption report (Section 4.2.4)
- 4-4 Draft gear and anchorage strength analysis report (Section 4.2.6)
- 4-5 Electrical coupler design analysis (Section 4.3)
- 4-6 Hinged front hood design report (Section 4.6)

**END OF SECTION 4**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 5  
OPERATOR'S CONTROLS AND CAB**

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## **SECTION 5: OPERATOR'S CAB**

### **5.1 Operator's Controls**

The operator's cab and controls shall be arranged in a manner similar to the existing ST1 vehicles.

The cab design shall utilize the principles of ergonomics in the development of the cab and instrumentation layout. The cab shall be designed for use by an operator in the size range of the fifth percentile female to the ninety-fifth percentile male of the general population, as defined in *The Measure of Man and Women*, Tilley, Henry Dreyfuss and Assoc., Revised Edition.

Sufficient space shall be provided in the cab for a second, standing person to monitor and train the vehicle operator. This space shall be determined by Sound Transit during the design review process.

A standing operator shall be able to see and confirm the position of the vehicle coupler on his or her train in order to confirm safe alignment for coupling.

The operator's controls shall be arranged in three distinct areas, the master controller (MC) area, the console, and the upper control panel.

The master controller area shall be located directly in front of and to the left of the operator's seat, and shall contain the master controller group and other specified devices.

The console shall be located directly in front of the operator and shall contain the console switch panel, console display panel, ATP Indicator and Controls Unit, audio system control head (ACH), automatic announcement control panel (AACP), radio system control head (RCH), train-to-wayside communications (TWC) unit, and a train operators display (TOD) See Video Monitors, below.

All console equipment systems shall be arrayed on the console in order of importance and use. The most often used shall be located most convenient to the operator.

All controls and indicators on the master controller area, the console, adjacent to the cab windows, and all other areas subject to liquid spray or spillage, shall be rated IP65 or better.

The upper control panel shall be located on the destination sign access cover, and shall contain the pantograph control switch, auxiliary control switch, HVAC control switch, audible alarms, by-pass switches, and other controls as may be specified.

The complete cab design and arrangement, including the location, appearance, and arrangement of the operator's master controller area, console, and upper control panel shall be subject to Sound Transit review and approval. The Contractor shall prepare a report on the cab design, arrangement, layout and space utilization, with analysis to show that the cab can be used by all operators described in the first paragraph of this Section, including access to cab side windows and all controls as required elsewhere in this Section. (CDRL 5-1)

### **5.1.1 Video Monitors**

The cab shall be equipped with video monitors dedicated to specific functions:

- Two video monitors, one on each side of the console, for the rear view cameras.
- A video monitor to display the forward view from the train's trailing cab. Monitor location shall be coordinated with other console components, as approved by ST.

### **5.1.2 Console and Master Controller Areas**

The console and master controller area surfaces shall be designed so that liquids on the surface will not pool or collect, and will not damage or interfere with operation of the components or back panel wiring. All console surfaces shall have a finish that can be cleaned with a soap and water solution.

Console switch and display panels shall be constructed of a corrosion resistant, flat black, non-reflective anodized aluminum, or integrally colored, non-glare, black melamine faced aluminum.

Fasteners on panel faces shall be limited to those necessary to fasten the panel to the console. Fastener shall be black, flush with the panel surface when installed, and of an approved tamper-resistant type. Fasteners shall thread into floating nuts or similar replaceable devices. Fasteners shall not thread directly into console structure.

Except for the master controller area, all console surfaces shall be sloped toward the operator.

A dimmable console lighting arrangement shall be provided as described in Section 8.

Console panels shall be provided with sufficient wire dress and slack to allow complete removal without wire strain or chafing, and allow ready access to attached components while connected.

The cabinets containing the console and master controller shall be constructed of integrally colored, melamine faced aluminum, thermoformed plastic material, or fiberglass reinforced polyester resin, to match adjacent cab lining materials.

The console and MC area cabinets shall be formed to permit operator easy access to both cab side windows.

#### **5.1.2.1 Master Controller Group**

The master controller group consists of a Key Switch, Reverser Switch, and Master Controller and shall be supplied as a single integrated unit. The master controller group shall be mounted to the left of the operator's seating position.

The location, height, and orientation of the master controller group shall be ergonomically designed and coordinated with the operator's seat design, position, and operator's seat to minimize the strain on operator's hand, arm and shoulder.

### **5.1.2.1.1 Key Switch**

Each master controller group shall be provided with a two-position Key Switch to select the cab status. The Key Switch shall be mechanically interlocked with the Master Controller and Reverser Switch.

The two positions shall have the following functionality:

- OFF Position:
  - All cab controls shall be non-functional, except the speedometer, the auxiliaries switch, pantograph switch, and the Maximum Brake pushbutton, and as described below.
  - A car with the console Key Switch OFF in both cabs shall respond to all trainlined control commands.
  - Doors, lighting other than passenger area lighting, communications equipment, HVAC, Inverter, LVPS, and the battery charger shall remain energized when the Key Switch is turned OFF. Passenger area lighting shall remain energized for 15 min after the Key Switch is turned off, then shall de-energize.
  - The key shall be removable only in this switch position.
- ON POSITION:
  - Console controls shall be functional, and all other consoles throughout the train shall be disabled, except for the items noted above for OFF.
  - The key shall not be removable in this position.
  - When keyed ON, all vehicle systems shall become enabled and activated, including auxiliaries, lighting, HVAC, and battery charging.
  - The controlling cab monitor shall automatically turn on and the monitor shall continuously display video from the forward-facing camera in the trailing cab in the train. See Section 13 for a functional description of the end-of-train camera.

Placing more than one key switch in a train in ON shall be detected by software and considered an invalid command and the additional cab shall not be activated. The attempt to activate an additional cab shall be annunciated on the TOD in the active cab.

Refer to this Section for additional switch and cab interlock control details, and the Auxiliaries switch functions.

It shall be possible to operate a train from any cab on an emergency basis, in ATP Street Running modes or ATP By-Pass.

The Key Switch shall be operated using the master controller key specified in Section 15.

### **5.1.2.1.2 Reverser Switch**

A three-position, (FORWARD, NEUTRAL, REVERSE), rotary type Reverser Switch shall be provided on the master controller group. The Key Switch and the Reverser Switch shall be mechanically interlocked so that the Reverser Switch cannot be moved from the NEUTRAL

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position unless the associated Key Switch is in the ON position, and the Key Switch cannot be moved from the ON position unless the Reverser Switch is in the NEUTRAL position.

The car control circuitry shall be such that car or train operation shall not be possible unless the Reverser Switch in the controlling cab is placed in either the FORWARD or REVERSE position.

The Reverser Switch shall be interlocked such that the Master Controller handle must be in the Full Service Brake (FSB) position in order to move the Reverser Switch out of either the FORWARD or REVERSE position.

### **5.1.2.1.3 Master Controller**

The Master Controller handle shall provide for hand control of motoring and braking. (Refer to Sections 2, 10, and 12) It shall be mechanically interlocked such that it may be moved from the FSB position only when the Reverser Switch is in either the FORWARD or REVERSE position.

The handle and its position during operation shall minimize strain and fatigue on the operator. The master controller handle shall be sufficiently long and the handle throw sufficiently great that all detents are easily reached. The size of the spring load, force required by detents, handle length, handle travel between detents, and other operational features shall be subject to Sound Transit review and approval. (CDRL 5-2)

Handle movement relative to function shall call for brake when moved back (toward the operator) and power when moved forward (away from the operator).

The Master Controller shall use cam-operated switches of modular construction to carry out its digital controlling functions. Analog functions shall be generated by directly driven encoders. All master controller parts shall be replaceable with common hand tools.

The Master Controller major detents (tactilely identifiable positions) shall be as follows:

<b>Position</b>	<b>Name</b>	<b>Nominal Rate</b>
MXP	Maximum Power	3.00 mphps (1.34 m/s <sup>2</sup> )
MNP	Minimum Power	0.30 mphps (0.13 m/s <sup>2</sup> )
Coast	Coast	0.00 mphps
MNB	Minimum Brake	0.30 mphps (0.13 m/s <sup>2</sup> )
SB	Safety Brake	2.00 mphps (0.89 m/s <sup>2</sup> )
FSB	Full Service Brake	3.00 mphps (1.34 m/s <sup>2</sup> )
FST	Full Service plus Track Brake	See Section 2
MXB	Maximum Brake	See Section 2

Between Maximum and Minimum power positions and between Minimum and Full Service braking positions, continuously variable rate commands that are linearly proportional to the handle position shall be available.

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The Master Controller shall provide an interlock contact that closes when the Master Controller handle is placed in the SB position, for use as an acknowledge indication to the ATP equipment. Refer to Section 14.

Refer to Section 2 for additional information on propulsion and braking requirements.

### **5.1.2.1.4 Deadman**

The Master Controller handle shall incorporate a deadman protection circuit consisting of a rotating, spring-loaded "T" handle. Release of the handle shall cause the deadman circuit to initiate a Safety Brake (SB) application after a two second time delay. The brake application shall be retrievable. The deadman function shall be bypassed when the controller handle is in the SB, FSB and FST positions. The circuit and timing function shall be vital as defined in Section 2. The deadman mechanism shall be designed to minimize strain for the operator, and shall be designed such that it cannot be readily defeated.

### **5.1.2.2 Console Switch Panel**

The console switch panel shall be mounted immediately to the right of the master controller group and directly in front of the operator. Console controls shall be heavy-duty push button, rocker, or rotary switches as indicated. Refer to Section 17 for specific switch material and design requirements.

As a minimum, the following controls, and type of switch, shall be included on each console. See other parts of this Section and other sections for additional console controls.

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<b>Control</b>	<b>Type</b>
Left Door Close	MPB (Illuminated Green)
Left Door Open	MPB (Illuminated Red)
Left Door Enable	MPB (Illuminated Yellow)
Wiper, Off/Intermittent/Low/High	4R
Wiper Delay Adjust	Rotary Potentiometer
Washer, Off/On	MPB
Headlight, Low/High	2R
Secondary Lights (if needed)	LPB (Illuminated Yellow)
Railroad Headlight, Low/Off/High/Emergency	4R
Hazard Lights	LPB (Illuminated Yellow)
Track Brake, Off/On	MPB
Cab Heater Fan, Low Speed/High Speed	2R
Cab Heat, Off/Variable Temperature Control	2R/Rotary Potentiometer
Cab Light, Off/On	2R
Horn, Off/High	MPB
Bell, Low/Off/High	3MRKC
Maximum Brake	Push to Stop/Pull to Reset Mushroom Type
Right Door Close	MPB (Illuminated Green)
Right Door Open	MPB (Illuminated Red)
Right Door Enable	MPB (Illuminated Yellow)
Car Wash	LPB (Illuminate Yellow)
Console lights and indicators dimmer	Rotary Potentiometer
Console lights Push-To-Test	MPB
Windshield Heater	LPB (Illuminate Yellow)
Push to talk, PA	MPB
Push to talk, Passenger Intercom	MPB (may be combined with PTT PA if design permits)
Coupler Isolate Switch, Isolate/Normal	2R
Uncouple Pushbutton	MPB

Type codes mean the following:

LPB	Latching pushbutton (push on, push off)
MPB	Momentary pushbutton
3MRKC	3 position momentary rocker, return to center
2R	2 position rotary
3R	3 position rotary
4R	4 position rotary
Rotary Potentiometer	Continuously adjustable control

Notes to Table:

- See Maximum Brake Control in this Section for maximum brake switch requirements.
- The latching function for latching pushbuttons shall be via electrical circuitry or software. Mechanical latching switches are prohibited.
- Clear, hinged, door pushbutton covers shall be installed over the Door Open and Release pushbuttons.
- The Left and Right Door Open, Release and Close switches shall be back illuminated to provide an indication of status. See Section 6 for additional switch requirements.
- Console and windshield design shall prevent glare from all illuminated console switches.
- Alternative arrangements which combine switch functions differently must be submitted for review and approval by Sound Transit.

### **5.1.2.3 Console Display Panel**

The console display panel shall consist of and incorporate the ATP Indicator and Control Unit, the system status annunciator panel, test button, and dimmer. It shall be located directly above the Console Switch Panel.

ATP Indicator and Control Unit shall be as described in Section 14.

The annunciator test button shall illuminate all lights on the console and display panel when pressed. The console lamp and annunciator dimmer shall be mounted adjacent to the test button.

#### **5.1.2.3.1 Annunciator Panel**

The annunciator panel shall be located on the right side of the display panel. The annunciator panel shall be an integrated unit with backlit indicators.

The annunciator panel shall be provided with a sun shield or other device to insure readability in bright sunlight.

The annunciator panel shall have the following annunciators and functionality:

<b>Annunciation</b>	<b>Color Lens</b>	<b>Applicability</b>	<b>Function</b>
SYSTEM FAULT	Red	Train	Fault in a system*
DOOR CUTOUT	Red	Train	Door cutout*
DOOR MANUAL RELEASE	Red	Train	Doors enabled
ATP BYPASS	Red	Local	ATP system bypassed
BYPASS/CUTOUT ACTIVE	Red	Local	Bypass active
SAND ON	Red	Train	Sand on
SP/SL ON	Yellow	Train	Spin-slide on
FRICITION BRAKE RELEASE	Green	Train	Disc brakes released
FRICITION BRAKE APPLIED	Yellow	Train	Disc brake applied
HEADLIGHT HIGHBEAM	Blue	Local	High beam on
RAILROAD LIGHT ON	Blue	Local	Railroad light on
TRACK BRAKE ON	Yellow	Train	Track brakes on
Hazard	Yellow	Train	Hazard signal on (flashing)

\*The faulted system and fault details, including speed restriction, shall be shown on Train Operator Display.

#### **5.1.2.4 Communications Control Heads**

The audio system control head (ACH) and radio system control head shall be located immediately to the right of the console switch panel. Refer to Section 13 for control head descriptions.

#### **5.1.2.5 ATP Indicator and Control Unit**

An ATP Indicator and Control Unit shall be provided as specified in Section 14.

The unit shall include the speedometer.

#### **5.1.2.6 TWC Control Panel**

The TWC control panel shall be located on the right side of the console directly behind the communications control heads. Refer to Section 14 for a description of the TWC system.

#### **5.1.2.7 Automatic Announcement Control Panel**

A passenger information system control panel shall be mounted to the right of the communications control heads. The panel shall be used to control the automatic destination signs and to control the automatic station announcement and display system, described in Section 13.

#### **5.1.2.8 Rear View Monitor**

The rear view, and end-of-train, monitors are described in Section 13, and shall be integrated into cab design for comfortable viewing by operators and standing personnel.

#### **5.1.2.9 Gooseneck Microphone**

The gooseneck microphone shall be mounted on the console as described in Section 13.

#### **5.1.2.10 Train Operator Display**

The Train Operator Display (TOD) shall be located to the left side of the console display panel. The minimum dimensions of the screen display area shall be 10 in (254 mm), measured diagonally. The screen shall function over the temperature ranges indicated in Section 2.

The display shall be a ruggedized, LED back-lit, color LCD, progressive scan, touch screen monitor suitable for industrial applications. The screen touch feature shall be usable with gloved fingers. Screen resolution shall be the same as provided for the video displays (see Section 13), and preferably by the same manufacturer.

The monitor shall be a physically distinct device, serving only as a display without networking or other vehicle functions.

The screen surface shall be treated for glare reduction, and shall be shrouded as necessary to prevent glare from other cab light sources or reflections.

The screen shall have an automatic as well as a manual brightness control feature.

The TOD shall become active automatically whenever a cab is keyed ON, and shall update and display vehicle and train status as described elsewhere.

TODs in non-active cabs may be activated for display of status via console switch or other methods. No vehicle or train commands shall be available, or functional, on TODs in inactive cabs.

The Operating Screen shall present information useful to the operator when the train is in motion or during a normal station stop.

An inoperative TOD, or its related systems, shall not affect vehicle safety systems, nor prevent operation of the train.

See Section 9 for details of TOD display screens and data.

#### **5.1.3 Upper Control Panel**

The upper control panel shall be mounted overhead of the operator. The controls, audible alerts, and indicators shall be arranged horizontally in one row.

## Operator's Controls and Cab

From left to right they shall be as follows:

<b>Control</b>	<b>Type</b>	<b>Reference Section</b>
Passenger Compartment lights, On/Off	MRC	8
Pantograph Switch, Up/Down	3MRC	9
Auxiliaries Switch, Off/On	3MRC	5
HVAC Control Switch, Off/On	3MRC	5
Audible Alert #1	Continuous	14
Audible Alert #2	Pulsed	5
Audible Alert #3	Momentary	14
Audible Alert #4	Pulsed	14
Audible Alert Bypass	Momentary Toggle, sealed	5
No Motion Bypass	Toggle, sealed	5
Door Interlock Bypass	Toggle, sealed	5
Speed Restriction Bypass	Toggle, sealed	5
ATP Bypass	Toggle, sealed	5
Truck A Disc Brake Release	Toggle, sealed	5
Truck B Disc Brake Release	Toggle, sealed	5
Truck C Disc Brake Release	Toggle, sealed	5

Type codes mean the following:

- MPB Momentary pushbutton
- 3MRC Three-position momentary rotary, return to center
- 2R Two-position rotary

Each audible alert shall have its own unique sound. The frequencies, tones and volumes of the audible alerts shall be subject to Sound Transit review and approval. (CDRL 5-3)

Alternatively, the above controls, bypass switches, and audible alerts, may be mounted within the cab in locations as approved by Sound Transit.

### 5.1.4 Miscellaneous Cab Equipment

#### 5.1.4.1 Windshield Wiper and Washer

A windshield wiper (or wipers) shall be provided for each cab windshield. At least 80% of the width and 60% of the height of the total windshield area shall be swept over a complete cycle. The drive unit shall provide two speeds of operation and the wiper blade(s) shall return to a "Park" position at extreme right hand end (operator's right hand) of the sweep in the "Off"

position. It shall include an adjustable intermittent, 3 to 20 second delayed mode of operation. Drive units shall be electrically operated and all mechanisms readily accessible for repair and replacement. The operating mechanisms shall be enclosed. Sweep range shall cover the field of view of the forward facing camera.

The wiper mechanism shall be mounted at the top or bottom of the windshield glass.

A washer shall be supplied for each windshield. The spray head or heads shall uniformly distribute the fluid over the length of the wiper blade. The supply tubing shall be mounted on the wiper arm(s).

A reservoir with a minimum of 1 gallon (3.8 liter) capacity shall be provided. The reservoir shall be located so as to permit filling from outside the vehicle and shall be subject to Sound Transit review and approval during the cab design review. The reservoir access cover shall be gasketed to prevent leaks of washer fluid or rainwater into the vehicle.

The system shall operate properly when filled with plain water and also when filled with anti-freeze washing solution.

#### **5.1.4.2 Warning Devices**

Warning devices meeting the requirements below shall be provided at the ends of the vehicle and shall be both "Horn" and "Bell" type. The Contractor shall provide examples of the horn and bell sounds for Sound Transit to review. The tone of the horn and bell shall be subject to Sound Transit review and approval. (CDRL 5-4)

Actuation of these warning devices shall require a minimum of hand/finger movement from the normal operating position. Sound from the warning devices shall emanate at the front end toward the direction of travel.

The electronic bell shall produce a repeating sound with a repetition rate of approximately twenty strikes per second in response to continuous switch activation. The bell shall emit a minimum of 70 - 72 dBA at 50 ft (15 m) in Low and 80 - 82 dBA at 50 ft (15 m) in High.

The horn shall have a high level output volume. The horn shall be accessible via the operator's console. The horn shall have an audible output of  $95 \pm 2$  dBA at a distance of 100 ft (30.5 m) at the high volume level. The horn output level shall be adjustable. The sound of the horn shall be a multi-tone air horn type, emulated by an electronic audio system.

#### **5.1.4.3 Air Comfort**

HVAC system shall provide the required comfort conditions in each cab as detailed in Section 7.

#### **5.1.4.4 Defroster/Defogger**

Cab window defrosting and defogging shall be provided as detailed in Section 7.

#### **5.1.4.5 Odometer**

An electronic odometer with permanent non-volatile memory and an LED display or mechanical odometer shall be provided in the A-end cab or ECU electric locker. Refer to Section 10. It shall be possible to read the odometer mileage without having to open access panels of any kind. In the event of having to replace the odometer, it shall be possible to use a PTU to set the odometer mileage. The odometer shall broadcast the LRV mileage to the MDS once a day after midnight and when the LRV is in the storage yard.

#### **5.1.4.6 Operator's Hand Hold**

A horizontal hand hold for the operator's right hand shall be provided at the front edge of the console shelf. The hand hold shall include a thumb-operated switch activating the low warning bell.

#### **5.2 Local Indicator Panels**

An indicator panel shall be provided in each cab electric locker to announce the state of, or faults within, the following local car systems, in the event of a defective Train Operator Display. The indicator panel shall be passive and shall be suitably buffered such that a failure within the indicator system does not affect the systems it is monitoring.

## Operator's Controls and Cab

The following local indicators shall be provided:

<b>Indication</b>	<b>Color</b>
Propulsion Fault, A Truck	Red
Propulsion Fault, B Truck	Red
Brake Fault, A Truck	Red
Brake Fault, B Truck	Red
Brake Fault, C Truck	Red
Friction Brake Fault	Red
Friction Brake Check	Red
Friction Brake On, A Truck	Red
Friction Brake On, B Truck	Red
Friction Brake On, C Truck	Red
Friction Brake Cutout	Red
Low Main Reservoir	Red
Floor Heat Ground Fault	Red
No Motion	Green
Aux Power Supply Fault, A Section	Red
Aux Power Supply Fault, B Section	Red
LVPS Fault, A Section	Red
LVPS Fault, B Section	Red
12VDC Power Supply Fault	Red
HVAC Fault, A Section	Red
HVAC Fault, B Section	Red
Air Compressor Fault	Red
HSCB Trip	Red

The indicators shall be high-brightness light emitting diodes (LEDs) mounted in replaceable plug-in modules.

Additionally, the High Speed Circuit Breaker (HSCB) reset button shall be located on the local indicator panel or in close proximity to permit resetting while observing the HSCB Trip indicator on the panel.

### 5.3 Vehicle Network, Trainlines, and Interlocks

The vehicle shall be controlled through a combination of redundant bi-directional data networks and battery voltage level trainlines. Refer to Section 9 for specific requirements. Various train control schemes shall be implemented as described below or in other sections of the Specifications. Control of systems not described below shall be determined by the Contractor, subject to Sound Transit review and approval. (CDRL 5-5)

### **5.3.1 Cab Interlock**

Interlock circuitry shall be used to interlock the cab controls such that no more than one cab can take control of a vehicle or train at the same time..

Interlocking that depends on mechanical locking of transfer switches with electrical solenoids is prohibited.

### **5.3.2 Direction Control**

Discrete trainlines shall provide direction signals, designated Forward and Reverse, originating from the Reverser Switch in the active cab. Relay logic shall preclude the possibility of commanding both directions simultaneously.

Conflicting signals shall inhibit propulsion and the fault shall be displayed on the TOD and the appropriate console and Local Indicator annunciators. Refer to Section 9.

### **5.3.3 Master Controller Signals**

The Master Controller shall generate the appropriate signals to command all propulsion, coast, and braking modes and rate levels. For ATP generated braking commands refer to Section 14.

### **5.3.4 Maximum Brake**

Operator control of maximum braking shall be provided by the Master Controller and by the pushbutton Maximum Brake Switch mounted on the cab console switch panel. See Section 2 for details of operation.

The console maximum brake switch shall be a heavy duty industrial grade pushbutton gang switch with a large mushroom shaped actuating head. The switch mechanism shall be arranged with two switches for the main maximum brake circuits, with one switch in each of the positive and negative portions of the circuits. The actuation mechanism shall be sufficiently strong that striking the mushroom head will assure breaking the circuit even with welded contacts.

### **5.3.5 Track Brake Control**

Track brakes shall be controlled manually via FST on the Master Controller, and by the console track brake switch. Audible Alert #2 shall sound in the operating cab when the track brakes are applied on any truck of a car or train.

Manual operation of the track brakes via the console Track Brake Switch shall not be canceled below the no-motion detection point. Propulsion shall not be inhibited by a manual track brake application, at any speed.

### **5.3.6 HVAC Control**

The HVAC system shall be activated automatically in all cars of a train whenever the auxiliaries are turned on. The HVAC shall be automatically shut down when the train auxiliaries are turned

off. Additionally, a means to manually shut off and turn on all HVAC systems in a train shall be available via an HVAC ON/OFF switch on the upper control panel. Refer to this Section.

See Section 7 for additional control details.

### **5.3.7 Auxiliaries Control**

The Auxiliaries ON/OFF switch shall control all low-voltage dc circuits except those associated with propulsion and braking controls, layover heat, protective heaters, and battery charging.

The auxiliaries shall be capable of being turned on and off in a car or train from any cab's Auxiliaries switch except that they cannot be turned off if a Key Switch is activated in any cab.

### **5.3.8 Pantograph Control**

Refer to Section 9.

### **5.3.9 Lighting Control**

#### **5.3.9.1 Interior**

Passenger compartment lights in all vehicles, and lights in the active cab shall turn on automatically when the Key Switch is turned to ON anywhere in the train. Lighting shall remain on when the Key Switch is turned to OFF, as indicated above, for 15 min, after which the passenger compartment lights shall turn off.

Passenger compartment lights may be turned off by the Passenger Salon switch, above, or turned back on by the same switch if an active cab exists. The neutral position of the Passenger Salon switch shall not prevent lighting activation or de-activation.

#### **5.3.9.2 Exterior**

Headlights shall turn on in the leading cab whenever a direction is selected by the Reverser. Headlights shall be controlled by the forward and reverse directional trainlines such that headlights function on the leading end, regardless of which cab is powered.

The high beam switch shall function only if the adjacent cab is active.

The Railway Headlight shall also illuminate in the leading cab when the switch is in the ON position.

Marker lights at both ends of a vehicle or consist shall be illuminated red whenever the auxiliaries are turned on and no direction selected. When a direction is selected the marker lights shall be illuminated red at the rear and amber at the front vehicle or consist.

Taillights shall be illuminated at the rear of a train whenever a direction has been selected. When the auxiliaries are on and no direction is selected, taillights shall be illuminated at both ends of the train. The tail lights shall not be illuminated at any other time.

Stop lights shall be illuminated at the rear of the train whenever a direction has been selected and any car in the train is in a braking mode. For this purpose, braking mode shall be the application of dynamic, friction, or track brakes.

### **5.3.9.3 Reverse Running**

When the Master Controller of the controlling cab is in Reverse, the railway light and headlights of the rear most facing cab of a car, or multicar consist, shall be energized in Bright when the direction selector switch of the active cab is selected to reverse.

### **5.3.9.4 Hazard Lights**

The hazard light console switch shall be enabled in all cars at all times.

All hazard lights shall be illuminated in a flashing mode when the Hazard push button on any console is pushed on; the lights shall turn off when the Hazard push button is pressed a second time. When pressed, only the switch that activated the hazard lights shall be illuminated, and shall flash with the hazard lights.

### **5.3.10 Door Control**

Door control shall be as described in Section 6.

### **5.3.11 Parking Brake Control**

Parking brakes shall be controlled in each car by the direction trainlines, and shall be released only when there is a valid Forward or Reverse trainline command.

Refer to Section 12.

### **5.3.12 Bypass Circuitry and Brake Release**

The following sealed switches shall be mounted on the upper control panel (Refer to this Section). The seal shall be breakable without tools by the operator. The bypass active indicator shall illuminate if any bypass switch except Audible Alert Bypass is thrown.

- Audible Alert Bypass - cancels the following audible alarms:
  - Emergency door operating device activated.
  - Propulsion fault.

The use of this switch shall not affect illuminated indicators associated with these alarms and its use shall not illuminate the Bypass Active light.

- No-Motion Bypass - this switch shall bypass the local no-motion detector which prevents door operation, in the event of a failure in the no-motion detector circuit.
- Door Interlock Bypass - this switch shall bypass the summary door interlock circuit which prevents propulsion in the event of an open door or unlocked door.

## *Operator's Controls and Cab*

- Speed Restriction Bypass - deactivates the circuit which limits or restricts train speed due to propulsion failure (refer to Section 10).
- ATP Bypass – bypasses the automatic train protection system to permit train movement in case of system failure (refer to Section 14).
- Truck A Friction Brake Release – releases friction disc brakes on the A Truck (refer to Section 12).
- Truck C Friction Brake Release – releases friction disc brakes on the C Truck (refer to Section 12).
- Truck B Friction Brake Release – releases friction disc brakes on the B Truck (refer to Section 12).

The bypass and disc brake release switches shall be in the circuit only if the operator's console is activated in the same cab as the bypass switches. When the console key is turned to OFF, all units shall return to normal function until that particular cab's console is re-activated.

### **5.4 Operator's Cab**

An Operator's cab shall be provided at each end of the vehicle, located as shown on Figure 2-4, General Arrangement. The cab area shall contain all equipment and appurtenances necessary for normal and abnormal train operation. The operator's space and equipment shall ensure safe and optimal operator performance for the personnel size range as described in this Section.

The cab shall be free of sharp edges, protruding objects, safety hazards and floor obstructions. Areas in which paper and other debris can accumulate will not be permitted.

The cab shall be full width and shall be fully enclosed to prevent unauthorized access. The enclosure shall be designed so that the operator's forward view is not obstructed while standing or sitting. A door in the cab partition shall be provided, as described in this Section, to allow access to the cab for operators.

See Section 7 for heating and defrosting requirements, Section 8 for lighting, and other sections for related requirements.

#### **5.4.1 Cab Partition**

A full width, transverse partition shall form the rear wall of the cab enclosure. The partition shall be constructed of 1/2-in (13-mm), melamine faced plymetal, of balanced construction, or approved equal. The cab partition shall be securely fastened to the car roof structure, floor, and car body side structure. The cab partition shall not be attached to ceiling panels or side lining panels.

The cab partition shall contain a door in the center with a vertically sliding sash window.

### **5.4.2 Cab Door**

The cab door shall swing into the passenger compartment when opened. The door shall be equipped with a full length, stainless steel, piano-type hinge.

The cab door shall contain a vertically sliding sash window in the upper portion of the door to allow the operator to look rearward into the passenger compartment. The sash shall be provided with a spring latch in the up (closed) position. The latch shall be operable only from within the cab.

The window shall be constructed of 1/4-in (6.4-mm) minimum thickness, laminated safety glass mounted in an aluminum frame. The glass shall be adequately tinted to prevent glare on the windshield while operating at night. The door window shall be fully supported by the cab door panel on all sides. The window material shall meet the requirements of Section 17.

Window curtains shall be provided on the cab door window to permit the operator to block light from entering the cab from the passenger compartment. Vandal Shield, or approved equal, shall be provided on the surface of the cab door window facing the passenger compartment.

The cab door shall be constructed of the same materials as the cab partition, and shall be cut from the cab partition panel to maintain a proper color and pattern match.

The door shall automatically latch and lock in the closed position, and the door shall be opened from inside with the door handle alone. The door lock shall have the capability to be unlocked from the passenger side with a crew key. Door handle, latch, and lock mechanisms shall be constructed from nickel-bronze or stainless steel.

The cab door shall be equipped with a sight-tight, louvered, grille in the lower portion for cab air return to the HVAC system.

The door shall be equipped with 0.030 in (0.76 mm) minimum thickness, stainless steel kick plates, 8 in (200 mm) high, along the bottom portion of the inside and outside face.

### **5.4.3 Cab Flooring**

The cab floor covering shall be the same as provided under the seats in the passenger section. Refer to Section 15 for details of construction and application.

### **5.4.4 Cab Side and End Walls**

Refer to Section 15 for details of construction of the cab side and end walls.

### **5.4.5 Cab Ceiling**

Refer to Section 15 for details of construction of the cab ceiling.

#### **5.4.6 Operator's Seat**

The operator area of each cab shall be equipped with an operator's seat of approved design and manufacturer, located and coordinated with the cab console and Master Controller groups, but not more than 10 in (254 mm) offset to the left of the car's longitudinal centerline.

The seat and back cushion shall be upholstered with low smoke foam as described in Section 15, covered with transportation grade fabric. Covering material shall breathe to minimize perspiration buildup and operator discomfort. Materials shall comply with the flammability and smoke emission requirements in Section 17.

The seat shall be adjustable vertically and in a forward and backward direction to accommodate the operator population described in this Section. The seat back angle shall also be adjustable, and include adjustable lumbar support.

The seat shall be equipped with flip-up armrests on both sides, and coordinated with the master controller location and arrangement.

The seat shall swivel to facilitate ease of entry by the operator. Swivel shall be continuous 90 degrees from left to right with a detent in the forward position, and the swivel operation shall not be obstructed or compromised with the seat in its full range of forward to rearward adjustment.

All seat adjustment controls shall be operable from a seated position. Pneumatic adjustment mechanisms will not be accepted.

The design of the operator's seat shall be coordinated with Master Controller group.

The seat frame shall be made of tubular stainless steel or powder coated carbon steel construction and shall be designed for hard vehicular usage. The seat and its attachment to the floor shall meet the strength requirements of Section 15.

Adequate foot space shall be provided to accommodate the operator's feet.

#### **5.4.7 Visors**

Two adjustable visors for the windshield and an adjustable visor for both the left side and the right side cab side windows shall be provided in each cab such that the operator can limit incoming sunlight. The visor shall be of polycarbonate, or similar material, transparent cast sheet tinted as approved. Each visor shall be at least 8 in (200 mm) high and shall be wide enough to cover half the windshield width.

The visors shall be adjustable over the full window height and shall rotate vertically and horizontally. Vibration and normal car motions shall not cause the visor's adjusted position to change.

A heavy duty roller shade will be permitted as a supplement to the visors for the windshield.

#### **5.4.8 Fire Extinguisher**

A 10 lb (4.5 kg) capacity fire extinguisher with a minimum rating of 4-A:30-B:C, marine type, shall be located in each operator's cab.

The fire extinguisher shall be listed by Underwriters Laboratory and shall be provided with a marine-type mounting bracket. The fire extinguisher shall be conspicuously marked by stamp imprinting in letters ½ in (13 mm) high with the following legend:

PROPERTY OF SOUND TRANSIT.

#### **5.4.9 Coat Hook**

A folding, flush, nickel-bronze coat hook of approved design shall be provided in each cab on the cab rear partition. A strap shall be provided to restrain hanging items.

#### **5.4.10 Operator's Storage Locker**

An easily accessible storage locker shall be provided in the cab for the storage of the operator's personal items while operating the train. The storage locker shall be leak-proof and have a door, which is attached by a stainless steel piano hinge. The door shall be secured with a lock, operable with the crew key. The locker shall be constructed of the same materials used in the construction of the adjacent cab linings.

#### **5.4.11 Waste Receptacle**

A detachable, stainless steel waste receptacle, of approximately 2 gallons (8 liters) capacity, shall be provided in the cab within reach of the operator when seated. The waste receptacle shall be leak-proof, and shall be secured to its mounting surface to prevent rattling when the vehicle is operating in service. The waste receptacle shall be designed to accommodate commercially available trash receptacle liners.

### **5.5 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 5-1 Cab layout and space utilization report (Section 5.1)
- 5-2 Master controller report (Section 5.1.2.1.3)
- 5-3 Audible alert sounds and pulse rates (Section 5.1.3)
- 5-4 Examples of horn, whistle, and bell sounds (Section 5.1.4.2)
- 5-5 Contractor-determined system control schemes (Section 5.3)

## **5.6 Cited References**

The following standards or references were cited in this Section at the referenced locations.

Ref. Book	Tilley, Henry Dreyfuss and Assoc., "The Measure of Man and Woman", Revised Edition (Section 5.1)
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**END OF SECTION 5**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 6  
PASSENGER DOORS**

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## **SECTION 6: PASSENGER DOORS**

### **6.1 General**

The design, operation, installation, arrangement, and signage of the door system shall comply with APTA-PR-CS-S-012-02, APTA-PR-M-S-18-10 and 49 CFR 37, 38, and 238.

Each car shall have door openings for the boarding of passengers, with configuration and quantity as specified in Section 2. All doors shall be of the sliding plug type, electrically operated and controlled from trainline signals issued by the operator. The exterior of the door panels shall be flush with the exterior of the car body proper when closed. Door opening and closing shall be interlocked with the no-motion circuits. Passengers shall be able to control doors from pushbuttons located on the door panels when the pushbuttons are enabled by the operator. Refer to Section 2 for doorway location requirements.

Each doorway shall include two door panels that slide in opposite directions, parallel to the side of the car. Clear door opening dimensions are specified in Section 2. Under any combination of vehicle loading, suspension deflection or failure, or wheel wear, the bottom of the door shall not mechanically interfere with the top of the wayside platform, as described in Section 2, during any portion of the open or close cycle. Doors shall not protrude more than 2.2 in (56 mm) from the car side during any portion of the open or close cycle.

The door panels, door mechanisms, door controls, and equipment shall be based on, and nearly identical to, a service-proven design, as defined in Section 2. The service-proven door controls and mechanisms shall have been used with door panels of comparable weight. The controls shall incorporate all product improvements that have been developed and proven as well as changes necessary for this specific application.

The door controls and all door equipment shall be interchangeable from one location to any other location and from car to car. To this extent, all mounting holes for all hardware shall be jig-drilled to ensure interchangeability.

All door equipment shall be free from audible and visible vibration and rattles while the vehicle is moving, and while doors are operating when the vehicle is stationary.

The door system shall be designed in accordance with the reliability, maintainability, and safety requirements of Section 2. Within 180 days of NTP the Contractor shall submit a door system design report. When data is requested in this Section for design review it shall be included in this report unless otherwise specified. (CDRL 6-1)

### **6.2 Door Panels**

#### **6.2.1 General Requirements**

All side doors shall be of FRP (Fiberglass Reinforced Plastic), phenolic resin or aluminum construction, graffiti resistant and joined into an integral unit by resistance welding, or by a Sound Transit authorized method for FRP construction. Internal reinforcement of the door panel

shall be provided by a steel or aluminum honeycomb core adhesive bonded to the panel skin. The reinforcing material shall be compatible with that of the base panel. All edges and joints shall be thoroughly sealed to prevent the infiltration of moisture. Interior cavities, where it is possible for condensation to form, shall be provided with drain holes at the bottom. Alternative door panel construction techniques will be considered for Sound Transit approval if doors made with these techniques have a service-proven design, as defined in Section 2. The exterior skins of the door panel shall have a finish identical to the adjacent exterior areas, and shall be free of all dimples, warping, welding depressions and other deformities. The interior skin of the door panel shall have a painted finish identical to the adjacent interior areas. Stainless steel reinforcements shall be provided internally for the attachment of all door hardware. The reinforcements shall be mechanically attached to retain them when door hardware is being changed.

Each door panel shall contain a fixed and laminated safety glass window as specified in Section 15, tinted to match the side windows. The door panel windows shall be similar in dimension and proportion to the existing vehicle fleet. An anti-graffiti film shall be applied to the inside of each door window using the same materials and retention method as for the side windows. The window top edge shall be in line with the top edge of the car side windows. The window height shall be sufficient to permit direct viewing of the door closing indicator by a passenger on the platform when the doors are closing. Refer to Figure 2-4, General Arrangement. Window openings shall be blanked out of the inside and outside door skins with the edges formed inward and welded together. Door windows shall be retained in the door panel by neoprene glazing strips. The window retention arrangement shall be watertight without the use of sealants. The ends of the glazing strip, if used, shall be joined together by the hot vulcanization process to form an endless glazing strip. Windows shall be replaceable from the car exterior. Window cutouts shall have proper radii for glass and glazing strips.

Each side door panel shall extend from the door header down to the threshold in one continuous panel.

A stainless steel kick plate shall be surface-mounted, with countersunk mechanical fasteners, on the interior of each door panel so that the surface is without protrusion. The kick plate shall extend 8 in (200 mm) up from the bottom of the door for the full width of the panel.

Door panels shall be constructed so that all hardware, windows and glazing strips are flush with the door panel. Any fasteners used to attach hardware to the door panel shall be countersunk.

Installed doors must be vibration- and rattle-free while the train is moving and while doors are operating when the train is stationary. The door system, in conjunction with the car's aerodynamics, shall prevent whistling and other objectionable noises at all train speeds.

### **6.2.2 Strength Requirements**

The door panel skin, structure, and mounting hardware shall be of an ample gauge to provide proper strength and rigidity to sustain a concentrated load of 200 lbf (890 N) applied perpendicularly to the plane of the door at any location on the panel, with the door panel installed on the car. The load bearing surface shall be a 4 in by 4 in (100 mm by 100 mm) area for this requirement. The allowable maximum deflection under these conditions with the door simply

supported at the top and bottom shall be limited to 3/8 in (10 mm) maximum with no permanent deformation after the force is removed.

### **6.2.3 Weather Sealing Requirements**

The door panels and doorways shall be weather-stripped to exclude water and moisture when the car is being washed and for service speeds up to 55 mph (88 km/h) with the worst case possible combination of climatic conditions as described in Section 2. Sealing shall be provided by a silicone rubber seal at the car body edges, the top edge of the door, the forward edge of the door where the panels meet in the closed position, and at the bottom edge. All seals shall be applied in a manner which enables them to be easily replaced with the door panels in place, and shall not be bonded to the panels or applied using sealants.

The leading edge seal shall have a contour designed to mate with the seal on the other panel. This seal shall incorporate an obstruction detection feature, described in the Door Obstruction section, below.

### **6.2.4 Mounting**

All door equipment shall be within the car interior and shall be protected by the weather sealing devices specified above. The door panels shall be suspended from the door operator assembly. Provisions for individually adjusting the height and angle of each door panel shall be incorporated. Adjustment range shall allow both panels to be adjusted parallel at the leading edges under worst case car body and door operator installation tolerances. Adjustments shall be from the car interior without removal of other equipment.

Except for the door panels, no portion of any door mechanism shall be visible or accessible to passengers.

### **6.3 Door Operator**

The door operator shall be electrically powered and shall be capable of reliably opening and closing the doors with the most unfavorable ambient wind and car pressurization conditions. The left and right door panels in a given doorway shall move simultaneously. One operator shall be provided per doorway.

The door operator shall impart motion to the door panels through a shaft or linkage arrangement. The linkage joints and pivot points shall be provided with permanently lubricated bearings and fittings. Linkage adjustments shall be fitted with locknuts or other locking devices. Operator adjustments shall not be required as part of routine maintenance. Sound Transit may consider a toothed belt drive arrangement for door panel operation, if such a system is shown to meet Sound Transit's service proven design and reliability requirements.

Cable driven systems are not permitted. If the dc motor is used for the door operator, it shall be of a brushless motor type. The door operator shall be located in the transom area above the doorway or other location suitable for the door arrangement. The shaft or linkage shall be concealed, except as necessary for the sliding mechanism, such that it is not directly visible when the door is opening and closing, or when the door is in the fully closed position. Access to the

door operator shall be by opening a cover or removing an access panel, without the need to move or disconnect other equipment. Entry to the door operator location shall be by Sound Transit crew key. Sufficient clearance and access space shall be provided to maintain all components on the operator assemblies and to remove the assemblies as complete units.

All door tracks shall be mounted within the car body or within the door panel. Separate sliding door lock assemblies, if required by the door design, shall be within the car body. The door operator shall be powered from the low-voltage dc power system and shall be capable of operating over the voltage range specified in Section 2 without affecting the reliability and service life of the operator. The operator shall be capable of withstanding stall current indefinitely, or alternately, shall be capable of detecting this condition and removing power if it persists for a preset time and be reset automatically when the trainlined door controls are cycled, without adverse effect on the reliability and service life of the equipment.

#### **6.4 Door Operator Control Panel**

Each door operator shall be controlled by a microprocessor-based control system located in the transom header area. Refer to Section 17 for software systems requirements. The system shall control all aspects of door motion, including opening speed, closing speed, closing forces, detection of stalls, obstruction detection, accelerations and decelerations, and door close time delays. The control system shall be adaptive such that performance is automatically maintained with changes in the environment or as components wear. Access to the transom header area shall be by Sound Transit crew key.

The controller shall read and respond to trainline, Ethernet and local commands, monitor door status, and provide system diagnostics as described in this Section.

The system shall monitor door position continuously from fully opened to fully closed as part of its control function. All position sensing for this function shall be via positive contact sensors. This position sensing is in addition to the interlock and position sensing requirements in the Door Functional Requirements section, below.

##### **6.4.1 Diagnostics and Adjustments**

The performance of each door operator shall be recorded and monitored via a diagnostic monitoring subsystem integral to the door controller.

The diagnostic system shall include a data/fault logger to monitor all critical internal functions, external inputs, and the mechanical door system, including door open, closed, and lock status and shall comply with the requirements of Section 9. Actual door performance, such as door speeds on opening and closing, shall also be monitored. System faults and associated system parameters shall be time stamped and stored in memory.

The diagnostic system shall function with the vehicle Monitoring and Diagnostics System (MDS) through a dedicated Ethernet network interface so as to permit diagnostic data from any door controller to be monitored via the MDS and displayed on the TOD. It shall also be possible to perform diagnostics via a Portable Test Unit (PTU). Each door shall be uniquely addressed by its physical location in each car to facilitate repair. Refer to Section 9 for the requirements of

Monitoring and Diagnostics System. Each door controller shall be serially linked with the other seven door controllers in any given vehicle such that the diagnostic output of any door controller in that vehicle may be monitored at a single location with a laptop computer and appropriate software. The location of the common diagnostics ports shall be subject to Sound Transit review and approval. (Include in CDRL 6-1) Failure of the diagnostic link shall have no effect on door operation. Link failures shall be monitored and detected by the MDS and announced on the TOD. Diagnostics from each door controller shall also be available either via separate Ethernet connector at the controller, or by disconnecting and using the common PTU Ethernet network connection.

The door controller shall also permit adjustments of all operating variables, such as door speeds and timing, via Portable Test Units. These adjustments shall be available both locally and via the common diagnostics port. The software system shall provide a visual prompt to notify the user that a variable has been changed and shall require a confirmation action by the user to initiate the change. There shall be a separate adjustment location for system wear. All operating variables shall be stored in flash memory in the door controller.

It shall be possible for Sound Transit maintenance personnel to manually change all door system settings via the vehicle Ethernet PTU network. When, in normal revenue service, a door controller detects that any setting has exceeded its allowable limits, it shall generate an alarm over the Ethernet network to the train operator. The alarm shall indicate the type of failure and the location of the door controller that has failed, so as to provide advance notice of an impending door malfunction.

Access to door cycling data and reprogramming shall be password-restricted.

It shall be impossible to affect the door parameters at speeds above No-Motion speed.

The mounting of all sensors and switches shall be such that no readjustment shall be necessary when any given sensor or switch is replaced.

The diagnostics and adjustment capabilities of the door system shall be reviewed and approved by Sound Transit. (Include in CDRL 6-1)

## **6.5 Door Functional Requirements**

The door motion shall be smooth and free of shock and impact. Controlled deceleration shall be provided at the end of door travel in both the opening and closing directions. The doors shall remain in the last commanded position during absence of local control power and when power is restored. With the sensitive edges functioning, the maximum force to prevent closing at any point in the closing cycle shall be as defined in the Door Obstruction section, below.

The delay time from receipt of a door command signal by the door controls to the first motion of a door panel shall not exceed 0.15 s after the required ADA pre-door closing warning. The operating time of any door, from time of first motion to the point of completion, including cushioning, shall be 2.5 s to open and 3.0 s to close, ( $\pm 0.2$  s for both functions). The maximum door closing speed shall be 1.3 ft/s (400 mm/s). Operating times shall be adjustable up to +0.5 s on opening and closing, accomplished in a minimum of three steps (nominal, +0.25 s, and

+0.5 s), by software. Alternative methods using a continuous adjustment may be proposed for Sound Transit approval. (Include in CDRL 6-1) A door lock function shall positively retain the doors in the closed position, even during loss of power. The lock function may be a positive mechanical lock or an over-center function of the operating linkage if the linkage is directly connected to the door panels. The lock shall automatically engage when both door panels at a doorway reach the closed position. A manual release device accessible to passengers shall be provided at each door location to release the door lock and allow all door panels to be manually opened in an emergency as described in this Section.

Electrical position-sensing switches shall be provided to detect that each door panel is fully closed and locked. Separate switches shall be provided for each detection requirement, and each switch shall directly detect actual panel and lock position. If the Contractor can show that an alternative approach utilizing one switch per panel will provide the same level of safety as two switches per panel, Sound Transit will consider approval of other arrangements provided that they positively detect both closed and locked positions. Sensing of shaft rotation or linkage position to accomplish these functions is not acceptable unless it can be demonstrated, to Sound Transit's satisfaction, that the design will not falsely detect a door closed or door locked condition due to mechanical breakage or switch failure when a door panel is not fully closed and locked. (Include in CDRL 6-1) The mounting of all sensing switches shall be such that no readjustment shall be necessary when any given switch is replaced. There shall be a separate adjustment point on each switch for system wear.

To open the doors by trainline signal, two independent trainline signals shall be required per side. One shall be the RELEASE signal, the other shall be the DOOR OPEN signal. To permit passenger opening of the doors by local pushbuttons, only the RELEASE signal shall be required. Both of these signals and the passenger pushbutton function shall be interlocked with the no-motion circuitry described in Section 2, so that they cannot be provided unless the train is stopped. Refer to this Section for further no-motion interlock requirements. The door control system shall be considered a train safety system and shall conform to the safety requirements of Section 2.

## **6.6 Door Obstruction Detection**

The door system shall automatically detect obstructions, prevent a door from becoming entrapped, and limit the forces imparted to a person in the doorway, per APTA-PR-CS-S-012-02. The door system shall detect obstructions by three types of sensing: electrical sensitive edge incorporated within the leading edge of each door panel, operator motor current sensing, and speed vs. time tracking, or other approved method. The design shall balance the sensitivity of all obstruction detection systems to optimize functional reliability and passenger safety. An electronic sensitive edge shall be incorporated within the leading edge of each door panel seal. The three obstruction detection systems shall be independent to the extent that failures in one will not affect the performance of other two.

### **6.6.1 Operational Requirements**

Upon detection of an obstruction, the door panels in the affected doorway shall immediately move to the open position and remain open for a preset period, controlled by an adjustable time

delay circuit, which shall be adjustable from 0 to 10 s. The door panels shall then again attempt to close. If the obstruction is no longer detected, the doors shall close and lock, and the obstruction detection monitoring circuitry shall be reset.

If the obstruction is still detected, the system shall cause the door panels to recycle until the obstruction is removed. Upon attaining a programmable number of recycles, originally set to five, the doors shall fully open and await further control signals.

### **6.6.2 Sensitivity Requirements**

The sensitivity of the obstruction detection system for each panel separately shall be as follows:

- It shall detect a flat bar, 3/8 in (10 mm) wide and 3 in (75 mm) high, held rigidly between and perpendicular to the door panel, as a hand might be held to stop the doors. This sensitivity shall be required everywhere along the length of the panel except the uppermost 3 in (75 mm) and lowermost 1 in (25 mm) of the nosing seal.
- It shall detect an object, 3/4 in (20 mm) in diameter, held rigidly between and perpendicular to the door panels at all locations along the length of the door nosing seal, except the uppermost 3 in (75 mm) and lowermost 1 in (25 mm) of the nosing seal.
- The equipment shall also permit an object not detected by the detection to be pulled free from the leading edges of doors that are fully closed and locked.
- A protection feature shall be provided that uses the sensitive edges to detect someone pulling on a leash, purse strap or small non-rigid object trapped between the door panel leading edges. The sensitive edges shall remain active 5 s after the door is closed. If activated during this time period, brakes shall be applied by opening the door summary loop, the door shall unlock and opened without the use of electrical power. The time shall be Sound Transit adjustable from 0 to 10 s.

### **6.6.3 Door Closing Forces**

The obstruction detection features of the door system shall be capable of detecting forces opposing door closing equal to or greater than a threshold value. The threshold value shall be 11 lbf (50 N) or less. Upon detection of an opposing force, at any point in the door closing cycle, the door system shall immediately begin to decelerate and reverse the door motion.

The force exerted on an obstacle required to trigger the detection of an obstruction shall not exceed the following when the door is powered to close as per APTA-PR-M-S-18-10:

- The “Effective Force,  $F_E$ ”, measured as defined in Figure 6-1, with a pulse threshold value of 11 lbf (50 N) shall not exceed 34 lbf (150 N).
- The “Peak Force,  $F_p$ ”, measured as defined in Figure 6-1 shall not exceed 68 lbf (300 N).

#### **6.6.4 Door Seal**

The door nosing seal shall be made from neoprene of a hardness and cross-section necessary to meet the following requirements:

- The seal shall be of a design appropriate for the door configuration to assist in the detection of obstructions as defined above, but without causing nuisance activations, and to avoid air and water infiltration.
- The seal shall be configured such that, if the obstruction detection system fails, a captured extremity of dimensions as defined above shall prevent the doors from fully closing and locking.
- The seal shall be readily replaceable with the door panel on the car.

### **6.7 Control Switches and Pushbuttons**

#### **6.7.1 General Requirements**

The doors shall be controlled from the crew switches, the cab console door-control pushbuttons, and the passenger pushbuttons. Switches and pushbuttons used for these controls shall be of heavy-duty, industrial, momentary-contact type, suitable for frequent use in the Seattle rail transit environment. Samples and comprehensive data sheets of all switches and pushbuttons selected shall be submitted to Sound Transit for evaluation with the preliminary design review package. (CDRL 6-2)

#### **6.7.2 Crew Switches**

The four outboard doors shall be provided with electrical, weatherproof, rotary switches operated by the Sound Transit crew key. Switches shall be located inside and outside the car, a total of two per doorway. The outside switches shall be located beyond the open position of the door.

Exterior switches shall be provided with a waterproof cover. Exterior switches shall be installed in recessed cavities in the car side structure, with a magnet lock cover flush with the car exterior body.

The switch and respective door operator shall be powered directly from the battery through a separate circuit breaker so that they can function when the train is not powered. When a train is powered, the crew switches shall be interlocked with the no-motion interlock circuitry. Any crew switch shall control the adjacent door only.

The switch and the adjacent door operator shall be arranged so that they can function independent of whether any cab console in the train is powered.

The crew switch shall function as a momentary switch and shall have 3 positions: OPEN, NEUTRAL, and CLOSE. The mechanism shall be configured for a spring return to the NEUTRAL position. The NEUTRAL position shall be the only position which allows the removal of the crew key. When the crew switch is rotated to the OPEN position, the adjacent door shall open within the time specified in this Section. When the switch is rotated to the

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CLOSED position, the door shall close within the time specified in this Section. The spring return to the NEUTRAL position and the removal of the crew key shall not interrupt the requested door operation. The control logic shall be configured to allow closing of a door that has been opened from the crew switch, from an energized cab console.

A key operated auxiliary on/off switch shall be provided at each outside crew switch panel location to permit the train auxiliary power system to be turned on or off.

The auxiliary power switch shall be arranged so that it can function only if no cab console in the train is powered.

The crew auxiliary power switch shall have three positions, ON, NEUTRAL, and OFF. The mechanism shall be configured for a spring return to the NEUTRAL position. When the auxiliary power switch is rotated to the ON position, the train auxiliary power system shall turn on. When the switch is rotated to the OFF position, the train auxiliary power system shall shut off, with the exception of passenger area lighting. Passenger area lighting shall remain on for 15 min after the crew auxiliary power switch is rotated to the OFF position, after which it shall turn off.

The locations of the switches will be part of the CDRL 6-1 review. The switches and associated circuitry shall be of the double-break configuration.

### **6.7.3 Cab Console Door Control Pushbuttons**

The cab console described in Section 5 shall incorporate control pushbuttons for the door system. The pushbuttons shall be functional in a cab only when the cab console is powered, the train has stopped, and the power handle of the master controller is in a braking position. Door open pushbuttons shall be covered with a clear flip-up plastic cover. The location and brightness of the cab console door pushbuttons shall be approved by Sound Transit.

Momentary energization of the RELEASE or DOOR trainline by the console pushbuttons shall cause the trainlines for the respective side of the train to latch in the energized state until unlatched and de-energized by the console CLOSE pushbutton.

All door control pushbutton switches shall be interlocked with the no-motion circuitry. The console pushbuttons shall operate as follows:

- Momentary activation of a right or left side OPEN pushbutton shall energize the DOOR and RELEASE trainlines for the associated car side, which shall cause the selected doors on the respective side of the train to open fully within the specified time. Both the DOOR and RELEASE trainlines must be energized for the doors to open from the console pushbuttons. The OPEN pushbutton shall be illuminated RED when the associated DOOR and RELEASE trainlines are energized or any door on the associated car side is not closed or not locked. After the train stops and the operator presses the OPEN pushbutton, the doors shall open immediately.
- Momentary activation of the right or left side RELEASE pushbutton shall energize the RELEASE trainline for the associated train side and shall cause control power to be

provided to the passenger DOOR pushbuttons on the respective side of the train, thereby causing them to illuminate GREEN, indicating that the pushbutton is enabled. The RELEASE console pushbutton shall be illuminated YELLOW when the associated RELEASE trainline is energized and the DOOR trainline is not.

- Momentary activation of the right or left side CLOSE pushbuttons shall de-energize the DOOR and RELEASE trainlines as appropriate, which shall initiate the door closing audible and visual indicators followed by the respective doors fully closing and locking within the specified time. The CLOSE pushbutton shall be illuminated GREEN when all doors on the associated side of the train are closed and locked.

#### **6.7.4 Passenger Pushbuttons**

Each doorway shall be provided with illuminated passenger DOOR pushbuttons on both the inside and outside of each car, a total of two (if external pushbuttons are mounted on the door panels) or three (if external pushbuttons are mounted adjacent to the doors) per doorway, for passenger opening of the doors. The Passenger Pushbuttons shall be 5 in (127 mm) in diameter and shall be of a robust design to ensure high impact resistance and to minimize vandalism. In addition, the four wheelchair areas in each car shall also have passenger DOOR pushbuttons (tape switches) located below the handrail in the wheel chair area for that door, accessible to a person seated in a wheelchair. Separate LED based red/green indicator assemblies shall be provided adjacent to these tape switches.

Pushbutton illumination shall be provided by high intensity LEDs within or around the active area of the pushbutton. Red and green LEDs shall alternate, with separate connections, to permit control of the illumination color. LED illumination shall be bright enough to permit discrimination between the LED on and off states when the car side is illuminated by bright sunshine.

DOOR pushbutton colors shall contrast with the background. The color may be used on the switch button area or may be applied to a band, approximately 1 in (25 mm) in width, which surrounds the switch. The switch functions shall be marked on the car, adjacent to the switches, in raised lettering dimensioned to permit sensing by a visually impaired person. Door pushbuttons, marking, and pushbutton color shall be submitted. (CDRL 6-3) Interior passenger DOOR pushbuttons shall be mounted on a door panel or to the right or left of the doorway on the adjacent cover panel. The switch centers shall be located between 30 in (760 mm) and 36 in (915 mm) above top-of-floor at the doorway.

Exterior passenger DOOR pushbuttons shall be located on a door panel or on the side of the car, just beyond the right and left edges of the open door panels (approximately 30 in (760 mm) from the door opening). The pushbuttons shall be mounted on a door panel just below the window, between 30 in (760 mm) and 36 in (915 mm) above top-of-floor at the doorway. Alternative pushbuttons locations will be considered during design review to optimize the locations relative to the door panels.

Opening of doors in a doorway by passengers shall be controlled by the adjacent passenger DOOR pushbuttons. Passenger DOOR pushbuttons shall be illuminated GREEN when released from the cab console. Momentary activation of any released passenger DOOR pushbutton shall

cause both panels in the adjacent doorway to fully open within the specified time and the pushbutton illumination for that doorway to change to RED. Door panels opened from the passenger pushbuttons shall remain open for an adjustable period of time or until commanded closed by trainline control. The time period shall be adjustable from 5 s to 30 s. After the door closes the illumination shall change to GREEN if the doors are still released or turn off if the doors have been closed.

Passenger pushbuttons shall be accessible by all passengers and shall not present a bump or catch point for passengers and their clothing.

## **6.8 Manual Door Release Mechanism**

Interior and exterior manual door release mechanisms shall be provided to permit doors to be unlocked and opened locally without the use of electrical power. The force to activate the manual release mechanisms shall not exceed 10 lbf (44 N). Activation of this release device shall unlock both panels in a doorway and allow them to be manually pushed open regardless of whether electrical power is available or not. This mechanism shall override all other door controls and devices.

When the manual release mechanism is activated the following shall automatically occur:

- The initial motion of the release knob or lever shall cause the release mechanism to interrupt the door status interlock causing propulsion power to be removed and an irretrievable Full Service Brake command to be applied to all cars in a train. Circuitry shall be provided to annunciate "PASSENGER EMERGENCY" on the console indicator panel in each cab and sound the cab Audible Alert #2. Refer to Section 5.
- The final motion of the release knob or lever shall then cause the mechanism to unlock the adjacent door panels and open them approximately 1 in (25 mm) to allow the door panels to be manually pushed fully open. Electrical power to the door operator shall be removed from the door operator. A reset device shall be provided to restore the doors to their normal operating condition after use of a manual release mechanism. The reset device shall be contained within the door control panel or transom area above the doors. Access to this area shall be by means of a Sound Transit crew key.

### **6.8.1 Interior Manual Door Release (Passenger Emergency Switch)**

A lever, pull knob or other device to operate the combination manual door release mechanism and passenger emergency switch (release device) shall be provided on the interior of the car at each doorway in a location accessible to passengers. This release device is to be used under emergency conditions only, and suitable measures shall be taken to ensure that its location and enclosure discourage casual use. The release device shall be located near the door in plain sight. Suitable graphics shall be provided to explain operation in an emergency and warn against unlawful use. The graphics shall advise that the emergency door opening device is also an emergency stop activating device. The manually operated device shall automatically retract to the reset position once released. The retraction device will return the door circuits to normal operation but the doors will not close until the operator re-energizes the circuit from the cab console by pressing the DOOR CLOSE pushbutton. There shall also be an Emergency Reset

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Switch (ERS) to re-energize the circuit at each manual Emergency Door Release location. The ERS Button shall easily be accessible from inside the car without opening any access panels.

Operation of the release mechanism shall not electrically bypass the no-motion interlock (Refer to the No-Motion Interlock section, below).

### **6.8.2 Exterior Manual Door Release**

Key operated manual door release devices shall be provided for crew, maintenance and emergency personnel use for entry to the car when no power is available. Two releases shall be provided, each diagonally opposite the other at the right hand outboard side doors, located inboard of the doorways. Use of this feature shall require the Sound Transit crew key. Design and location of the manual door release shall be subject to Sound Transit review and approval. (Include in CDRL 6-1)The Exterior Emergency Door Release shall be recessed into the side of the car and covered by a flat panel that is held flush with the car side by a magnetic catch. The release shall be accessible from the ground along the wayside, and from the high level platform.

### **6.9 Lock and Interlock Requirements**

It shall not be possible to move a train if any door is not physically closed and locked, unless the Door Interlock Bypass in the cab is activated or the door has been cut out.

A door locking device shall be provided for each door panel. The lock shall automatically engage when the door panels in a doorway reach the closed position, and lock engagement shall not require the presence of power. The door locks and panel position shall be mechanically linked such that a door locked indication cannot be achieved unless the panel is in a closed position.

A single locking device per doorway may be considered by Sound Transit if a safety analysis shows that, with the lock engaged, neither panel can be opened.

The integrity of either locking scheme shall be verified by rigorous safety analysis, including structural analysis of all relevant components. This analysis shall be submitted for approval (CDRL 6-4).

#### **6.9.1 No-Motion Interlock**

All door controls and operators shall be electrically interlocked in a safe manner with the no-motion circuitry described in Section 2 so that the doors can be powered open only when the train is stopped. When motion is detected, and after expiration of sensitive edges time delay described in this Section, a DOOR CLOSE command shall be issued to all doors in a train, and the doors shall ignore all electrical unlocking, opening and release commands until no-motion is once again detected.

Power to the opening circuits for the door operators, controls and logic packages shall be switched with non-welding critical circuit relays controlled by the no-motion logic. When motion is detected, both the positive and negative feeds for these circuits shall be disconnected from low-voltage power. Other service proven and safety certified methods will be considered, subject to Sound Transit approval.

## **6.9.2 Door Status Interlock**

An electrical loop circuit shall be provided to monitor door panel position. Position sensing switches shall be provided for each door panel to positively and directly detect that each panel is fully closed. Separate sensing switches shall be provided to positively and directly detect that each door panel is locked unless other configurations are approved per the Door Functional Requirements section, above.

A loop circuit consisting of a series connection of both the closed and locked contacts for each door panel shall be provided for each side of the car. Each of the two car loop circuits shall activate a summary door status relay. The contacts of the summary door status relays shall be arranged in series to form a train loop circuit for each side of the train to indicate all doors on that side of the train are closed and locked. If any one of the closed or locked switches in the car loop is not made up, the interior and exterior door light for that doorway shall be illuminated and the summary door status relay for that side shall not be energized. If either train loop circuit is not energized the cab console DOOR OPEN light for that side of the train shall be illuminated, propulsion power shall be removed, and Full Service Brake (FSB) shall be applied.

If an attempt is made to apply power with the doors not closed and locked, the master controller shall have to be placed in the FSB position after the summary door status relays are energized, before the brakes can be released and power applied.

## **6.10 Bypass Devices**

Bypass devices shall be provided to circumvent specific door system faults so that the train can continue in revenue service, be removed from revenue service and returned to Sound Transit's service and inspection facility, or moved to clear the line.

### **6.10.1 Door Interlock Bypass**

A sealed door interlock bypass feature shall be provided in each cab. This function shall be active only when the associated cab console is powered. It shall permit movement of the train under emergency conditions in the event that all doors are not sensed as being closed and locked and the source of the difficulty cannot be readily determined. The activation of the bypass switch shall be recorded and logged by the monitoring and diagnostics system Event Recorder.

The door interlock bypass feature shall bypass the door status interlock so that the brakes can be released and power applied. It shall not provide a false doors closed indication.

### **6.10.2 Door Cutout**

A door cut-out device shall be provided at each door operator and shall be arranged to perform the following functions in the event that a defective door must be cut out:

- Disconnect door motor;
- Bypass door-closed and door-locked interlocks for that door;

## *Passenger Doors*

- Ensure that door remains closed by mechanical restraint. However, operation of the manual door release devices (refer to the Manual Door Release Mechanism section) shall disable or release this mechanical restraint to allow the door to be opened; and
- Deactivate the local passenger pushbutton light, activate the trainline door cut-out indicator (see Section 5) and activate the car DOOR OUT-OF-SERVICE indicators, as described in the Annunciators section, below. The cutout device shall be located in the transom area above the doorway.

### **6.11 Annunciators**

#### **6.11.1 Door Open and Release Indications**

As part of the cab console left and right door control pushbuttons, the following indicator status lights shall be provided:

- Red LED cluster DOOR OPEN, with door open pushbuttons.
- Yellow LED cluster DOOR RELEASED, with door release pushbuttons.
- Green LED cluster DOOR CLOSED, with door close pushbuttons.

All shall function as described in the Cab Console Door Control Pushbuttons section, above.

Yellow LED cluster DOOR OPEN indicator status lights shall also be provided on the car interior on the underside of the door transom above each doorway and on the outside, mounted above the center of the doorway. When either panel in the adjacent doorway is sensed as being mechanically unlocked, open, or both, the indicators at that doorway shall be illuminated.

#### **6.11.2 Door OUT-OF-SERVICE Illuminated Indicator**

Red LED cluster, DOOR OUT-OF-SERVICE illuminated indicators shall be provided on the car interior and exterior at each doorway, along with associated graphics advising "Use Other Door". The indicator shall be illuminated any time a door is removed from service by activation of the DOOR CUT-OUT device. The interior DOOR OUT-OF-SERVICE indicator shall be located above the doorway in the transom. The exterior DOOR OUT-OF-SERVICE indicators shall be an LED backlighted sign, showing a "Use Other Door" legend only when lighted, and shall be located adjacent to the associated passenger DOOR switches, or immediately above and near the center of the associated doorway. The exterior door out-of-service sign shall be readable in direct sunlight when illuminated.

#### **6.11.3 Door Closing Warning Indicators**

An audible indication that the doors are closing shall be provided independently at each doorway 1 s (adjustable) prior to the start of closing, for all closing situations except obstruction detection recycling. The door closing audible indication shall be identical to what is currently installed on the existing ST1 LRVs, generated electronically by the local door control system. The audible indication shall be audible inside and outside the car at each doorway. The public address system shall not be used for this audible indication. The time delay shall be adjustable from 0 s to 2 s.

## *Passenger Doors*

Tone and intensity of the audible indication shall be as reviewed and approved by Sound Transit. (CDRL 6-5) Means shall be provided, for use by maintenance personnel, to suppress the audible indication when the car is undergoing maintenance.

Amber visual door closing warning indicators shall flash with the audible warning indication on both sides at each doorway and for the duration of the closing sequence. The visual indicators shall be located on the side of the door post, approximately 2 ft (600 mm) above the floor, visible both inside and outside the car regardless of door position. If the visual door indicator cannot be seen from outside the car with the doors closed a duplicate, weatherproof device shall be provided on the outside of the car at each doorway. The indicator(s) shall be as approved by Sound Transit. (Include in CDRL 6-1) Both the audible and visual warnings shall be compliant with 49 CFR 38.

### **6.12 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 6-1 Door system design report (Section 6.1)
- 6-2 Samples of control switches and pushbuttons (Section 6.7.1)
- 6-3 Passenger door switch colors (Section 6.7.4)
- 6-4 Safety Analysis for The Integrity of Locking Scheme (Section 6.9)
- 6-5 Door warning tone and intensity (Section 6.11.3)

### **6.13 Cited References**

The following standards or references were cited in this Section at the referenced location:

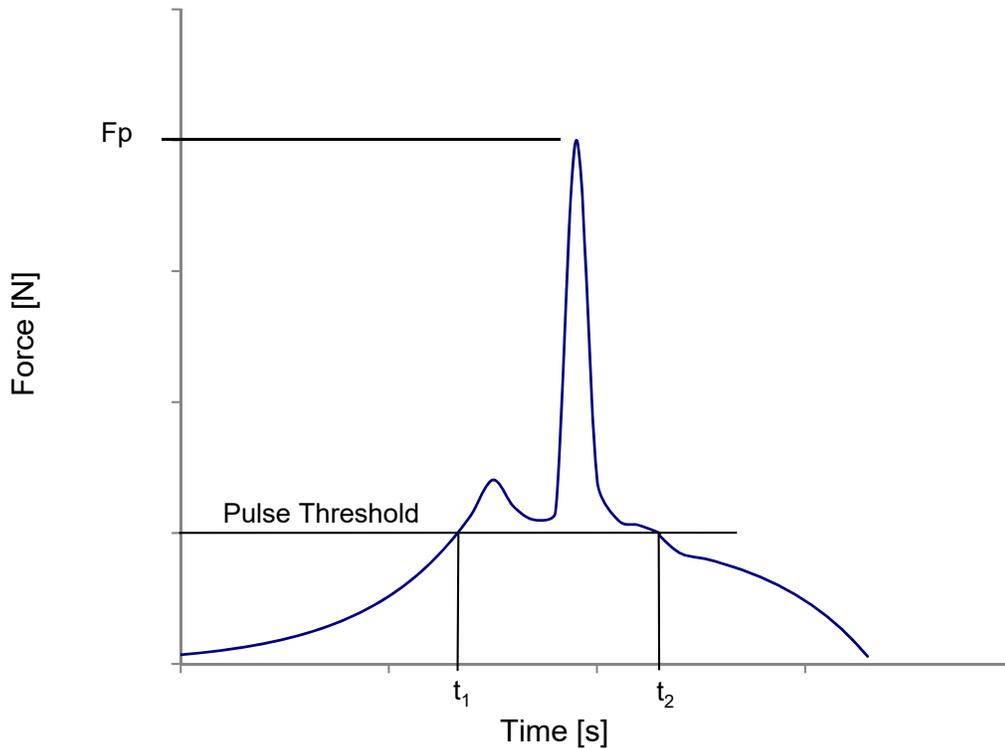
- APTA-PR-CS-S-012-02 Standard for Door Systems for New and Rebuilt Passenger Cars (Sections 6.1, 6.6)
- APTA-PR-M-S-18-10 Standard for Powered Exterior Side Door System Design for New Passenger Cars Section (Sections 6.1, 6.6.3, Figure 6-1)
- 49 CFR 37 Transportation Services for Individuals with Disabilities (ADA) (Section 6.1)
- 49 CFR 38 Americans with Disabilities Act (ADA Accessibility Specifications for Transportation Vehicles (Sections 6.1, 6.11.3)
- 49 CFR 238 Passenger Equipment Safety Standards (Section 6.1)

**Figure 6-1: Typical Force vs. Time Measurement**

**Measurement of Door Closing Forces**

The forces developed at the edge of a door closing against an obstruction are a time-dependent function of several factors. These factors include the mass of the door panel, acceleration of the door panel and stiffness of the obstruction. Refer to APTA-PR-M-S-18-10 Appendix A for the door closing force measurement.

A graph of force versus time may have the general characteristics shown below.



**Figure 6-2: Force Measuring Device**

The effective force,  $F_E$  is defined by the equation:

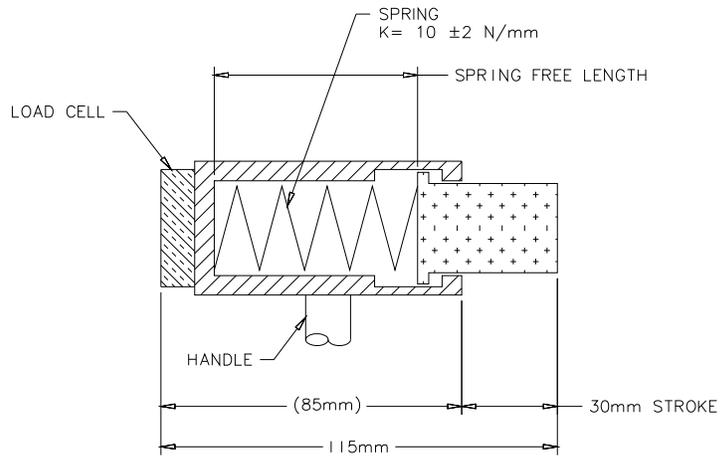
$$F_E = \frac{1}{T} \int_{t_1}^{t_2} F(t) dt$$

Where:

- $t_1$  is the time at which the value of the opposing force exceeds the Pulse Threshold value;
- $t_2$  is the time at which the value of the opposing force falls below the Pulse Threshold value
- Pulse Duration:  $T = t_2 - t_1$

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- Closing Force  $F(t)$ : Time-dependent force function, measured at the closing edges of the door.



**END OF SECTION 6**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 7  
HEATING, VENTILATING, AND AIR CONDITIONING**

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**SECTION 7: HEATING, VENTILATING, AND AIR CONDITIONING**

**7.1 General**

The cars shall be provided with a heating, ventilating, cooling and reheating system to meet the requirements identified in this Section. All systems and system components shall be service-proven, as defined in Section 2, and supported by design and test data adequate to demonstrate compliance with the Specifications.

The HVAC system equipment design, construction, and assembly shall meet, as a minimum, the rules of NFPA 70 (National Electrical Code), NFPA 130, ASHRAE Standard 15, and the safety requirements of UL 1995. The equipment shall be identified and marked with name plates according to UL 1995.

The apparatus described in this Section shall be designed and manufactured to comply with materials, design workmanship, test and other relevant sections of the Specifications.

**7.2 Design Criteria**

<b>Parameter</b>	<b>Value</b>	<b>Reference</b>
Ambient Temperature (Summer)	85°F (29°C) DB 65°F (18°C) WB	Condition A
Ambient Temperature (Summer)	95°F(35°C) DB 75°F (24°C) WB	Condition B
Ambient Temperature (Summer)	104°F(40°C) DB 83°F (28°C) WB	Condition C
Ambient Temperature (Summer)	115°F (46°C) DB 86°F (30°C) WB	Condition D
Ambient Temperature (Summer or Winter)	45°F (7°C) DB	Condition E
Ambient Temperature (Winter)	25°F (-4°C) Dry Bulb, 50% RH	Condition F
Passenger Load	190 (not less than 450 Btu/hr (132 W) per person with 55% SHR)	Pax A
Interior Design Conditions	75°F (24°C) DB and 55% RH (Cooling) 67°F (19°C) DB (Heating)	
Fresh air	Variable depending on the number of passengers with 7.5 ft <sup>3</sup> /min ( 12.74 m <sup>3</sup> /h) per passenger, including operator	
Total air flow	Sufficient to meet the internal temperature, humidity and car pressurization requirements of this Specification	

<b>Parameter</b>	<b>Value</b>	<b>Reference</b>
Car body heat transmission	In accordance with the Contractor's car body and insulation design to meet the requirements of this Specification, but in no case more than 1400 Btu/h/°F (740 W/°C)	
Lighting load	Power generated by LED transformers	
Solar load	In accordance with ASHRAE calculation methods	
Miscellaneous equipment	In accordance with Contractor's design data and shall include, but is not limited to, interior lights, blowers, and equipment	

The Contractor shall submit performance calculations with a load analysis of the car passenger area and the cabs, detailing the required heating and cooling system capacities and the required supply airflow, as part of the design review submittals. The Contractor shall use actual air density for all capacity calculations.

The cooling system shall be able to start and operate without damage at any time of the year when the exterior temperature is above 45°F (7°C) (Condition E). The system design shall allow full cooling operation without the influence of modulation control with the ambient temperature up to 104°F (40°C) dry bulb and 83°F (28°C) wet bulb at the condenser and fresh air intakes (Condition C). The system must be capable of operation, at reduced capacity if necessary, up to an ambient temperature of 115°F (46°C) dry bulb and 86°F (30°C) wet bulb (Condition D) with design internal and solar loads.

The HVAC system shall be designed and constructed to operate under the shock and vibration conditions specified in Section 2, and shall be tested to those requirements. The HVAC system shall not impose vibrations greater than those specified in Section 2 to the carbody in any mode of operation. Interior and exterior sound levels shall meet the requirements of Section 2 respectively.

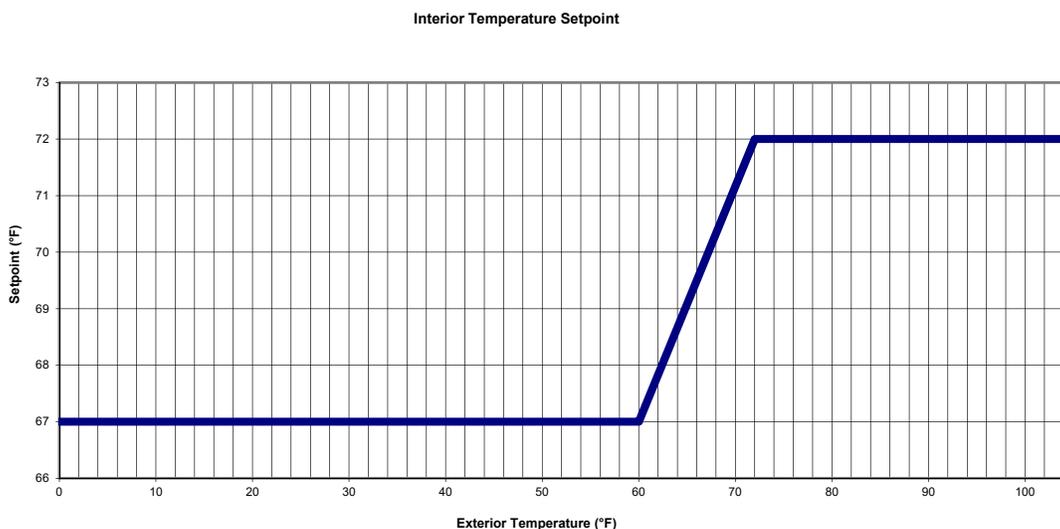
The comfort control system shall be designed to automatically provide the specified control of car interior temperatures with any ambient temperature from Condition F to Condition A, with or without variable internal heat loads such as passengers, motors, lights and solar gain, at nominal applied voltages as described in Section 2.

The controls shall operate from the low-voltage dc power supply. Overall control system and thermostat sensitivity and accuracy shall be such that the requirements of this Section are met.

The system shall include provisions to monitor system operation and store system data and fault events to support troubleshooting and maintenance of the system, and to interface with the MDS.

### 7.2.1 Required Interior Car Temperature

The interior temperature setpoint shall be controlled per the following chart. The exact set-points shall be adjusted as necessary during the vehicle climate room test described in Section 16 in order to maintain the conditions shown in the Table in Section 7.2, above.



**Figure 7-1: Interior Temperature Setpoint**

The system shall maintain the average temperature inside the car within  $\pm 1.5^{\circ}\text{F}$  (1 K) of the setpoint at any time that the net heating or cooling power required is within the capacity of the system. When the net heating or cooling power required exceeds the available capacity of the system, the setpoint shall be maintained, but the interior temperature shall be allowed to deviate from the setpoint in proportion to the difference between the available heating or cooling power and the net heating or cooling power required. When cooling is required at or below design conditions of this Section, the interior relative humidity shall be within the comfort zone limits as defined by ASHRAE Standard 55.

At design conditions, the temperature in the operating compartment, with the side windows and partition door closed, the cab air diffusers throttled to half of their full flow, and with cab heater available, shall conform to the requirements for interior car temperature.

The following temporal and spatial variations in interior car temperatures are the maximum that shall be allowed during steady-state operation:

- At any given time, among all points in the same horizontal plane from one end of the car to the other:  $\pm 3^{\circ}\text{F}$  (1.5 K) from the average.
- At any given time, between any point approximately 43 in (1,100 mm) above the floor and the corresponding point 4 in (100 mm) above the floor in a vertical plane at the seating areas:  $7^{\circ}\text{F}$  (4 K).

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- At any given point in the car, and in the entrance ways, and at least 12 in (300 mm) from the ceiling and 4 in (100 mm) from the floor and walls over a period of time: 5°F (3 K).

### **7.2.2 Ventilation and Pressurization**

The evaporator blowers shall operate to ventilate the car whenever the HVAC system is energized and the ac power supply described in Section 9 is available.

The fresh air supplied to the car shall vary depending on the number of passengers, with a minimum of 7.5 ft<sup>3</sup>/min (12.74 m<sup>3</sup>/h) fresh air per person, including the operator. A minimum fresh air volume necessary for maintaining interior pressurization of 0.10 inches of water (25 Pa) shall be provided to the car at all times, regardless of the number of passengers.

The cab door shall be provided with a grille of sufficient strength to prevent it from being inadvertently damaged, as specified in Section 5. It shall permit the conditioned air supplied to the cab to return to the passenger compartment.

### **7.3 HVAC Control Arrangement**

The control system shall be designed to automatically maintain the car interior temperature at the specified conditions, with or without variable internal heat loads such as passengers, motors, lights and solar gain. The control system shall operate from the low-voltage power system, and its sensitivity and accuracy shall permit the requirements of this Section to be met.

The Contractor shall be responsible for providing uniformly distributed system airflow, selection of a temperature control system, and proper modulation of cooling capacity, overhead heat power, and floor heat power to meet the temperature control requirements provided in the Specifications. The Contractor shall make all modifications necessary to the controls and cooling apparatus to make all cars conform to the final control configuration determined at the vehicle climate room test.

Trainline control of the HVAC systems is described in Section 5. Layover heat control shall be enabled any time low-voltage and high-voltage dc power is available and the auxiliary trainline is not active.

The HVAC control shall be coordinated with the Auxiliary Power Supply control and car control logic such that when the Auxiliary switch in any cab is moved to the “OFF” position (if no cab is activated), all HVAC systems shall remain operational for a period of 30 minutes (adjustable from 0 to 60 minutes) to allow changing control cab and/or vehicle cleaning while still maintaining the required interior conditions. When operating in cooling mode, after the expiration of the shut down time delay, the HVAC system shall initiate a pump-down and perform an orderly shutdown sequence. The Auxiliary Power Units shall not be allowed to shut down until all HVAC units have completed their shutdown sequence.

The heating and air conditioning control system shall obtain temperature information by means of thermistor sensors. The thermistors shall be encapsulated in a protective stainless steel tube. The layover thermostat may be a rail service-proven bimetallic type with set points as specified.

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Humidity control shall be provided using cooling with modulated reheat, or cooling alone, as required to maintain the proper interior temperature and humidity. The use of a humidistat may be proposed for Sound Transit consideration.

Temperature sensors shall be mounted to ensure that they are not unduly influenced by local sources of heat, such as motors or resistors; that they are easily accessible for maintenance and replacement; that they are protected from damage during routine air conditioning servicing, such as replacing filters; that they are not unduly influenced by adjacent air streams; and that they do not present a safety hazard to maintenance personnel.

Sensors accuracy shall be that required to comply with the requirements of the Specifications.

The static temperature controller shall control the heating, ventilating and air conditioning contactors directly through power switching transistors provided as part of the unit without the use of pilot relays.

The static temperature control electronics shall be selected in strict conformance with the requirements of Sections 17, and shall be packaged in a single, rugged, totally enclosed sheet metal enclosure. The control electronics shall interface with the MDS as required by Section 9 and include a data/fault logger function that complies with the requirements of Section 9. Required heat dissipation shall be accomplished by external cooling fins arranged to avoid the collection of dirt. The unit enclosure shall be arranged for quick removal and replacement with no more than four captive fasteners. Electrical connections shall be by means of environmentally-sealed connectors that comply with the requirements of Section 17. Portable test unit connectors shall be as specified in Section 18.

An LED or LCD display shall be incorporated into the front face cover of the unit, accessible from inside the vehicle as described in this Section. The display shall indicate the following temperature control function status as a minimum:

- Compressors Operating;
- Cooling Mode (full or partial/modulated)
- Overhead Heat, including staging and/or PWM percentage;
- Floor Heat (Stage 1);
- Floor Heat (Stage 2);
- Floor Heat Ground Fault Trip (Stage 1);
- Floor Heat Ground Fault Trip (Stage 2);
- High/Low Pressure Trip and Lock-out;
- Overheat Devices Trip and Lock-out;
- Hot Car;
- Cold Car;

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- Temperature Sensors (return air and fresh air temperature);
- General Fault

In addition, the display shall indicate the return air temperature and fresh air temperature. Key circuit "NORMAL/ABNORMAL" LED indicators shall be provided to aid in rapid identification of major circuit problems.

As a minimum, indicators shall be provided to verify normal input voltage, normal internal power supply voltages (if applicable), and an inherently generated circuit which indicates that temperature sensing thermistors are "NORMAL" or open or shorted.

A reliable and accurate means of reporting air comfort system failures to the Monitoring and Diagnostic System shall be incorporated. Refer to Section 9. In the event of power loss, all faults shall be retained upon restart of the HVAC System.

### **7.3.1 Refrigerant Control Devices**

The following devices shall be included as part of the refrigeration control compartment described in this Section.

#### **7.3.1.1 Low-Pressure Cutoff Switch**

A low-pressure cutoff switch shall be provided to monitor compressor suction pressure to protect the compressor and other system components from potentially damaging low-pressure operation. The switch shall directly deactivate the compressor motor contactor when the pressure drops below the safe limit. The switch shall automatically reset and allow the system to energize the compressor motor, following a suitable time delay, when the pressure rises; suitable hysteresis shall be provided to prevent short-term system cycling at the cut-out pressure. In addition to providing the low-pressure protective function, the low-pressure control may function as the normal compressor control deactivating device following a normal pump-down cycle.

#### **7.3.1.2 High-Pressure Cutoff Switch**

A hard-wired high-pressure cutoff switch shall be provided to monitor the compressor discharge to protect the system from excessively high system pressures. The switch shall be wired directly into the compressor contactor. The switch shall automatically reset and allow the system to energize the compressor motor when the pressure drops to the safe operating pressure determined by the HVAC unit design. The circuit shall be arranged such that condenser fan(s) operation is not interrupted by the high-pressure cutoff control. The high-pressure cutoff switch shall be provided with an external pulsation snubber.

#### **7.3.1.3 Pressure Transducers**

Capacity control pressure transducers shall be provided. In addition to controlling cooling capacity, the transducers shall monitor discharge line pressure and maintain system operation by reducing the air conditioning system capacity when conditions cause discharge pressures to approach the high-pressure cutoff point.

#### **7.3.1.4 Pressure Switches and Transducers Construction and Mounting**

All pressure switches and transducers shall be suitable for operation in the range of voltages, currents, temperatures and pressures expected. Wetted parts shall be suitable for contact with the refrigerant specified and the lubricant used. Set point tolerance shall not exceed  $\pm 2\%$ .

Pressure switches and transducers shall be connected with gauge ports to the system into a common brass manifold such that they can be replaced, when necessary, without significant loss of refrigerant. The system side of the connection shall be equipped with a check valve to allow switch replacement without the need to recover the refrigerant from the system. Pressure switch and transducer connections shall be color-coded. The transducers shall report the information to the MDS.

#### **7.3.1.5 Gage and Service Ports**

High and low side gage will be installed and service ports shall be provided. Each port shall be fitted with a self-sealing Schrader®-type valve, with chain-retained, metal-to-metal seal caps. Each line shall be equipped with a diaphragm-type manual isolation valve. The manual valves and gage connections shall be color-coded red for high side and blue for low side.

### **7.3.2 Heating Control**

The overhead heat shall be controlled such that the power output, as a minimum, offsets the fresh air ventilation heating load, except during pull-up, when the overhead heat shall operate at full power. The floor heaters shall be cycled as required to offset all other losses and maintain interior temperature within the requirements of this Section.

#### **7.3.2.1 Overhead Heat Control**

Each overhead heater stage shall be energized through a solid-state contactor capable of modulating the power continuously from zero to full rated power. Modulation shall be accomplished by a timed pulse cycle controlling the ratio of “heater on” to “heater off” time.

A duct temperature control sensor shall be provided. The system shall compare the duct sensor reading with the return air sensor reading and, using a PI or PID control algorithm, maintain supply air temperature at or not more than 5°F (3 K) above the sensed return air temperature under stabilized conditions when cooling is not required.

In order to reduce cold car pull-up time, overhead heat shall operate at full power when the return air sensor reading is 10°F (5.5 K) or more below the required interior temperature.

#### **7.3.2.2 Overheat and Loss of Air Flow Protective Devices**

The control logic shall ensure that power may not be applied to the overhead heaters unless operation of the blowers is proven.

In addition, the following protection shall be provided at each unit against possible over-temperature conditions:

- A self-resetting thermostat shall be installed adjacent to each overhead heater unit to detect the presence of excessive temperature. Upon detection, it shall open the overhead heat contactors supplying that unit. It shall not open at any temperature which is possible with all car equipment operating normally and dc line voltage as specified in Section 2.
- An ultimate protection device shall be provided in the form of a fusible link, or approved equal, in the line to the overhead heat coils to remove power in the event of excessive heat. A means to suppress the arc at rupture shall be provided. Design of this feature shall be subject to Sound Transit review. (CDRL 7-1). The fusion temperature of the link shall be high enough to allow the link to rupture only in the event of a failure of the primary protective apparatus, but still prevent damage to the equipment and other carbody components. The fusible link shall be accessible for maintenance in the installed unit.

Both protective devices shall have their ratings, type, and location designed such that maximum protection is provided, without nuisance activations, under all possible combinations of operating conditions, including dirty filters.

### **7.3.2.3 Floor Heater Control (Passenger Compartment)**

The floor heat control shall sense the return air temperature and, using a PI or PID control algorithm, shall control the floor heaters as required to maintain the desired interior conditions.

Each floor heater stage shall be energized through a contactor. Each circuit shall have its own breaker and ground protection circuit. Each circuit shall have current input to and output from the floor heaters monitored by a differential relay that energizes for a predetermined difference between the two. When this relay energizes, both the positive and negative feeds to the affected floor heater circuit shall be interrupted.

The ground-fault type circuit shall remain latched in the disconnected mode until manually reset by means of a momentary reset button. The fault trip must not be affected by control power loss or fluctuations. A tripped ground fault circuit shall be annunciated by means of an LED indicator for each stage on the ground fault detection device in the HVAC control box and on the MDS. The sensor device shall be designed such that it is not necessary to disconnect heater power leads to remove and replace the ground fault detection unit. A separable sensing coil or other approved method shall be provided to accomplish this requirement.

Alternate methods of ground fault detection and protection may be submitted for Sound Transit review. (CDRL 7-2)

### **7.3.2.4 Layover Heat Control**

The cars shall be equipped with a thermostatically-controlled layover heating system. A service-proven bimetallic-type thermostat shall control layover heating, installed in an approved location, and protected from splashed cleaning solutions. The thermostat shall operate to maintain average car temperature at  $45^{\circ}\text{F} \pm 5^{\circ}\text{F}$  ( $7^{\circ}\text{C} \pm 3\text{ K}$ ) using the floor heaters only. Floor

## *Heating, Ventilating, and Air Conditioning*

surface temperature shall not fall below 34°F (1°C) anywhere in the car, to prevent water freezing and slipping hazard.

The thermostat shall be located so that it's wiring and terminations are inaccessible except to maintenance personnel. Location of the thermostat shall be subject to Sound Transit review. (CDRL 7-3)

### **7.4 Floor Heat**

Passenger compartment heat shall be provided using electric heaters mounted within stainless steel or aluminum heater enclosures along the side wall at floor level. The removable section of the enclosures shall be made of stainless steel or aluminum. The enclosure shall totally encase the heater elements except for holes required for convective air circulation.

Floor heat shall be automatically controlled by the temperature control system and shall function whenever regular heating is required. The floor heat system shall have sufficient capacity to maintain an average interior car temperature of 42°F (23 K) above the outside ambient temperature with ventilating fans inoperative, overhead heat inoperative, and without benefit of solar or passenger load. The floor heaters shall be uniformly distributed and have their total capacity available at 208 Vac. The heaters shall be powered from the nominal 208 Vac three - phase auxiliary power supply (refer to Section 2), with control as described in this Section.

The heaters shall be of the strip heater type consisting of a nickel-chromium wire embedded in a baked, compressed refractory material or of the Calvane type consisting of a nickel-chromium wire sealed within a rust-resistant high-heat-transfer steel sheath. Individual wires in a heater strip shall be connected in series and sealed within a rust-resistant high-heat-transfer steel or aluminum sheath. The watt density shall not exceed 165 W per linear foot of element. The heater mounting design shall allow freedom for thermal expansion and contraction of the heater, as well as provide full electrical insulation between the heating element sheath and the carbody. The heater elements shall be mounted on insulators to the carbody or fixed portions of the heater enclosure, not to the heater guard. No more than two types of floor heater element shall be permitted.

Air shall enter the heater guard through slots in the bottom, pass over the heaters in the enclosures, and rise by convection through holes in the top portion of the enclosure. Heater guards shall be designed to facilitate the convection of hot air and shall be insulated in an approved manner if necessary to prevent the surfaces with which passengers may come in contact from exceeding 125°F (52°C).

The heater guard front sections shall be constructed so that sections may be easily removed for replacement of heating elements, without dismantling any seats, adjacent heater guards, or other fixed appurtenances. The front of the heater guard shall be fastened with reusable screws. Self-tapping screws are not permitted for fastening heater covers. The heater guards shall be independently grounded to the carbody, with each guard utilizing a single ground point. Heater guards shall be sloped so as to not trap or collect debris.

The lower section of the heater box construction shall prevent the accumulation of dirt.

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Wiring to the floor-heater elements shall have insulation rated for 150°C, and shall be so arranged that electrically "live" points cannot be reached if a long thin object, such as a knife or screwdriver blade, is inserted through the holes in the heater guard face. Terminal connections shall be covered with a protective boot rated for high temperature.

At least two separate floor heater circuits shall be provided in each car, and ground terminations to each shall be separately brought to a terminal board to facilitate the location of open or grounded heater elements. Each circuit shall have its own circuit breaker and ground protection device. Each circuit shall have current input to and output from the floor heaters monitored by a differential relay that energizes for a predetermined difference between the two. When this relay energizes, the three feeds to the affected floor heater circuit shall be interrupted.

The ground fault type circuit shall remain latched in the disconnected mode until manually reset by means of a momentary reset button located in the HVAC control box. The fault trip must not be affected by control power loss or fluctuations. A tripped ground fault circuit shall be annunciated by means of an LED indicator on the ground fault detection device. The sensor device shall be designed such that it is not necessary to disconnect heater power leads to remove and replace the ground fault detection unit. A separable sensing coil or other approved method shall be provided to accomplish this requirement.

Floor heater wiring shall be routed in an approved manner. If the wiring is routed to the underfloor, the design must prevent the entry of water and contaminants into the conduit that carries the wire underfloor. As a minimum, conduits carrying wires to the underfloor must extend 1.5 in (38 mm) above the top of the finished floor plane and must be sealed with an elastomeric environmental sealing bushing or other approved method.

### **7.5 Cab Heat**

The operator's cab shall be provided with one or two forced-air cab heaters for heating the cab. They shall have a capacity adequate to maintain a temperature of not less than 70°F (21°C) in the full-width cab compartment with 25°F (-4°C) exterior ambient temperature, the overhead air diffuser shut-off, and the side windows closed. The heaters shall be distributed in the cab and shall supply heat at the operator's feet, and direction of air flow shall be adjustable

The cab heaters shall be thermostatically controlled, and shall be operational in active and non-active cabs as long as auxiliary power is available. If two cab heaters are used, they shall be connected in parallel and controlled simultaneously.

The heater elements and blower motors shall operate from the ac supply.

The heater housings shall be constructed of approved heat-resistant, nonflammable material and shall fully enclose the heater elements. Surface temperatures of the enclosures exposed to operating personnel shall not exceed 125°F (52°C).

An approved automatic high-limit thermostat and back-up protection device shall be provided inside the heater housing, which shall remove power in the event excessive temperature is

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developed. The heater assembly and case shall be permanently grounded. The cab heater and controls shall be accessible for repair and replacement through access panels.

The controls shall be active only in an active cab. In non-active cabs, the layover conditions shall be maintained. A positive interlock shall be provided to open the heat contactors in the event the cab heater blower is not operating.

Heating units installed in the cab shall not interfere with personnel access to the side cab windows for monitoring exterior status lights and door operation.

Heated/cooled ventilation air shall also be supplied to the cab under the control of the comfort control system from the adjustable ceiling-mounted cab air diffuser. When closed the cab air diffuser shall prevent airflow into the operators cab.

### **7.6 Heated Glass**

The defrosting and defogging of the operator's cab windshield and side windows shall be by means of electrically-heated glass operating on nominal 28.5 Vdc from the vehicle low-voltage system or 120/208 Vac. The heated glass shall be capable of clearing the entire surface of the window of ice, frost and fog. An on/off switch shall be provided in the operator's cab for the heated windshield and side windows. The control power shall be from the low-voltage dc power source and shall operate a solid state switch which will switch the power to the heating element. An LED shall be illuminated whenever the windshield and side window heaters are energized. The circuit breaker for the heated glass shall be located in the low-voltage dc circuit breaker panel in the cab.

The defogging time shall not exceed 15 min with a 30°F (-1°C) outside ambient and 70°F (21°C) dew point inside.

Defrosting shall follow the guidelines established within SAE J902, J953, or approved equal. The maximum time to defrost the cab windshield shall be 15 min.

The heater power level to achieve the specified deicing and defogging shall be designed to provide the required performance without damaging the windshield. The electrically heated glass feature shall be available in the non-active cab but shall be disconnected after 30 min of operation. An automatically-resetting high limit thermostat shall also be provided to remove power from the heating element to prevent excessive windshield temperatures.

### **7.7 Low Temperature Protective Heat Control**

Protective heating elements shall be provided at the air supply system drainage devices, and as required for the proper operation of all vehicle systems as recommended by the equipment manufacturers. The Contractor shall propose the power source for each protective heater for Sound Transit review. (CDRL 7-4) No heated surface associated with the protective heaters shall be warmer than 125°F (52°C) when powered at the nominal voltage as stated in Section 2 with a 40°F (4°C) ambient. Heaters shall be installed in a manner that facilitates maintenance, and shall be protected from accumulations of moisture and salt. Protective heater elements shall be hermetically sealed.

All protective heaters shall be controlled by single outdoor air non-adjustable thermostat, which shall energize the heaters at temperatures of 40°F ±5°F (4°C ±3 K) and below. Heaters and controls shall be protected by dedicated circuit breakers and shall operate whenever the auxiliary power system and LVPS, as appropriate, on the vehicle is functioning.

If necessary for the Contractor's design, the control of low temperature protective heaters may be accomplished by the HVAC control system.

## **7.8 Ducts, Diffusers and Grilles**

### **7.8.1 Main Air Ducts**

The top and sides of the main air distribution ducts shall be constructed of stainless steel or aluminum. As an alternative, fiberglass reinforced plastic (FRP) molded ducts meeting the requirements of Section 17 may be proposed. (CDRL 7-5) A separate, but identical, main air distribution duct arrangement shall be provided for each "A" and "B" section of the vehicle. The ducts in each "A" and "B" section shall be supplied with conditioned air from the HVAC Unit, and shall discharge that air through two rows of continuous, double-slot type air diffusers into the passenger compartment. Duct systems on each "A" and "B" section shall be equipped with flexible duct extensions to provide conditioned air to the "C" section. There shall be no direct connection between the "A" section and "B" section ducts, however.

The main air distribution ducts shall be located above the car ceiling. The main air distribution ducts shall be sized so that air velocity does not exceed 1,200 ft/min (6.1 m/s) while meeting all other criteria of this Section. Thermal and acoustical insulation shall be applied on the outside of the ducts. The bottom of the duct shall be similarly constructed or the ceiling panels may serve as the duct bottom. In either case, its insulating value shall be sufficient to prevent the formation of condensation. The top of the ducts shall be insulated to a thermal resistance value of R-11 or greater, including the car body insulation. The sides of the distribution ducts shall be insulated to a thermal resistance value of R-4.5 or greater, as required to prevent the formation of condensation, and shall be provided with an approved vapor barrier or vapor barrier coating. Insulation spikes or other Sound Transit approved supplementary mechanical fastening method shall be used on vertical and inverted horizontal duct surfaces. Thermal breaks shall be used where ducts are fastened to the car structure. All insulation and adhesives shall be in accordance with the smoke, flammability, and toxicity requirements of Section 17.

The duct design shall ensure that the available static pressure is approximately equal along the entire length of the passenger area slot diffusers, and the discharge velocity meets the requirements of this Section.

### **7.8.2 Auxiliary and Cab Distribution Ducts**

Conditioned air shall be provided to the cab diffusers through rigid auxiliary distribution ducts. These ducts shall be constructed and insulated with the same materials and methods used for the main air ducts.

The auxiliary ducts shall connect to the main air duct sufficiently far downstream of the HVAC unit or transition duct to ensure that the main duct flow is fully developed. The design shall produce the minimum pressure drop possible.

### **7.8.3 Acoustic Insulation**

Acoustic insulation, which may be the same as thermal insulation, shall be provided to meet the interior noise requirements of Section 2.

### **7.8.4 Passenger Compartment Diffusers**

Air shall be discharged into the passenger compartment through two rows of continuous, flush, double slot-type air diffusers located in the ceiling. Diffusers may be separate from, or integrated with the light fixtures; however, the interior design shall be subject to Sound Transit review. (CDRL 7-6) The diffusers shall be designed to provide uniform distribution of air throughout the car. The diffusers shall extend longitudinally along the bottom of the supply air distribution duct. The diffusers may be blocked adjacent to the return air grilles to prevent short-circuiting of the airflow if the interior temperature uniformity requirements of this Section can be met with the diffusers so arranged.

Auxiliary diffusers shall be installed in the area below the HVAC unit as required to meet the temperature uniformity requirements of this Section.

The diffuser settings shall be determined on the climate room test car, and shall be designed for adjustment from within the passenger compartment without dropping panels or dismantling the diffusers, using a screwdriver or other commonly available tool for adjustment. All subsequent cars shall use the identical diffusers and shall be set to the identical positions as on the climate room test car.

The diffusers shall be designed to produce rapid mixing of conditioned and car air. The efficiency of the diffusers shall be such that the initial temperature differential is reduced by at least one-half at a distance of 6 in (150 mm) below the face of the diffusers. The maximum air velocity throughout the car interior, in the passenger area, shall not be greater than 100 ft/min (0.5 m/s) between 43 in (1,100 mm) and 67 in (1,700 mm) above the floor and shall not be greater than 70 ft/min (0.35 m/s) from the floor to 43 in (1,100 mm) above the floor. All exposed surfaces of the diffuser shall be of unpainted, satin-finish, anodized aluminum.

### **7.8.5 Cab Diffusers**

Air shall be discharged into the operating compartment through an adjustable diffuser which shall be subject to Sound Transit review. (CDRL 7-7) The Operator shall be able to manually control airflow to the cab from full flow to a minimum flow required and control the direction of air discharge.

Operator's cab diffusers shall not be subject to the 100 ft/m (0.5 m/s) velocity limitation. However, all interior noise requirements must be met with the cab diffuser set at any flow rate.

### **7.8.6 Return Air Grille**

Recirculated air shall be drawn in through a grille in the ceiling below the HVAC unit. The recirculated air grille shall be of sturdy and rattle-free construction and shall have a core and satin-finished frame of anodized aluminum, hinged on one side and provided with approved captive fasteners and two safety catches. The recirculated air grille shall be designed to pass the required quantity of air with sound levels such that the requirements of Section 2 are met anywhere 1 ft (300 mm) from the grille.

The grill design shall not allow a direct line of sight from the car interior to the mixed air plenum, and shall preclude small objects such as cigarettes entering the plenum.

The grille shall be fitted with a mechanically attached bulb-type seal or approved alternative seal to the car ducting. Flat foam strips will not be permitted. Balancing plates (if needed) shall utilize a fixed and flared orifice design, subject to Sound Transit approval. Balancing plates shall be located at the air leaving side of the return air grilles to promote even flow across the grille. Balancing plates shall be secured and sealed to the return air grilles through the use of no more than six captive fasteners and an approved gasket material.

### **7.8.7 Water Eliminators**

Water eliminating baffles or louvers shall be provided to prevent water that enters the fresh air intakes from being drawn into the unit. Eliminators shall be fabricated from stainless steel or anodized aluminum. Eliminators shall be easily removable for cleaning and servicing. Cleaning and servicing of the water eliminators shall not be required more often than once a year without any significant reduction in the system performance. Fresh air filters shall not be considered part of the water elimination design and shall not become wet.

### **7.9 Air Filters**

The fresh and mixed return and fresh air shall be filtered by disposable type, 2-in (50-mm) thick, pleated media filters of cardboard frame type, in a standard size which is commercially available from at least two suppliers. Face velocity shall not exceed the manufacturer's recommendation. Filters shall comply to the requirements of ASHRAE Standard 52.2, MERV 8.

The fresh and mixed filters shall allow 60 days of normal operation between required filter changes. The filters and filter holders shall be sealed at their edges to prevent filter by-pass. Support of the filter elements shall be provided to prevent blowout of the filter elements under clogged conditions. Both fresh and return air filters shall be readily accessible from inside the vehicle through the recirculated air opening. Air filters shall meet the requirements of UL 900 Class 2, and shall not ignite when exposed to a lit cigarette.

## **7.10 CFD Model and Analysis**

The HVAC system Preliminary Design Review transmittal shall include a Computational Fluid Dynamics (CFD) model and analysis of the cooling and air distribution system (CDRL 7-8). The model shall include accurate representations of the following at a minimum:

- All car body ductwork
- Diffusers
- Return air grills
- Exhaust grills
- Interior furnishings
- HVAC unit components in the fresh, return, mixed and conditioned air streams

All internal and external loads may be modeled as sensible heat sources only, and the evaporator coil may be modeled as a sensible heat sink.

The analysis results shall demonstrate that the proposed air distribution system is capable of meeting the diffuser discharge velocity, interior air velocity and temperature uniformity requirements of this Section. Should the analysis not show compliance to these requirements, the design of the air distribution system shall be modified, and the analysis repeated until conformance with Specification requirements can be demonstrated.

## **7.11 Unit Requirements**

### **7.11.1 General**

Each vehicle shall be provided with a heating, ventilating, and air cooling (HVAC) system to meet the requirements identified in the Specifications. The HVAC system, including all specified equipment and components, shall be supported by design and test data that demonstrate compliance with the Specifications.

Each vehicle shall have two HVAC units, one mounted in each “A” and “B” section of the carbody. The structure and enclosure of the unit shall be stainless steel meeting the requirements of Section 17. Units shall be identical and interchangeable between ends without the need to make any changes. If identification of unit location on a vehicle is required by the Contractor’s design, the HVAC control software, and jumpers in the carbody connection wiring shall accomplish this.

Equipment design and installation shall provide full accessibility for maintenance, troubleshooting, and repair without interference with other systems. Each unit shall be designed to minimize removal and replacement time. Each unit shall be provided with compression seals on air duct interfaces to facilitate replacement. Flat foam strips will not be permitted.

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The following components shall be a part of the unit and shall be accessible for servicing and replacement through a hinged grille which provides access to the return air plenum from the inside of the vehicle:

- Air filters
- All electric and pressure controls
- Contactors and circuit breakers
- Refrigerant gage ports
- Liquid line sight glass
- Return and fresh air thermostats
- Diagnostic test plug for the PTU described in Section 18; and
- System fault and status LEDs or LCD display

All other components shall be accessible for servicing and replacement through access panels on the roof-mounted units.

The air conditioning unit shall be designed such that from street or platform level it appears to be an integral part of the car body. This shall be achieved by either streamlining the unit contour itself or by using shrouds or a roof well. The HVAC equipment shall not be a part of the carbody structure. The Contractor and HVAC equipment manufacturer shall cooperate in the design of the equipment interface to the vehicle.

All electrical connections to the units shall be by means of quick disconnects, for each voltage level with the exception of the grounding strap, in accordance with Section 17.

The roof-mounted units shall be secured to the car structure using a maximum of eight threaded fasteners. The mounting system shall be such that the air conditioning unit shall be safely retained to the vehicle even in the event of failure of one or more fasteners. A ground strap shall be provided between the unit frame and the car body. The unit shall be furnished with Sound Transit-approved lifting provisions and shall be removable without disassembling refrigerant piping.

### **7.11.2 Ventilation**

Ventilation of the car shall be accomplished by the centrifugal fans supplied as part of each unit. The vehicle fresh air volume specified in the design criteria shall be provided at all times, regardless of the position of the car in the consist, and at any train speed. Ventilation shall be available at all times when the units are operating, including conditions when heating and/or air conditioning functions have failed. The ventilation system shall maintain a positive interior static pressure at all operating speeds in accordance with this Section.

Fresh air shall be drawn into each air conditioning unit through screened weather-protected openings on the unit, shall be filtered and then delivered to an integral mixing plenum. The

design shall preclude wind-driven rain or snow from accumulating and leaking into the HVAC Unit, and ultimately, the vehicle interior.

Recirculated air shall pass through the ceiling-mounted, hinged grille to the plenum where it shall mix with the filtered fresh air. The mixture of filtered fresh air and recirculated air shall then pass through a filter into the blowers or evaporator coil. Alternately, the fresh and return air may be filtered separately, then mix and pass through the evaporator coil. Mixing efficiency of fresh and return air shall ensure that the mixed air entering the coil is at a uniform temperature. Airflow velocity shall be uniform across the entire face of the filters and evaporator coils.

Perforated baffle plates, along with the fresh air adjustment baffles, shall be used to adjust the volumes of fresh and recirculated air. Baffle plate setting shall be initially determined as part of the CFD analysis, required by this Section, and verified as part of qualification test program described in Section 16. Baffle plates shall be located far enough upstream of the filters to allow airflow across the full face of the filters and over the thermostats. Alternate methods of air volume adjustment may be proposed. (CDRL 7-10) The exhaust of air shall be accomplished by the natural leakage from the car body around the doors.

The design and construction of the unit shall ensure that air streams enter the unit only at the intended locations, and air does not bypass the filters or coils.

#### **7.11.2.1 Motor-Blower Assembly**

Each blower motor shall be of a permanently lubricated roller bearing TENV or TEAO design. Each shall operate from the ac power supply described in Section 9. The motor's electrical connections shall include a terminal for a safety ground to electrically bond the fan motor frame to the HVAC unit structure. The motor shaft shall be stainless steel, to prevent corrosion.

Motors and blowers shall be easily removable for repair, cleaning, or replacement, either individually or as an assembly. Motors and blowers shall also be accessible for routine inspection and maintenance. Blower wheels shall be direct mounted and keyed to the motor shaft. Anti-seize compound shall be applied to prevent the blower wheels from seizing to the shaft. Routine blower assembly inspection shall not be required more often than once every 90 days.

Each motor-blower assembly shall be balanced in two correction planes, in-situ as defined in ANSI/AMCA 204. The residual unbalance shall limit the motor-blower assembly vibration to not more than 0.001 in (1 mil, or .025 mm) peak-to-peak displacement in any direction at the motor end bells when mounted in the unit. The motor-blower assembly shall be isolated such that motor and fan noise and vibration transmitted to the car structure shall be below the limits specified in Section 2. One motor shall be subject to a motor winding temperature rise test, prior to, or during the qualification testing. A flexible braided copper ground strap shall provide electrical grounding of the motor frame to the vehicle structure.

### **7.11.3 Unit-to-Car Body Transition Ducts**

The HVAC unit-to-car body interface shall be such that connection of the unit's air plenum to the car air ducts and plenums is automatic when the unit is installed on the car. The design shall preclude the entry of water, dust or other contaminants into the duct system.

Turning vanes, flow straighteners and sound attenuators shall be included as necessary to ensure that all other provisions of the Specifications are met.

### **7.11.4 Heating System**

#### **7.11.4.1 General**

The cars shall be electrically heated, using a combination of the overhead heat from the heater elements, supplied as part of the unitized HVAC system, and the floor level sidewall heaters evenly distributed throughout the car.

High temperature wire (150°C) and wire markers shall be used for interconnecting all heater elements, including low-voltage and high-voltage circuits.

#### **7.11.4.2 Overhead Heat**

Overhead heaters shall provide tempering for fresh air intake and reheat to maintain humidity control under partial cooling operation of the air conditioning apparatus. The heater coils shall be located downstream from the cooling coils, and shall have sufficient capacity to heat the total input of fresh air from 25°F (-4°C) to 67°F (19°C) at 208 Vac auxiliary power. The heater capacity shall be PWM controlled, as described in this Section, to provide the required heating capacity. The heater elements shall be of the low-thermal-inertia, open-coil, resistance-wire type with terminations and insulated supports, and shall be subject to Sound Transit review. (CDRL 7-11) Finned tubular heating elements may be proposed. (CDRL 7-12) Electrical connections directly to the heater elements shall be via approved crimp connectors and bolted connections using tinned, flexible copper cable of maximum 24 AWG strand size, having an approved wire insulation with a 150°C (or higher) UL continuous service certification, and as otherwise specified in Section 17. The heaters shall be powered from the 208 Vac three-phase auxiliary power supply (refer to Section 2).

The heater unit shall be designed to allow easy removal and replacement by means of a maximum of 10 captive fasteners. There shall be no exposed, uninsulated or unprotected high-voltage components, wiring or terminal connections in the heater area, except the heater element coils.

### **7.11.5 Cooling System**

#### **7.11.5.1 General**

The air conditioning system shall be capable of cooling and dehumidifying the car with direct-expansion, electromechanical vapor-cycle equipment using R-407C or other Sound Transit approved refrigerant listed in the U.S. EPA SNAP list for Motor Vehicle Air Conditioners for

Passenger Train end-use. (CDRL 7-9) The refrigerant shall have an ASHRAE Safety Rating of not less than A1. The Contractor shall provide the acceptable charging procedure for the system charged with the blended refrigerant.

Every pressure-containing component of the equipment, except piping, shall be listed as having been pressure tested and approved by a nationally-recognized testing laboratory. Alternatively, each component shall be designed, constructed, and assembled to have an ultimate strength sufficient to withstand five times the design working pressure. All such components shall be factory tested to at least 1.5 times the design working pressure for which it is rated.

The refrigerant system controls shall include an automatic pump-down cycle. Pump-down shall not be initiated if the system shut down is initiated by a protective safety device such as excessive pressure, temperature or current protective devices. Additionally, the controls shall include a start-up/pump-down sequence or approved alternative provision where the HVAC system performs a normal pump-down immediately after every requested start in a cooling mode if the system was OFF for predetermined time, as recommended by the manufacturer, regardless if a normal pump-down previously occurred.

Except for the pressure switches, the refrigerant system shall be non-field accessible. EPA-required system access ports shall be located on the low and high side of the system. All tubing shall be joined as specified in Section 17.

An airflow switch or evaporator blower motor current sensor shall initiate system pump-down upon reduction in airflow below a level where equipment damage may occur.

Refrigerant piping shall be sized in accordance with recommendations contained in ASHRAE Fundamentals.

### **7.11.5.2 Evaporator Section**

#### **7.11.5.2.1 Evaporator Coil Assembly**

The evaporator coil fin assembly shall be housed in a rigid stainless steel frame. The tubes shall be supported at each end, and in the center of the coil. The tube support sheets shall be constructed of stainless steel with die-formed support collars for each tube. The evaporator coil shall be of copper fin or coated aluminum fin construction and copper tube construction with nominal fin thickness of 0.008 in (0.2 mm) and with a maximum of 10 fins per in (2.5 mm minimum between the fins). The tubes shall be expanded to positively retain the fins in position.

The evaporator coil circuitry shall be split into two separate circuits, using an interlaced circuit arrangement, with each circuit being fed by its own liquid line solenoid valve and thermal expansion valve. The capacity of each circuit shall be determined by the HVAC system calculations in order to provide the most efficient operation during partial cooling and reheating modes.

The design of the evaporator area shall provide a space of not less than 3 in (75 mm) between the evaporator coil and the heater elements to enable the cleaning of the coil by either back blowing or washing. The unit's design shall also prevent any air by-pass through the drain pan or around

the heat exchangers of the evaporator and heater elements. The coil face area shall be sufficiently large to prevent condensate carryover into the fan plenum or main air duct, and to meet the requirements of the condensate carryover tests of Section 16. In any event, the average coil face velocity shall not exceed 450 ft/min (2.3 m/s).

#### **7.11.5.2.2 Condensate Drain System**

A condensate drain pan shall be provided beneath the evaporator coil, headers, thermal expansion valves, and coil "U"-bends in order to collect condensation. The drain pan shall be made of stainless steel, with stainless steel or copper-alloy fittings. The drain pan and fittings shall be baffled and arranged so that water does not spill over into the ceiling area under any operating conditions, including the worst case combination of track grade, curve superelevation, car acceleration (positive or negative) and car roll.

Condensate from the HVAC system shall be discharged into positively sloped drain lines leading to the underside of the car and shall not be routed through electrical or electronic cabinets. Horizontal sections of drain lines shall be sloped a minimum of ¼-in per ft of piping (2%). Discharge of condensate onto the car roof is not acceptable. An elastomeric flapper valve (“kazoo”) shall be attached to the drain line termination underneath the car, or at the unit’s condensate discharge point. The condensate drain lines, coil housing, and pan shall be insulated to prevent condensation formation.

Connection between the HVAC unit’s drain pan and the car body condensate drain lines shall be automatic, without the use of tools, when the HVAC unit is installed on the car. The entire condensate drain pan and tubes shall be easily accessible for cleaning from the top of the HVAC Unit with the unit’s covers removed.

#### **7.11.5.2.3 Other Evaporator Components**

Other components that shall be included as part of each evaporator portion are as follows:

- A liquid line solenoid valve for each circuit of the two-stage evaporator coils. The solenoid valves shall be of a compact design with pilot-operated disc construction. Solenoid valves shall have an operating differential rating of 300 lbf/in<sup>2</sup> (20.7 bar) minimum.
- Non-field adjustable balance-ported thermal expansion valves (TXVs) for each evaporator coil circuit. They shall have external equalizers, and field-replaceable working parts. The TXV diaphragms shall be flat (not corrugated), stainless steel. The TXVs shall be located to provide easy access for maintenance either through the return air plenum or through an exterior access panel in the HVAC Unit frame. The valves shall be spaced a reasonable distance from the coil out of the air stream and staggered to provide access for maintenance. System superheat shall be determined by the manufacturer based on the design parameters and is subject to Sound Transit review, but not less than 7°F (4 K).
- A liquid line sight glass and moisture indicator. The liquid line sight glass and moisture indicator shall be located in the return air plenum, and visible from the vehicle floor with the return air grille open. It shall allow observation of the refrigerant flow state.

In addition, the units used for qualification testing and the units on the vehicle climate-room test car shall have the following test fittings:

- Air pressure taps for measuring evaporator coil and mixed air filter pressure drop, either combined or alone. The pressure opening diameter in the side wall shall comply with ASHRAE Standard 51, Figure 2.
- Schrader®-type pressure tap fittings in each suction header adjacent to the expansion valve equalizer connections.
- Liquid line pressure tap fitting.
- Additional pressure tap fittings in the refrigerant circuit to allow all required test data to be collected.
- Provisions for thermocouples on the evaporator coil suction headers for measuring header temperature during low ambient cooling operation (to check for oil trapping inside the header).

### **7.11.5.3 Compressor/Condenser Section**

The compressor-condenser portion of the self-contained unit shall meet the following requirements.

#### **7.11.5.3.1 Refrigerant Compressor**

The refrigeration compressor(s) shall be of hermetic scroll compressor (or multiple compressors) sized to meet the requirements of the Specifications. The compressor motor shall be equipped with internal over-temperature protection, and shall be suitable for operation when supplied power by the ac power supply described in Section 9. The compressor body shall be fitted with a removable crankcase heater operating on low-voltage dc power.

Compressor capacity control shall be provided, sufficient to meet the temperature control requirements of the Specifications without causing excessive compressor on/off cycling. If a distributed auxiliary power system is used, capacity control shall be by means of variable compressor speed. Positive, quick-disconnect electrical connection to the compressor shall be provided to ensure proper rotation once the connection is made.

In either case, the compressor shall be resiliently mounted within the HVAC unit. A flexible copper strap shall be provided to electrically ground the compressor to the unit frame.

#### **7.11.5.3.2 Condenser Coil Assembly**

The condenser coil(s) shall be housed in a stainless steel frame with suitable fan shrouding and protective screening. The coil(s) shall be of a copper tube and copper fin or coated aluminum fin construction with minimal fin thickness of 0.008 in (0.2 mm). Maximum number of fins shall be 8 per in (3.125 mm minimum between the fins). The tubes shall be expanded to positively retain the fins in position. The tube support sheets shall be constructed of stainless steel with die-formed support collars for each tube. Where coil tubing connects to the inlet/outlet headers, the

tube support sheets shall include a provision to prevent chafing of the tubes against the end plates during expansion/contraction. A center tube support sheet shall be provided if the total tube length is greater than 36 in (915 mm). The coil shall utilize copper tubes of sufficient wall thickness to withstand system pressure. The coil "U" bends and external piping from the coil shall be protected by a stainless steel channel of sufficient strength to prevent any pipe damage by flying debris, if located outside the enclosure. The coils shall be designed to ensure that the air conditioning system can operate under extreme ambient conditions with full internal passenger loading without the risk of creating abnormal system pressures at air flow restricted at 15% to simulate dirty coil conditions.

The condenser coil design shall provide a minimum of 10°F (5.5 K) sub-cooling, measured at the expansion valve inlet at design load conditions, and shall provide sub-cooled liquid to the expansion valve inlet at all operating conditions.

The condenser coil shall be proof tested by the manufacturer at 1.5 times the maximum pressure or 600 lbf/in<sup>2</sup> gauge (41 bar) minimum, whichever is greater. As an alternative, the first coil may be burst tested to demonstrate a positive margin of safety and all other coils proof tested to the maximum operating pressure.

#### **7.11.5.3.3 Condenser Fan and Motor**

The condenser fan(s) shall be driven directly by three-phase motor(s), powered from the ac power supply described in Section 9. The motors shall be totally enclosed and rated for wash-down applications with permanently lubricated rolling element bearings and have sufficient capacity to drive the condenser fan under all load conditions. The motor's electrical connections shall include a terminal for a safety ground to electrically bond the condenser fan motor frame to the HVAC unit structure. The safety ground shall run in the same conduit as the power leads. Designs which utilize a motor with its shaft oriented vertically up shall require the application of a slinger on the motor shaft to prevent moisture penetration to the inside of the motor.

The fan(s) shall be a multi-blade axial fan(s) and the blades shall have airfoil profiles or approved equal to ensure optimum fan efficiency and minimum noise generation. Connection of the fan hub to the motor shaft shall be approved by Sound Transit. To facilitate removal of the condenser fan, the condenser fan motor shaft shall be of a corrosion-resistant material, or it shall be treated to prevent corrosion and seizing of the fan hub on the shaft. The condenser section design shall result in the discharge of condenser air vertically upwards.

Each condenser fan assembly shall be balanced in two correction planes, in-situ as defined in ANSI/AMCA 204. The residual unbalance shall limit the motor-blower assembly vibration to not more than 0.002 in (0.050 mm) peak-to-peak displacement in any direction at the motor end bells when mounted in the unit.

#### **7.11.5.3.4 Other Condensing Section Components**

The following shall be provided:

- A filter-drier assembly in the liquid line.

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- A discharge line check valve.
- A fusible plug to protect the refrigeration system against explosion, installed in the system as recommended by UL 1995.
- Service valve and sight glass caps, safety chained to the unit to retain them with the valve or sight glass when removed.
- Vibration eliminators with the compressor discharge line and suction line, installed in an approved manner. The vibration eliminators shall be provided with neoprene covering over the flexible bronze wire braid to provide resistance to abrasion and prevent condensation from freezing behind the ferrules.

Sound Transit strongly prefers a design without a refrigerant receiver. A receiver will not be considered without sound technical justification as to why a receiver-less design meeting the requirements of this Specification cannot be provided. If a receiver is allowed, then it shall not include liquid level sight glasses.

If a receiver is allowed, a separate sub-cooler must be provided, providing the sub-cooling performance listed in this Section.

### **7.11.5.4 Refrigeration Control Compartment**

The refrigeration control compartment shall be accessible from the return air plenum with the unit installed on the car. It shall also be accessible from the top with the unit removed from the car. The refrigeration control compartment shall contain the controls listed in this Section.

### **7.11.5.5 Electrical Compartment**

The electrical compartment shall be an integral part of the unit. It shall be accessible for system servicing through the return air grille.

The electrical control compartment shall contain the following components, except as noted:

- Relays, contactors, solid-state power controllers and individual component isolation circuit breakers
- Electrical controls
- Diagnostic test plug for attachment of the PTU described in Section 18
- Power and control wire terminals
- Control power switch
- Static temperature control unit
- Fault and status indication panel

### **7.11.6 Insulation**

The HVAC unit shall be insulated to reduce conductive heat transfer from the exterior to the return and supply airstreams as required in this Section. All insulation material shall be mold/fungi resistant. Insulation shall be mechanically retained in addition to adhesive. Insulation shall not be used as a sealing gasket between parts. All piping insulation corners shall be mitered and sealed with a sealant recommended by the manufacturer of the insulation.

Refrigerant suction lines shall be wrapped with a fire-retardant closed cell foam insulation. All insulation and adhesives shall meet flammability, toxicity and smoke emission requirements of Section 17.

### **7.12 Evacuation-Dehydration**

The HVAC equipment manufacturer shall pressure test and then evacuate and dehydrate the system to 50 microns pressure, or less. This vacuum must be maintained for a minimum of two hours with the vacuum pump running. After two hours, the vacuum pump shall be isolated from the system. The system pressure shall not rise above 300 microns in a two-hour period after vacuum pump isolation.

### **7.13 Refrigerant Charge Determination**

The refrigerant charge weight shall be determined during the equipment qualification test. The refrigerant type and refrigerant charge established at this test shall be included on the unit nameplate.

### **7.14 Refrigerant Sampling**

The Contractor shall incorporate a refrigerant sampling program as part of the production process for all HVAC units. The program shall include testing of refrigerant from a system after the functional routine test following the criteria under ARI Standard 700, but considering that the sample is being taken from a completed unit. In that regard, the acceptable water content is not higher than 30 ppm by weight, and high boiling residue up to 5% may be permitted. All other criteria shall apply. The testing program shall be submitted. Any discrepancies in the testing results shall be analyzed and appropriate adjustments shall be made to the cleaning procedure to ensure that the HVAC units meet quality standards of the OEM, Contractor and Sound Transit. As part of its Quality Assurance program, Sound Transit may conduct periodic audits of these sampling results during the production cycle. The Contractor shall immediately address any discrepancies with appropriate action.

### **7.15 Portable Test Units**

Portable Test Units (PTU) for the HVAC system shall be provided as specified in Section 18. The PTUs will be used by maintenance personnel to isolate refrigeration circuit problems and temperature control problems in the static circuitry by function and system, load new software (password protected), and monitor the status of the system as it functions. The PTUs shall be able to override the automatic heating and cooling control system such that any possible operational mode can be selected, unless doing so will result in equipment damage, in which

case the PTU shall display a message that the requested mode cannot be implemented at this time. The PTU shall also provide the ability to individually control each powered device in the system, however, doing so shall not allow safety functions to be overridden. The PTU shall indicate and verify the function status of all HVAC control devices.

## **7.16 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 7-1 Means of suppressing arc when fusible link ruptures (Section 7.3.2.2)
- 7-2 Alternative methods of ground fault detection and protection (Section 7.3.2.3)
- 7-3 Layover heat thermostat locations (Section 7.3.2.4)
- 7-4 Power source report for each protective heater (Section 7.7)
- 7-5 Alternative material for air ducts (Section 7.8.1)
- 7-6 Passenger compartment diffuser (as part of overall interior design) (Section 7.8.4)
- 7-7 Cab diffuser design (Section 7.8.5)
- 7-8 CFD model and analysis report (Section 7.10)
- 7-9 Selection of refrigerant (Section 7.11.5.1)
- 7-10 Alternative methods of air volume adjustment (Section 7.11.2)
- 7-11 Heater element design (Section 7.11.4.2)
- 7-12 Finned heater alternative (Section 7.11.4.2)

## **7.17 Cited References**

The following standards or references were cited in this Section at the referenced location:

- |                    |  |
|--------------------|--|
| ANSI/AMCA 204      | Balance Quality and Vibration Levels for Fans (Sections 7.11.2.1, 7.11.5.3.3)                              |
| ARI Standard 700   | Specifications for Fluorocarbon Refrigerants (Section 7.14)  |
| ASHRAE             | ASHRAE Fundamentals (Section 7.11.5.1)   |
| ASHRAE Standard 15 | Safety Standard for Refrigeration Systems and Designation and Classification of Refrigerants (Section 7.1) |

*Heating, Ventilating, and Air Conditioning*

ASHRAE Standard 51	Laboratory Methods of Testing Fans for Aerodynamic Performance Rating (Section 7.11.5.2.3)
ASHRAE Standard 52.2	Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size (Section 7.9)
ASHRAE Standard 55	Thermal Environmental Conditions for Human Occupancy (Section 7.2.1)
NFPA 70	National Electrical Code (Section 7.1)
NFPA 130	Standard for Fixed Guideway Transit and Passenger Rail Systems (Section 7.1)
SAE J902	Passenger Car Windshield Demisting and Defrosting Systems (Section 7.6)
SAE J953	Passenger Car Backlight Defogging System (Section 7.6)
UL 900	Air Filter Units (Section 7.9)
UL 1995	Heating and Cooling Equipment (Sections 7.1, 7.11.5.3.4)

**END OF SECTION 7**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 8  
LIGHTING**

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## **SECTION 8: LIGHTING**

### **8.1 General Description**

The vehicle lighting systems shall be designed to withstand the vibration and shock loads, seasonal design conditions, applicable voltage ranges, and environmental conditions typical of the rail transit environment in the Seattle area as described in Section 2.

All light sources shall be LED lamps, including console indicators where practicable.

LED rated life for indicator applications, such as on the console, shall be no less than 100,000 hours. LED rated life for illumination applications shall be no less than 50,000 hours.

All lighting fixtures shall provide ease of lamp replacement, cleaning, and maintenance. Except for permanently sealed light fixtures, lamp access shall be by gasketed enclosure covers secured by captive, stainless steel fasteners. Where possible, covers shall be retained by hinges. Hinges located on the vehicle exterior shall be made from stainless steel.

Fixtures installed on the vehicle exterior and in the interior within 2 ft (610 mm) of a doorway shall be watertight except for interior ceiling lights. All fixtures shall be dustproof to minimize the accumulation of airborne dirt and dust within the fixture.

Unless specified otherwise, all lighting shall operate directly from the LVPS source, over the voltage range indicated in Section 2. All power conversion and transient protection shall be integral to the lamp or lamp fixture.

All lamps shall be provided with standard dimensions and electrical connections.

All lamp circuits shall be electrically isolated from the fixture and the car structure. All metallic fixtures and exposed metallic surfaces shall be grounded to the vehicle structure as described in Section 9.

Within 180 days after NTP the Contractor shall submit a design report that lists and describes all light fixtures, assemblies, and lamps for Sound Transit review and approval. The report shall include illuminating characteristics, beam spread, and intensity for all lamps and assemblies to confirm compliance with the requirements of this Section, including confirmation of compliance with cited SAE standards. The report shall include a sample of each light, and connector used for interior and exterior lighting. (CDRL 8-1)

### **8.2 Interior Lighting**

All interior lamps shall be free from glare, and shall be provided with frosted-type diffusers such that the individual LEDs in the lamp are not discernible, while providing specified lighting levels and color rendition.

## *Lighting*

### **8.2.1 Overhead Lights**

The average illumination within the car at an elevation of 33 to 66 in (840 to 1680 mm) above the floor shall be at least 30 footcandles (320 lux) at rated voltage.

The average light intensity at the floor in the passenger aisles and articulation section shall not be less than 20 footcandles (215 lux).

The average light intensity at the car entrances and exits within 20 in (500 mm) of the doors shall not be less than 20 footcandles (215 lux) at the floor.

#### **8.2.1.1 Passenger Compartment Overhead Lighting Fixtures**

The passenger section shall be illuminated by two continuous rows of lighting fixtures mounted in the ceiling above the seats.

The light fixtures shall be dust and moisture proof and may be combined with the air diffusers. All exposed metallic portions of the fixtures shall be anodized aluminum or etched finish. All visible portions shall have a brush or etched finish. The reflector shall be painted glossy white or a polished semi specular aluminum finish on the inside of the fixture.

The Correlated Color Temperature (CCT) of the installed fixtures shall be adjusted to mimic the warm white color of fluorescent tube lighting (2700-3000 K). The nominal CCT of the fixtures shall be per ANSI C78.377, Table 1, Nominal CCT Categories.

Each fixture shall include a lens contained in a door with an integral, concealed hinge. The lens shall be manufactured from transparent polycarbonate, with a smooth exposed surface and patterned back surface designed to achieve specified illumination levels and even distribution of light. The lens mounting shall preclude the lens from being pushed into the fixture housing by passengers and shall prevent the lens from vibrating under all operating conditions.

The lens door shall be secured in the closed position with tamper-proof fasteners. The fasteners shall be stainless steel, captive, and of the quarter-turn type, as specified in Section 17. Lens material shall meet the flammability and smoke emission guidelines of Section 17.

#### **8.2.1.2 Fixture LED Drivers**

The light fixture lamp assemblies shall include high efficiency dc/dc LED driver modules, integrated into the lamp fixture unless otherwise approved. The modules shall include transient protection as specified in Section 2, and shall include reverse polarity protection.

Provisions to dim the lamps in each fixture shall be provided, using modulation techniques appropriate for LED dimming and as recommended by the LED lamp supplier. Implementation of dimming features shall be determined by Sound Transit at a later date.

The driver modules shall be located for accessibility, and easy repair and replacement. Connectors meeting the requirements of Section 17 may be used to satisfy this requirement.

## *Lighting*

Overhead LED power supplies shall have the ability to withstand the input voltage fluctuations inherent in this type of service, including the most severe transients. Power supply surge protection shall comply with the recommended practices and testing in IEEE C62.41.1, C62.41.2, and C62.45 as applicable to the transit environment. The power supplies shall operate at a frequency above the audible spectrum, but no less than 25 kHz, shall have electrical noise suppression to meet the EMI requirements of Section 2, and shall operate LEDs with no flicker. Power supplies shall be solid-state electronic type with efficiency greater than 90% and shall meet Federal requirements for EMI/RFI (47 CFR 15 and 18). The power supplies shall be protected with individual fuses.

Power supplies shall be provided with the following design features:

- Input surge protection
- Reverse polarity protection
- Over temperature protection
- Under/over voltage protection
- MTBF greater than 500,000 hours
- No audible noise

### **8.2.1.3 Interior Lighting Control**

The main interior lighting shall be turned on whenever the car auxiliaries are turned on by the Master Controller Key Switch or the Auxiliaries Switch (refer to Section 5). The interior lighting system shall be separated into three separate circuits with approximately equal lamp distribution, with alternating sets of lights powered by the separate circuits. The emergency lights shall occupy one circuit while the remaining interior lights shall be divided into two other circuits. Each circuit shall be fed through a separate circuit breaker. The lighting circuits shall remain on when LVPS output is momentarily lost, such as when the car is going through a non-bridging isolator. If LVPS output is lost for an extended period, only the emergency lights shall remain on. Refer to Section 9 for emergency power requirements.

### **8.2.2 Doorway Floor Lights**

If necessary to provide the specified illumination, lights shall be provided at each doorway for threshold and platform illumination. The lamps shall provide not less than 2 footcandles (22 lux) of illumination measured on the surface of the platform from the car side to 3 ft (915 mm) away from the vehicle side in the horizontal direction.

The light shall be illuminated when the passenger door starts to open and shall be extinguished when the door is closed and locked.

The doorway floor lights may be deleted if the passenger section overhead lights provide the illumination levels specified for the doorway floor lights.

## *Lighting*

### **8.2.3 Operator's Cab Light**

Each cab shall be provided with lamp fixtures powered from the LVPS. The fixtures shall be suitably placed in the ceiling to illuminate the cab area, but not cause glare on the console surfaces or windshield. The average illumination measured at an elevation of 33 in (840 mm) above the floor shall be at least 20 footcandles (215 lux) at rated voltage.

The cab light shall be controlled from the Cab Light switch on the Operator's console that shall function at all times that the car auxiliaries are turned on. (Refer to Section 5).

### **8.2.4 Console Light**

The cab console surface shall be illuminated to enable the Operator to see the console labels, pushbuttons and switches under varying lighting conditions.

Alternative lighting arrangements that meet the requirements of this Section will be considered and approved by Sound Transit.

The console light shall be mounted at the top edge of the console and shielded from the Operator's eyes. When illuminated, the console light shall not cause glare on the windshield.

The console light shall be energized automatically when the cab is keyed on. A dimmer control, appropriate for LEDs, shall be provided for variable adjustment of the brightness. At all other times, the light shall be extinguished.

### **8.2.5 Door Closing Warning Light**

Amber lights shall be provided on each side of each doorway to indicate that a door will be closing. Refer to Section 6 for location and functional requirements.

## **8.3 Exterior Lighting**

Exterior lighting assemblies shall be set in waterproof fixtures. All bezels and trim, if provided, shall be made of stainless steel with captive stainless steel fasteners.

Lights at the coupled ends of vehicles in a train shall not illuminate, except for the marker lights, railway headlight, and destination sign lights. The Railway Headlight operating logic is described in the Railway Headlight section, below.

Headlights, secondary lights, taillights, stop lights, and marker lights shall conform to requirements in 49 CFR 571.108 for vehicles of 80 in (2030 mm) or more overall width.

### **8.3.1 Headlights**

Two LED headlights shall be provided on each end of the vehicle.

The headlights shall be adjustable to permit proper aiming of the beams.

## *Lighting*

### **8.3.1.1 Secondary Lights**

Two LED secondary lights shall be provided on each end of the vehicle if the coupler hood configuration is such that, in its open position, it obstructs the illumination from the headlights. The secondary lights shall be adjustable to permit proper aiming of the beams. The secondary lights shall be housed in enclosures suitable for exterior and underfloor mounting, as applicable.

### **8.3.2 Railway Headlight**

One 200,000 candela LED railway-type headlight shall be mounted centered above the destination sign at each end of the vehicle. The lamp assembly shall be set in an adjustable bezel that is recessed into the front of the vehicle.

The railway headlight shall be dimmable. The dim setting brightness shall be as determined by Sound Transit.

The Operator's console shall include a four-position switch (refer to Section 5) to control the railway headlight at that end of the vehicle. The four positions are as follows:

- Bright
- Off
- Dim
- Emergency

When Emergency position is selected in any cab, all Railway headlights in the consist shall illuminate in bright mode.

The railway lamp shall be aimed to illuminate a person standing in the center of the track at a distance of 800 ft (244 m) in front of the vehicle, at the bright setting.

### **8.3.3 Tail Lights and Stop Lights**

Two red taillights meeting the requirements of SAE J2040 shall be provided at each end of each vehicle.

When illuminated, the tail lights shall be plainly visible from a distance of not less than 500 ft (152 m) during daylight, bright sunny conditions.

Two red stop lights meeting the requirements of 49 CFR 571.108 shall also be provided per end. They shall be part of the tail light assemblies. The stop lights shall be illuminated on the trailing end of a train, as determined by the forward and reverse directional trainlines, when the train is powered with the reverser switch in FORWARD or REVERSE, and the dynamic, friction, track, or parking brakes are applied.

Lamps shall be replaceable from the outside of the vehicle.

## *Lighting*

### **8.3.4 Marker Lights**

One amber and one red marker light meeting the requirements of SAE J2042 shall be provided near each upper end corner of the vehicle (eight per vehicle). When illuminated, each marker light shall be plainly visible from a distance of not less than 500 ft (152 m).

### **8.3.5 Door Open Indicator Light**

An amber light shall be provided above each doorway to indicate that the door is open or unlocked. The indicator assemblies shall be shielded from sunlight and aimed toward the front and back so that they are visible from all cabs in the train. Refer to Section 6.

### **8.3.6 Door Out-of-Service Illuminated Indicator**

A red illuminated sign shall be provided at each doorway to indicate that the door is out of service. Refer to Section 6 for detailed requirements.

### **8.3.7 Hazard Indicators**

Two amber light assemblies shall be provided at each end of the car mounted near the stop lights and one amber cluster light assembly shall be located on each side of each A and B body section above the power truck to function as hazard indicators.

The flashing hazard indicators shall be synchronized throughout the consist.

## **8.4 Emergency Lighting**

The following lights shall be powered directly from the battery, and shall remain on or available after the loss of low-voltage output from the LVPS:

- One main overhead light in each doorway;
- All of the doorway floor lights;
- One main overhead light to illuminate each stairway;
- Operating cab console and lights;
- Headlights;
- Railway light;
- All of the tail lights, stop lights; and
- All exterior marker and indicator lights.

## **8.5 U.S. Fixtures**

All lighting fixtures and lamps shall either be of U.S. manufacture or shall be identical to standard U.S. hardware currently available from U.S. manufacturers.

## *Lighting*

### **8.6 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

8-1 Lighting design report (Section 8.1)

### **8.7 Cited References**

ANSI C78.377	American National Standard for Electric Lamps: Specifications for the Chromaticity of Solid State Lighting (SSL) Products (Section 8.2.1.1)
IEEE C62.41.1	IEEE Guide on the Surge Environment in Low-Voltage (1000 V and less) AC Power Circuits (Section 8.2.1.2)
IEEE C62.41.2	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits (Section 8.2.1.2)
IEEE C62.45	IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and less) AC Power Circuits (Section 8.2.1.2)
SAE J2040	Tail Lamps (Rear Position Lamps) for Use on Motor Vehicles 2032 mm or More in Overall Width (Section 8.3.3)
SAE J2042	Sidemarkers Lamps for Use on Motor Vehicles 2032 mm or More in Overall Width (Section 8.3.4)
47 CFR 15	Radio Frequency Devices (Section 8.2.1.2)
47 CFR 18	Industrial, Scientific, and Medical Equipment (Section 8.2.1.2)
49 CFR 571.108	Federal Motor Vehicle Safety Standard No. 108, Lamps, Reflective Devices, and Associated Equipment (Sections 8.3, 8.3.3)

**END OF SECTION 8**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 9  
GENERAL ELECTRICAL EQUIPMENT**

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## **SECTION 9: GENERAL ELECTRICAL EQUIPMENT**

### **9.1 General**

This Section specifies general vehicle electrical requirements. Included are the overhead power collection system, power distribution, grounding, ac and dc supplies, data communication system, required discreet trainlines, monitoring and diagnostics, and similar equipment and systems.

Other electrical requirements, including switch and breaker panel requirements, appear in Section 17. Propulsion equipment is described in Section 10. Cab controls are described in Section 5. See other sections for specific electrical requirements.

Refer to Section 17 for smoke, flammability, and toxicity requirements.

The Contractor shall submit 90 days after NTP dedicated single-line power distribution diagrams for primary, ac and dc loads. (CDRL 9-1) The diagrams shall show loads, return current paths, protections and grounds.

The Contractor shall submit the load analyses for the ac and dc systems as part of the preliminary and final design submittals. (CDRL 9-2)

#### **9.1.1 General Configuration and Isolation**

The term "auxiliary" used in this Section refers to the vehicle-sourced electrical power distribution system and supplies. The term "primary" used in this Section refers to high-voltage dc circuits.

All electric equipment, wiring, connections, and other devices shall be selected to function properly and safely under the worst case combination of ambient conditions, equipment operating tolerances, train length, and voltage drop on wiring, connections, and the coupler.

The vehicle electrical circuits shall be physically and functionally segregated according to voltage. Refer to Section 17 for a list of circuits that require segregation, and for circuit separation requirements. Where circuits of different voltages must function together, prevent interaction by component location and as specified in Section 17.

No high-voltage dc wiring shall be run within the passenger area, except as specified elsewhere or as specifically authorized by Sound Transit. Where authorized, such wiring shall be run in grounded steel conduit.

#### **9.1.2 Safety Grounding**

All equipment on the vehicle, including resiliently mounted equipment, enclosures, the truck frame, and truck-mounted equipment, shall be safety grounded to the vehicle structure. The vehicle structure shall be safety grounded to the axles. Specific requirements appear later in this Section.

## *General Electrical Equipment*

The Contractor shall submit a complete grounding scheme to Sound Transit. (CDRL 9-3)

### **9.1.3 Circuit Protection**

AC circuits and low-voltage dc circuits shall be protected by circuit breakers as specified in Section 17. Low-voltage dc circuit breakers shall be mounted in panels in the operator's cab. AC circuit breakers shall be mounted separately in an equipment locker.

High-voltage dc circuits shall be protected at the pantograph interface level by high speed dc rated circuit breakers or fuses. Primary distribution circuits in the vehicle shall be individually protected by high-voltage dc rated fuses mounted in insulated self-extracting fuse holders.

Local circuit protection shall be coordinated with main source protection as specified in Section 17.

All equipment operated from the Overhead Contact System (OCS) shall be rated for continuous operation at the maximum OCS voltage, as described in Section 2. All such equipment shall be protected against transient voltage spikes as may occur on the Sound Transit OCS.

Reference Section 17 for circuit breaker and fuse requirements.

### **9.1.4 Return Circuits**

The vehicle structure shall not be used as a normal circuit return path for any electrical equipment.

The primary return circuits shall be grounded to the axles per the requirements of this Section.

The low-voltage dc return circuits shall not be grounded to the vehicle structure at any location, except at a single point common to the battery and LVPS. See Low-Voltage Grounding, below. The ground connection type shall be designed in coordination with EMC requirements.

A common LVPS return bus shall be provided and distributed along the vehicle, sized to carry all low-voltage circuit loads, and terminated in low-voltage distribution circuit breaker panels. Access to the return bus shall be provided via terminal blocks in electric lockers and dedicated junction boxes. Each low-voltage circuit shall have its own return wire, connected either to the nearest return bus connection point, or to the electric locker containing its circuit breaker.

The ac neutral shall be grounded to the car structure at a single point.

Refer also to Section 17.

### **9.1.5 Wiring**

Wiring shall be sized in accordance with Section 17. Minimum wire sizes are shown in Section 17.

### **9.1.6 Equipment Connections**

All control wiring connections to replaceable equipment shall be via multi-pin connectors mounted on the enclosure.

### **9.1.7 Articulation Connections**

Flexible hoses, wiring and cabling routed across the articulation unit shall be run in ducting with non-conductive inserts. Cables may be run on either side of the articulation section or on the centerline, but the routing shall minimize excess length and unnecessary flexing. In whatever route selected, the cables shall have sufficient length and support to permit full motion of the articulation without chafing or excessive stress to the cables.

All primary power wiring shall be run on the roof. Low-voltage wiring may be run below or above the floor line but not on the roof.

Disconnects shall be provided for both primary and low-voltage circuits on both sides of each articulation. Low-voltage disconnects shall be multi-pin connectors. Primary disconnects shall be by bolted terminal connection.

### **9.1.8 Vehicle-to-Truck Wiring**

For each wiring system on a truck, the Contractor shall provide flexible cable connecting the vehicle and truck, with waterproof quick disconnect cable connectors as specified in Section 17 to facilitate removal of trucks, and with other requirements as noted below:

- Route cable to accommodate all truck motions without interference or excess strain.
- Provide cable with strain relief on both the vehicle end and the truck end.
- Flexible cable construction shall be selected for 30 year life under repeated flexing caused by truck motions.
- Connectors shall be selected for the shock and vibration environment.
- Cabling to connectors on the truck side shall be restrained to prevent fatigue and chafing to the wiring or connectors.
- Wire lengths, supports, and dress shall minimize strain at termination and support points under worst-case truck motions.

See Section 10 for additional requirements related to connection to traction motors.

### **9.1.9 Transient Protection**

All vehicle equipment shall be protected against transients, whether originating internal or external to the vehicle. All vehicle equipment capable of generating transients shall have transient suppression devices. Also refer to Sections 2, 10, and 17. Situations where transient suppression cannot be applied, or must be minimized due to performance considerations, shall be submitted as part of that system's design review package.

## **9.2 Primary Power System**

### **9.2.1 Pantograph**

A single pantograph shall be located on the roof of the vehicle, as described in Section 2. The pantograph shall incorporate the following salient features:

- The pantograph shall be a service-proven, single-arm design, with a spring supported contact head assembly, including two carbon assemblies (shoe devices); capable of stable bi-directional operation at all specified vehicle speeds and external system characteristics, including in-tunnel operation at specified track speeds (aerodynamic considerations). The design shall comply with IEC 60494-2 and IEC 61133 requirements.
- The shoe device shall contain a replaceable curved carbon insert of one to four segments and an aluminum horn at each end. The shoe assembly shall include provisions to adjust the shoe so that the entire width of the shoe contacts the contact wire. The shoe device and insert shall be replaceable with common hand tools.
- Each shoe device on the shoe assembly shall be independently spring-mounted on each end of the shoe device. The shoe devices shall be capable of vertical movement on one side without affecting either the other side of the shoe device or the other shoe device. The range of vertical movement shall not exceed 1 in (25 mm).
- The shoe assembly shall rotate about a lateral axis, be spring-mounted with dampers to the upper arms of the pantograph, and shall provide stable tracking of the contact wire at all speeds. Robust means to limit rotation shall be provided. The suspension shall decouple the shoe assembly from the pantograph arms, allowing the suspension to absorb small variations in contact wire height and slope and prevent the pantograph arms from responding to small rapid wire height variations.
- Each carbon strip assembly shall be individually adjustable to permit the strips to be set in the same plane to provide for continuous contact with the overhead wire.
- Shoe force on the contact wire shall be selected for optimum tracking and minimum wear and shall initially be set to the value specified in the Pantograph Dimensions section of Section 2. Shoe force shall be adjustable over the range specified in Section 2 and shall not vary by more than 5 lbf (22 N) over the combined full ranges of operating height, vehicle speed, and direction.
- A lateral load of 65 lbf (290 N) on the pantograph shoe axis with the pantograph at maximum operating height shall cause the shoe to deflect no more than 1.5 in (38 mm).
- Carbons shall be heated. Associated fuses and switchgear shall be provided to permit the heaters to be operated from high-voltage dc power from the pantograph.
- The pantograph carbon heaters shall be independent of the pantograph carbons to allow for ease of heater-only replacement.
- The pantograph heaters shall be thermostatically controlled.

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- Four ice scrapers shall be provided that fit directly in place of normal shoe devices.
- Bearings shall be sealed anti-friction ball bearings.
- Tinned copper braided wire shunts shall be used to bypass all movable joints and bearings.
- A shear pin safety system shall be provided to minimize pantograph and OCS damage caused by hard contact between some part of the pantograph and an overhead obstruction. Impact shall cause the pin to shear, causing the pantograph to drop to its lowered position.
- The pantograph shall be lowered electrically. When commanded to lower, the lowering mechanism shall provide a rapid initial motion away from the contact wire to reduce arcing. A reduction in lowering speed shall be provided prior to latching.
- The pantograph shall be spring raised when the restraining mechanisms are released. The raising speed may be damped or otherwise controlled if needed to prevent carbon strip damage upon striking the contact wire. If provided, this speed control shall be active at all times except during normal wire tracking. If needed to optimize tracking, damping may be provided for downward motion of the pantograph arms.
- The pantograph raising and lowering circuit shall be trainlined and shall be operable from any cab in a consist, while the train is at rest or moving, provided the train auxiliaries are ON. A lowering of the pantograph shall not affect a requested brake rate and shall result in a coast mode if coast or power mode is requested. Electric raising and lowering mechanisms shall operate throughout the voltage range specified in Section 2 for all low-voltage equipment.
- Provision shall be made for manual raising, lowering and unlatching the pantograph in the event of a loss of power or control. These manual mechanisms shall be operable from and stored within the vehicle, but shall be accessible only to the operator.
- The pantograph latch mechanism shall not engage when the pantograph is pushed or bounces down; it shall function only when the pantograph is deliberately lowered by the electrical or manual mechanism.

The Contractor shall prepare a design report on the pantograph, including data to support the ratings of the components, data sheets on each component, parts lists, electrical drawings, dynamic envelope and assembly drawings. (CDRL 9-4)

### **9.2.2 Primary Circuit Protection**

Adequately rated overvoltage protection, current sensing, ground fault sensing, fault clearing devices, and any other circuit protection deemed necessary by the Contractor shall be provided to protect all primary supplied devices including propulsion system components from fault or overcurrent damage, and ground faults.

Fault clearing devices shall be shielded to prevent damage to adjacent equipment or vehicle structure. Adequate measures shall be taken against plasma build-up in the enclosures that house

fault clearing devices. If necessary for plasma build-up reduction, the enclosures where fault clearing devices are mounted may be connected to the atmosphere via screened and filtered openings. Any filter elements used for this purpose shall be designed to preclude snow and water ingestion into the enclosure, and shall have a replacement interval in excess of two years. Direct venting of the arc chutes to the atmosphere is prohibited.

### **9.2.2.1 Lightning Arrestor**

A dry-type lightning arrestor shall be mounted on the roof, on or adjacent to the pantograph base. The arrestor shall be rated, by the manufacturer, for outdoor dc operation.

The lightning arrestor shall be coordinated with individual equipment protection such that this arrestor provides the primary overvoltage protection for the vehicle. The arrestor rating shall be selected to prevent voltage transients and surges from damaging or degrading carborne equipment, including the arrestor itself. An arrestor rating selection analysis shall be submitted. (CDRL 9-5)

### **9.2.2.2 High Speed Circuit Breaker**

A roof-mounted, High Speed Circuit Breaker (HSCB) shall be provided to protect the propulsion primary power circuits. A separate high speed fuse or HSCB shall be used to protect the auxiliary primary power circuits. The HSCB shall be operated by the low-voltage power supply.

The HSCB shall have the following features: remote trip and reset, trip opening in 10 ms or less, complete arc extinguishment, and fault interruption in less than 50 ms. The HSCB trip values and ratings shall be coordinated with the traction electrification system supplier such that the HSCB will clear all vehicle system fault currents without nuisance trips of the wayside breakers.

The Auxiliary HSCB (AHSCB), if used, shall not require special action for vehicle startup, with automatic restart of vehicle auxiliary circuits when primary power is restored, including during low battery voltage situations. Means shall be provided to permit resetting the AHSCB when the battery is discharged below the AHSCB pick-up voltage.

The HSCB automatic reset logic shall be coordinated between the two propulsion systems, and any other systems that are fed by this device, in order to maximize vehicle availability and enhance performance and operation capabilities. In addition, the HSCB shall be capable of being reset electrically on a local basis, by means of the HSCB reset button on the local indicator panel (refer to Section 5). The number of electrical resets shall be limited to three within any 15 min period, after which resetting via the Portable Test Unit or MDS maintenance screen shall be required.

Annunciation of a tripped or open HSCB shall be provided on both a local and trainlined basis. Refer to the Fault Annunciation section, below.

The Contractor shall submit a design report on the HSCB and associated components, including data to support the proposed coordination logic between the two propulsion systems on the LRV and the HSCB, the ratings of the components, data sheets on each component, parts lists, electrical drawings and assembly drawings. (CDRL 9-6)

### **9.2.2.3 Shop Power Connection**

Provide a connector and related circuitry to allow connection of 208 Vac power to the vehicle from the shop system. The connector shall mate with the existing shop connector, and include the interlock pins and wiring to prevent connections or disconnections with an energized cable.

With shop power connected to the vehicle, all ac and low-voltage dc vehicle circuits shall be powered and function normally, including the LVPS(s) and battery charging.

The vehicle connector shall be located such that the shop connector and cable have minimum strain when connected, and the cable does not drape over other equipment.

Provide one shop-side mating connector for each vehicle in this contract, plus 10% spares or 10 connectors whichever is greater.

The vehicle mounted shop power receptacle shall be a TTAB ABCIRH05EV49A10PCNF80 or approved equal.

The Contractor shall prepare a design report, including data to support the ratings of the components, data sheets on each component, parts lists, electrical drawings and assembly drawings. (CDRL 9-7)

### **9.2.2.4 Primary Ground Fault Protection**

Separate ground fault protection systems shall be provided for the auxiliary primary circuits and propulsion primary circuits to protect against the return of primary current through paths other than the normal paths from the devices to the primary return buses. Separate ground fault protection devices are required for each floor heater circuit; refer to Section 7 for additional floor heater circuit requirements.

Ground fault detection shall be provided by verifying that the primary power and return currents sum to zero for a circuit. This shall be done by comparing the feed current from the system line switch (refer to Section 10) or fuse, with the return current to the circuit return bus. Detection of a ground fault shall trip the HSCB for devices fed through it or open the appropriate line switch or contactor. The arrangement to accomplish this shall be submitted to Sound Transit. (CDRL 9-8) The detection level shall be as sensitive as is consistent with the avoidance of nuisance trips.

Annunciation of a ground fault trip shall be provided on both a local and trainlined basis. Refer to the Fault Annunciation section, below.

### **9.2.2.5 Fault Annunciation**

Individual visual annunciation of the HSCB tripped, Auxiliary Power Supply Fault, LVPS Fault, and Propulsion Fault shall be indicated on the local indicator panel described in Section 5. Trainlined visual indication of these conditions shall be provided on a summary basis as System Faults on the annunciation panel described in Section 5 with details indicated on the Train Operator's Display (TOD) Trouble Screen described in this Section and Section 5. Other fault indications and data appropriate for the provided systems, such as propulsion and auxiliary

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primary power ground fault or heater circuit ground fault shall be indicated on the TOD Trouble and Maintenance Screens.

### **9.2.3 Ground Brushes**

#### **9.2.3.1 Primary Power Return Circuit and Ground Brushes**

Refer to the general return circuit requirements above.

The size and quantity of ground brushes shall be selected such that with the removal of one ground brush, the remaining ground brushes shall retain the collective capacity to carry 2.0 times the circuit rms current, and 1.5 times the total primary circuit peak current without exceeding the manufacturer's ratings. No less than one general return ground brush per motor truck axle shall be provided.

The general return bus in each vehicle section shall be insulated from the carbody and shall be connected together via a cable through the articulation section.

The ground brush assemblies on each center truck wheel assembly shall be connected by a jumper cable for the purpose of providing effective rail-to-rail shunting for the wayside signal system. The resistance between wheel tire on one side of the axle assembly to the wheel tire on the other side shall be less than 0.05 ohm. As an alternate, the Contractor may propose to use the center truck safety ground brushes for this function. The proposal, including technical justification, shall be submitted to Sound Transit as required below.

Alternative power return ground brush arrangements and ground connections, as required by different hardware or EMC control schemes will be considered by Sound Transit. (CDRL 9-9)

#### **9.2.3.2 Safety Ground Brushes**

Safety ground brushes shall be provided to carry ground fault return currents to the rail. These brushes shall be isolated from the normal ground return brushes. The size and quantity of safety ground brushes shall be selected such that with the removal of one safety ground brush, the remaining brushes shall retain the collective capacity to carry the maximum fault current until cleared by the respective protective device without exceeding manufacturer's ratings. Under such conditions, the rise in car body voltage shall not exceed 50 V. No less than one safety ground brush per motor truck axle and one per center truck wheel shall be provided. See Section 9, Grounding Device.

Alternative safety ground brush arrangements and ground connections, as required by different hardware or EMC control schemes, will be considered by Sound Transit. (Include in CDRL 9-9).

#### **9.2.3.3 Ground Brush Assemblies**

Axle and wheel mounted ground brushes may be of the radially or axially mounted type. The selected type shall be of a proven design in wide use in the rail transit industry. Carbon-to-carbon ground brush assemblies are allowed.

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Radially mounted ground brushes shall use a ground ring as described in Section 11. Brushes shall be made from metal graphite.

Axially mounted ground brushes shall mount to the ends of the axles and bear on a bronze disk bolted to the end of the axle. The torque reaction arm shall be mounted to the truck frame with an insulated linkage that permits normal relative motion between the axle and truck frame.

Ground brush life shall not be less than 130,000 mi (209,000 km). The safety ground brushes shall be selected to carry zero current without wear surface scoring or reduction in life.

Ground brush wiring design shall be coordinated with the truck design to ensure that all bearings are protected against stray current flow.

Refer to Section 11 for related requirements.

### **9.2.4 Line Filters**

Independent line filters shall be provided for each propulsion system and each auxiliary power converter. If a combined propulsion/auxiliary inverter is provided, then the line inductors may be shared; however, capacitor banks shall not be shared. If the line inductors are shared, system isolation switches or contactors shall be supplied to permit independent operation of each supplied system.

The filters shall suppress all vehicle-generated high frequency voltage transients caused by converter or inverter switching operations, under both normal and abnormal equipment operation, for any allowable line voltage at any location and any combination of active and inactive substations. The resonant frequency of each filter shall be less than 40 Hz, and shall be inductive above 50 Hz. Filter performance, including capacitance and ripple current capabilities, shall be maintained at the low ambient temperatures specified in Section 2.

The line filters shall have a self-test feature during the power-up or power-down sequence to verify capacitor health. If the tested capacitance value is outside of the allowed tolerance band, a failure message shall be sent to the MDS. The detection of a failure shall not immobilize the vehicle, but upon detection of a failure, the power draw of the inverter with the defective filter shall be reduced by 50% until the defective condition is corrected.

A design report for the line filter design arrangement shall be submitted, and shall include simulations demonstrating proper operation of the line filters for both normal operation and for operation with possible failures in the supplied auxiliary and propulsion systems. (CDRL 9-10) The simulations shall include the full tolerance band of the capacitance of the input filter. The design report shall include, for each system filter:

- Frequency characteristics
- Component types, values, manufacturer
- Calculations demonstrating life expectancies of the capacitors, including manufacturer's data and application information, ripple currents and ambient and operating temperatures

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- Installation details, if the filter is not included within the system enclosure
- Filter degradation monitoring methods
- Simulation results with sufficient information to demonstrate compliance with the Specifications, including all EMI requirements

Car level qualification tests described in Section 16 shall include validation of the results of this design report, demonstrating that the vehicle conducted current emissions spectrum conforms to the Specifications.

Capacitors shall have a rated life of at least 12 years.

Individual capacitors shall be arranged in functionally grouped assemblies to facilitate replacement.

Filter capacitor inrush current, during initial charging, shall be limited according to the needs of the circuit, but in no case shall the inrush be greater than 500 A for the entire car. Current limiting devices shall not be applied across the main contacts of the HSCB. The design basis for the current limiting value shall be based on nominal primary line voltage, nominal filter parameters (inductance and capacitance), and minimum damping resistance.

A bleeder resistor shall be permanently connected across the terminals of each capacitor in the capacitor bank. The resistance value shall be selected to reduce the voltage at the terminals of the capacitor bank to 50 V or less within 3 min after primary power is removed from the bank. A robust, permanently affixed placard shall be positioned adjacent to the capacitors to warn maintenance personnel to pull down the pantograph, wait 5 min, manually bleed, and then short circuit the capacitor before commencing work. A switch shall be provided to enable maintenance technicians to safely and easily short circuit the filter capacitor bank. The placard shall be visible when the door to the enclosure which houses the capacitor bank assembly is open.

Line inductors shall be mounted in an enclosure that shall be watertight when subjected to a water test equal in severity to that for the vehicle body. The enclosure shall have drain holes to permit condensate or leakage water to drain, without permitting water to enter. Thermal ratings of inductors shall include the effects of the enclosure and the worst case ambient temperatures experienced in the vehicle undercar, which would be higher than the ambient temperature external to the undercar.

Line inductors shall be designed for a service life of 30 years, and shall comply with IEC 60310 for construction and testing, and IEC 61373 or other approved standard for shock and vibration.

### **9.3 AC Power Supply**

#### **9.3.1 General Requirements**

Loads that require three-phase or single phase ac power shall be powered by Variable Voltage Variable Frequency (VVVF) dc-to-ac auxiliary power inverters, powered directly from the high voltage dc input,

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One auxiliary power inverter shall be provided on each vehicle half, each providing ac power to equipment on their respective vehicle halves. Vehicle ac circuits shall be segregated as necessary to isolate the two inverters. See Load Management, below.

The inverters shall be rated for the worst-case peak and continuous loading, including loadings defined in Load Management, whichever is worst. The inverters shall be rated equally and fully interchangeable.

Each inverter shall have a reserve capacity of at least 20% to allow for future equipment installation.

Arrangements with the ac power supply in the same container as the propulsion inverter will be permitted by Sound Transit if functional independence is provided for the two systems.

Integrated inverter/LVPS arrangements will also be permitted, subject to Load and Failure Management requirements. The LVPS shall be identical in each unit.

The inverters shall operate over the line-voltage range specified in Section 2. The inverters may shut down when the steady-state input voltage is out of range as specified in Section 2, but shall not be shut down by switching transients generated by the propulsion system. Refer to Sections 2 and 10.

The inverters shall automatically start when primary power is applied. Battery power shall not be required as a prerequisite to starting, or for closing circuit breakers or contactors needed to permit inverter operation or start-up. Methods used to fulfill this requirement shall ensure galvanic isolation between high- and low-voltage circuits. The inverters shall be sized for continuous operation of each load simultaneously, and short-time rated for the starting of the largest individual load with all other loads applied.

The design, selection, and installation of all ac-powered equipment and wiring that is to be powered from an inverter shall be coordinated with the expected output characteristics of the inverter so that the design life, performance, maintenance, and operation of any equipment is not adversely affected. This involves coordinating the worst case harmonic distortion from the inverter output to the frame size and heating tolerance characteristics of the ac motor loads.

Inverters shall be either convection-cooled or clean-air ventilated, and rated in a manner similar to IEEE Std 11. Equipment ventilation requirements are contained in this Section.

Inverters shall include an output transformer to electrically isolate the primary supply system from the ac output. This requirement may be waived, with Sound Transit approval during design review of CDRL 9-11, provided that all loads are designed to withstand full line voltage that may result from inverter failures, and that isolation transformers are provided for convenience outlets and other loads that cannot withstand full OCS line voltage.

All inverter ac loads shall have ground fault protection.

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The inverter waveform generation scheme, harmonic distortion content, output transformer quality (if provided), component mounting, acoustical shielding, and other parameters shall be optimized to minimize audible noise. Audible noise requirements are given in Section 2.

Refer to the Line Filters section, above, for line filter requirements and Section 2 for electromagnetic interference and compatibility requirements.

The Contractor shall prepare a design report on the ac inverter systems, demonstrating compliance with these requirements. It shall include load analysis, operation under Load Management conditions, description of how the equipment operates under extreme conditions and faults, ratings sheets, software descriptions, electrical schematics drawings, and assembly drawings. (CDRL 9-11)

### **9.3.2 Voltage and Frequency Regulation**

The nominal, steady state output of the inverters shall be 208/120 Vac rms, three-phase, four-wire, 60 Hz, over the full range of input voltage and load.

The voltage waveform shall be sinusoidal with a maximum total harmonic distortion of 10%. Systems with higher distortion levels may be proposed in CDRL 9-11, provided that load devices are designed to operate with the higher distortion and filters are provided for the convenience outlets and other loads that require lower distortion levels.

The tolerance on steady state frequency shall be  $\pm 2\%$  during normal steady state operation. The voltage-to-frequency ratio shall be maintained within 2% under falling output voltage conditions. Output overvoltage protection shall be provided.

The transient output response to line variations (within the specified range), and to load variations (of the actual loads), shall not damage or degrade connected apparatus.

### **9.3.3 Load and Failure Management**

The application and removal of loads to the ac inverters, and the shutdown and startup sequences of major loads, shall be actively managed to limit peak inverter loading, maintain voltage at loads, and reduce delays of equipment starting or restarting due to application or interruption of line voltage. Communication between systems to coordinate load management shall be via the vehicle's data communications network.

In the event of failures that disable one inverter, critical ac loads shall be automatically transferred to the remaining inverter. Inverters shall be sized for this eventuality. Critical loads are those ac loads necessary to keep the vehicle functioning, such as cooling fans for propulsion equipment, air compressor motors, and similar while maintaining passenger safety. HVAC and/or floor heat loads in the vehicle with the failed inverter may be shed completely. For integrated inverter/LVPS configurations, the surviving LVPS shall provide all vehicle dc loads. The LVPSs shall be sized for this eventuality. See the Low-Voltage Power Supply section, below.

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The inverter shall have sufficient energy storage capacity to maintain the ac output voltage at nominal values when the input power is interrupted for 10 ms, allowing the voltage to sag while maintaining the specified volts-to-hertz ratio frequency.

The load management scheme may partially shed HVAC and/or floor heat loads with extended line voltages below 1200 V.

Load management details shall be submitted during the system design review process. (CDRL 9-12)

### **9.3.4 Fault Monitoring and Control**

The controls for the inverters shall be designed to prevent damage both to auxiliary equipment, and the inverter itself, resulting from:

- Frequency errors
- Output over- or under- voltage
- Output over-current
- Out of tolerance voltage-to-frequency ratio
- Input over- or under- voltage
- Input over-current
- Input filter failures
- Frequent repetitive starts (Manufacturer defined limits)
- Rapid variations and transients in line voltage or loads
- All primary power interruptions (input power interruptions of less than 25 ms shall be suppressed and shall not appear as a fault)
- Excessive harmonic distortion
- Phase imbalance
- Control logic faults
- Cooling faults
- Load ground faults and short circuits

The control logic shall permit the equipment to automatically restart for shutdowns caused by self-correcting failure conditions. Major faults shall latch the equipment off until reset by maintenance personnel.

Circuitry used to provide protection for voltage and frequency deviations shall be wholly independent of the circuits used to control voltage and frequency. The permissible range of voltage and frequency deviations shall depend on the requirements of the specific load components, but once established, these values shall be set in the circuitry and have a self-testing capability.

Inverters shall interface with the Monitoring and Diagnostics System specified in this Section.

Inverter system time setting shall be performed each time the vehicle is keyed on by the Master Controller key, or anytime the inverter clock and the vehicle clock differ by more than 2 s.

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Each inverter shall be provided with a data/fault logger that complies with the requirements of this Section. The data/fault logger shall create a record of at least eight relevant signals and time of recording whenever an unusual or erroneous condition is encountered during operation. Signals shall be converted to engineering units (e.g. volts, amps, etc.). The fault information shall both be stored locally and transmitted to the Monitoring and Diagnostic System computer for storage and retrieval; refer to this Section.

### **9.3.5 Convenience Outlets**

Four duplex convenience outlets shall be installed for single-phase 120 Vac, 20 A service, one in each cab and one in the passenger area of each “A” and “B” car body section. Use of any or all of these outlets at the maximum current output shall not trigger the inverter phase-imbalance protection.

The convenience outlets shall not be accessible to passengers. Each outlet shall be fed from a dedicated circuit breaker with ground fault circuit interruption (GFI) protection.

## **9.4 Low-Voltage System**

### **9.4.1 General**

All vehicle control circuitry shall be powered from a nominal 24 Vdc low-voltage system provided by one or more Low-Voltage Power Supplies (LVPS), and a backup battery. Refer to Section 2 for specific voltage range and design requirements.

IEEE Std 1476 shall be used as a general guide to presenting data and rating the LVPS and battery to the extent that it does not contradict other requirements of the Specifications.

#### **9.4.1.1 Low-Voltage Grounding**

All low-voltage system negative return wiring shall be insulated from the vehicle body, except for a single point connection. The connection shall include filter components designed both to eliminate the imposition of common mode voltages onto low-voltage circuits, and to remove spurious or nuisance ac signals (EMI) from the low-voltage network to carshell.

#### **9.4.1.2 Low-Voltage Trainlines**

Low-voltage, positive and negative, dc trainlines shall be provided to supply power to an adjacent vehicle with a non-functioning LVPS.

The low-voltage trainlines shall have sufficient current capacity to permit all of the low-voltage loads (other than battery charging) on one car with a non-functioning LVPS, to be supplied by the functioning LVPS in the adjacent car. Voltage drop in the battery trainlines shall be controlled such that no equipment in the failed vehicle is operating at more than 4 volts below the LVPS nominal voltage. These criteria shall be met with the battery disconnected in the failed vehicle and with any cab in the pair in control, but without track brake activation.

Low-voltage trainline “ballast” resistors shall not be used.

### **9.4.2 Low-Voltage Power Supply**

One or more LVPSs shall be provided to power the low-voltage dc equipment in the vehicle, and to charge the battery.

The LVPS shall be a regulated dc power supply, unless otherwise approved.

If a single LVPS is provided, it shall be powered directly from dc line voltage and not share components with other equipment. The LVPS shall be rated to provide all peak and continuous load of the vehicle, including the low-voltage trainline load and battery charging.

For configurations that integrate ac inverters and LVPS, an LVPS unit shall be provided with each inverter. The LVPS units may be powered from the inverter three-phase output, or from the dc line voltage. If dc line voltage powered, the inverter/LVPS units may share line-voltage filter components. Both LVPS units shall feed a common dc bus. The combined ratings of the LVPS units shall be sufficient to provide the peak and continuous vehicle dc loads, including the low-voltage trainline loads and battery charging. With a loss of one LVPS, the remaining LVPS shall be rated to provide all vehicle loads except the low-voltage trainline. See the Load and Failure Management section, above.

The LVPS shall be designed for complete electrical isolation from input to output, and from both input and output to the enclosure and vehicle body.

Each LVPS shall have a reserve capacity of at least 20% to allow for future equipment installation or modifications.

The Contractor shall prepare a design report on the low-voltage power supply, the battery, and associated loads to justify the selected configuration and to confirm compliance with the requirements of the Specifications. It shall include load analysis, description of the equipment and how it operates under extreme conditions and faults, ratings sheets, software descriptions, electrical schematics drawings, and assembly drawings. (CDRL 9-13)

The output voltage of the LVPS shall be initially set to float charge the battery at 1.45 volts/per cell, or as recommended by the battery manufacturer. Contractor shall provide an adjustment range of at least +/-10% of that initial voltage setting.

The LVPS shall be of sufficient capacity to maintain constant output voltage under all low-voltage transient and continuous loads, including battery charging and any dedicated battery loads, and low-voltage trainline loads. See above.

The battery shall be charged via a dedicated output on the LVPS, with automatic current limiting based on battery charge states, as recommended by the battery manufacturer. Battery charging current shall be temperature regulated.

The batteries shall be isolated from the LVPS bus via a rectifier such that the LVPS bus does not charge the batteries in connected vehicles via the low-voltage trainlines. See above.

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In case of LVPS failure or loss of input power, LVPS loads shall be transferred instantly to the battery.

For load or fault conditions of very low load resistance (such as a dead short), the LVPS control shall "fold back" (limit both current and voltage), disconnect the output, or shut off, as appropriate to the severity of the fault. Normal operation shall automatically resume when the overload or short circuit is removed.

The LVPS shall automatically start when primary power is applied. Battery power shall not be required as a prerequisite to starting, or for closing circuit breakers or contactors needed to permit LVPS operation. Methods used to fulfill this requirement shall ensure galvanic isolation between high- and low-voltage circuits.

The LVPS shall interface with the Monitoring and Diagnostic System specified in this Section by means of the vehicle data bus also specified in this Section. LVPS system time setting shall be performed each time the vehicle is keyed on by the Master Controller key, or anytime the LVPS clock and the vehicle clock differ by more than 2s.

Each LVPS shall be provided with a data/fault logger that complies with the requirements of this Section. The data/fault logger shall create a record of at least eight relevant signals and time of recording whenever an unusual or erroneous condition is encountered during operation. Signals shall be converted to engineering units (e.g. volts, amps, etc.). The fault information shall both be stored locally and transmitted to the Monitoring and Diagnostic System computer for storage and retrieval (refer to this Section).

### **9.4.2.1 Ripple and Regulation**

Ripple in the LVPS output shall not exceed 3% in accordance with the definitions for current ripple and smooth current in IEEE Std 11.

LVPS regulation shall be as required by the loads, including the battery, but shall be  $\pm 1.5\%$  or less for the full range of input voltage and output loads.

### **9.4.2.2 Indications**

The LVPS shall include circuitry to detect LVPS failures. The fault detection circuit shall provide fault indications on both the local indicator panel and the trainlined annunciator panel described in Section 5, with the details indicated on the Train Operator's Display Trouble Screen described in this Section and Section 5.

## **9.4.3 Storage Battery**

### **9.4.3.1 Emergency Power**

When LVPS output on a car is lost for more than 30 s, non-emergency low-voltage loads shall be disconnected. They shall be reconnected after LVPS output is restored.

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Emergency power shall be provided by a battery. The battery shall be sized to provide at least the following loads, with associated duty cycles:

- Emergency Lighting (continuous)
- Door Control (cycle doors open for 20 s every 2 min)
- Communications (operate PA and radio 20 s every 2 min)
- Propulsion System Control (continuous)
- Friction Braking Control and Power (continuous)
- Operator's Console Indicators, and Interlocks (continuous)
- Bell and Horn (on for 5s every 2 min)
- Track Brakes (on for 30s at end of each 20 min period)
- Pantograph Control (raise and lower twice)
- Coupler control (one couple and uncouple cycle)
- Windshield Wiper (continuous)
- Automatic Train Protection (continuous)
- Train-to-Wayside Communications (continuous)
- Event recorder (continuous)
- Railway light in the emergency position (continuous)
- Monitoring and diagnostic system (continuous)
- Close circuit television (CCTV) (continuous)
- Propulsion container blower fans (if low-voltage dc powered) (continuous)

For an initial battery condition with the cells at 90% of full charge and 20°F (-6.7°C) ambient temperature, the battery capacity shall be able to carry all the above loads for a period of one hour without discharge to below 1.0 V per cell.

### **9.4.3.2 Battery Type**

A nickel cadmium storage battery with cell cases of an approved high-temperature rated material shall be provided. The battery shall be rated for emergency duty cycle service in the indicated operating environment over a normal service life of not less than 10 years. The battery shall be maintained at rated charge by the LVPS as described in this Section.

### **9.4.3.3 Battery Capacity**

During LVPS failure or shutdown, the battery shall supply power to the emergency loads as described in this Section. A discharge rate beyond the rating of the battery shall not permanently damage the cells or reduce capacity.

Electrolyte capacity shall be sufficient to require adding water only during normal (90 day) maintenance.

### **9.4.3.4 Battery Installation**

The battery shall be installed on the vehicle roof in a ventilated welded stainless steel, battery compartment box. Within the battery box, the battery shall be placed in a containment device or tray that will safely contain electrolyte in the event of a failure of the battery physical structure; electrolyte shall not be allowed to drain from the battery box.

Battery cells shall be interconnected by hardware recommended and supplied by the battery manufacturer. Installation of this hardware shall be as recommended by the battery manufacturer.

The cells shall be clamped with using mechanical method which incorporates treated wood, polyethylene, or other material as recommended by the battery manufacturer to prevent stressing or cracking the battery cells.

All cells shall be readily accessible for servicing.

Hinges, fasteners that are removed periodically, and all other devices that move by sliding or rolling on other devices shall be stainless steel.

Cell arrangement in the tray shall permit checking of electrolyte levels through the filler holes. Electrolyte levels shall be observable and maintainable without removal of any equipment.

Vent caps shall be of the captive type and shall be spray-proof.

### **9.4.3.5 Battery Circuit and Over-temperature Protection**

A circuit breaker shall be provided for battery and battery circuit protection. The circuit breaker shall be a two-pole, explosion-proof breaker mounted in the battery box or of non-explosion proof design located in an electric locker within 10 ft (3 m) of the battery box. Parallel breakers are not permitted. The circuit breaker shall be rated to withstand the short circuit capacity of the battery and shall be connected into the B+ and B- leads from the battery terminals.

A battery over-temperature sensor shall be located on the main battery bus bars and arranged to trip the battery circuit breaker upon detection of an over-temperature condition.

#### **9.4.3.6 Emergency Battery Cut-Out Switch**

Contractor shall provide an emergency cutoff system for the battery as required by NFPA 130. If the battery circuit breaker is not accessible from the side of the vehicle or at a convenient interior location, Contractor shall provide an accessible battery cut-out switch.

### **9.5 Equipment Ventilation**

Forced air ventilation may be used by the propulsion control system, and shall be used by other systems only upon review and approval by Sound Transit. (CDRL 9-14)

For noise control, it is required that major equipment ventilation blowers not be run continuously. Temperature sensors or temperature calculations based on internal circuit measurements shall be used to control the blowers.

Air for force-ventilated equipment shall be processed as described in this Section. A common air supply system may be shared by multiple systems. Equipment shall be mounted and the air flow channeled so that high voltage elements and insulators will not be located in the ventilating air flow; this is to prevent ventilation air from contaminating insulators with dirt or moisture and otherwise allowing contaminants to build up on the high-voltage equipment.

#### **9.5.1 Air Intakes and Filters**

Air intakes shall be screened and positioned above the vehicle roof level on the outside of the vehicle and oriented to minimize ingestion of snow, water, and debris. Suitable baffling and drains shall provide for removing and draining ingested moisture.

All equipment ventilation air filter designs shall be submitted to Sound Transit. (CDRL 9-15) Self-cleaning inertial type filters are required.

#### **9.5.2 Equipment Ventilation Blowers**

Equipment ventilation blowers, if used, shall be a service proven design as defined in Section 2. See also Load and Failure Management, above.

The blowers shall be direct driven by three-phase motors that are powered by the inverters. The blower and motor shall have sealed, NFL, antifriction bearings. Bearings shall have an L10 rating life equivalent to six years or more of Sound Transit operation.

The motor shall be insulated for Class F and shall comply with the temperature rise limits of IEC 60349 and the standards which it references.

The motors and motor blower assemblies shall be dynamically balanced to meet the vibration requirements of IEC 60349 and the standards which it references.

Motor and fan inspection covers shall be provided and shall be accessible without removing other equipment.

## **9.6 Trainline and Local Signal Architecture**

The Contractor shall utilize modern network communication technologies where feasible for both trainlined and local functions, except where specifically prohibited.

Vehicle networks shall conform to TCN (Train Communication Network), in accordance with IEC 61375-1. The following network types are permitted:

- MVB (Multifunction Vehicle Bus): IEC 61375-3-1
- CCN (CANOpen Consist Network): IEC 61375-3-3
- ECN (Ethernet Consist Network): IEC 61375-3-4
- WTB (Redundant Wire Train Bus): IEC 61375-2-1
- ETB (Redundant Ethernet Train Backbone): IEC 61375-2-5

The main per vehicle network may be MVB or ECN. CCN may be used for local equipment networking.

See Section 13, Vehicle Communication Systems, for communications network requirements.

The car builder shall submit a detailed plan regarding the identification and manner of transmission of all control signals subject to the constraints in the remainder of this Section. (CDRL 9-16)

Physical designs shall presume that there are static and dynamic differences in the ground reference level between vehicles and between a vehicle and equipment packages within a vehicle. All such equipment shall be operated from the low-voltage dc system via fully isolated dc-dc power supplies. All I/O to vehicle battery-level circuits shall be galvanically isolated and shall have transient protection. I/O to other equipment shall have circuit characteristics selected to eliminate interference from other car equipment. Electrical characteristics, especially signal levels, shall be augmented to compensate for the electrical environment and wiring lengths.

### **9.6.1 Prescribed Discrete Trainlines**

Conventional battery level trainlines shall be used for all safety-critical signals. At a minimum these shall include:

- Emergency brake
- Door open and release commands
- Doors closed and locked status signal
- Propulsion mode
- Brake mode
- Track brake
- Friction brake released signals
- Forward
- Reverse

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- Sand control trainlines

Vehicle systems shall respond only to the discrete trainlines.

The following discrete trainline signals shall also be monitored and propagated by the vehicle networks, and checked for correlation with the discrete trainline by the vehicle network controllers. Lack of correspondence shall be recorded as a system error and indicated on the TOD as a critical error. Failure of correspondence in which the discrete trainline is in a more permissive state than the network signal shall force an irretrievable full service brake application.

- Emergency brake
- Door open and release commands
- Doors closed and locked status signal
- Propulsion mode
- Coast mode
- Brake mode

### **9.6.2 Other Trainline and Vehicle Control Circuits**

Networks used for train and door control shall be redundant, regardless of the type of data bus selected. The design shall allow either network to operate the train without degradation of performance whenever at least one network is operational. The systems shall always maximize the use of available data so problems with one network will result in the immediate use of data, if available, from the other network. Management protocols for the trainline networks shall be submitted to Sound Transit. (Include in CDRL 9-17)

Diagnostic data described in this Section shall be communicated using an independent Ethernet network. See Section 17 for Ethernet cable and connector requirements. If it can be shown that diagnostic information can be transmitted on the vehicle command bus, and cause no collisions with the command data and still provide the design margin required in this Section, then that scheme may be proposed. (Include in CDRL 9-17)

### **9.6.3 Network Requirements**

#### **9.6.3.1 General**

- The network protocols and transmission methodology shall be submitted to Sound Transit. (CDRL 9-17)
- Each vehicle shall include two redundant Vehicle Network Controllers (VNC). Only one VNC shall be active at any one time. Should one fail, the other shall immediately and seamlessly assume all the functionality of the failed VNC. One VNC shall manage the local vehicle network(s) and manage the data flow between the local vehicle network and the trainline networks. Data that does not need to pass between the various networks shall be restricted from so doing. Each VNC may be considered as a functional entity and may be physically implemented within a more comprehensive equipment package. Each VNC shall automatically identify the vehicle upon which it is installed. The VNCs shall act as a router and shall also prevent local vehicle faults from interfering with train operation.

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- Complete network interface descriptions and details shall be provided to Sound Transit. (Include in CDRL 9-17) Network components and transceivers shall be available from multiple sources.
- Network communication related to real time control, such as propulsion control, shall be prioritized to the extent that anomalies in system stability and operation are prevented. The Contractor shall present calculations of the variations in transmission time, as related to the real-time control requirements, to Sound Transit. The submittal shall include a statement of acceptability by the propulsion, brake, and ATC Suppliers. (Include in CDRL 9-17)
- Within each vehicle there shall be a functional entity Trainline Network Controller (TNC). The TNC shall act as the gateway router between the vehicle and trainline data communication. When vehicles are coupled and uncoupled, the TNC shall automatically reconfigure itself for the new train configuration. It shall identify every vehicle in the train by Car Number. The TNC shall know the order of the vehicles in the train, and shall explicitly identify the ends of the train. Defective TNC or VNC network equipment in a vehicle shall not prevent the proper configuring of the train. Under such circumstances, the TNC shall identify that the defective vehicle is present or what portions of a VNC are not reporting.
- Prior to approval of the network design, the Contractor shall submit detailed calculations of peak and average data traffic levels and calculations of network delays. (Include in CDRL 9-17) The network delay calculations shall include the expected average delays and the distribution of the delay times. The Contractor shall also submit peak and average traffic levels for the transmission media, as recommended by the protocol Supplier. (Include in CDRL 9-17) The calculated peak and average traffic levels shall not exceed 60% of the recommended peak and average traffic levels. During vehicle commissioning the Contractor shall measure peak and average traffic levels. The actual peak and average traffic levels shall not exceed 70% of the recommended peak and average traffic levels.
- All protocols shall include error detection and retransmission. Statistics regarding current and historical error rates for all nodes shall be collected and made available through the Monitoring and Diagnostic System.
- Vehicle networks shall function successfully, and at maximum required transmission rates, with the selected coupler pin connections and their limitations, including normal wear and coupler motions. Reference Section 4 and Section 17. The physical network shall include redundancy and shall be constructed using twisted shielded wire. Multiple logical networks may be employed.
- Network wires shall be physically isolated from sources of EMI. Where redundant networks are employed, they shall not be run in the same conduit, wire-way, or other such routing path.
- In the consideration of fault tolerance, the network design shall include an evaluation of the network topology and whether the network is operated as Peer-to-Peer or Client-Server.

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- The Contractor shall describe the process whereby problems with the networks will be detected, reported, and repaired. (Include in CDRL 9-17)

Note related software requirements in Section 17 of the Specifications.

### **9.6.3.2 Fault Tolerance and Maintenance**

Network interfaces shall be designed to eliminate the possibility that a transceiver component fault will disable the network. Component faults shall neither inhibit nor severely degrade train control functions other than those functions assigned to the failed component. All single point failures that would cripple a train must be identified and provided to Sound Transit regarding their degree of acceptability. (Include in CDRL 9-17) Network fault recovery shall be automatic. Network systems shall be designed so that the failure of any network element to respond properly shall not inhibit or severely degrade network functions outside of the unresponsive portion. The latter case includes periods of time during which a vehicle subsystem is being reset.

Network component faults shall cause the affected vehicle equipment to revert to a safe default mode of operation. The network system shall automatically diagnose and announce what node is defective.

When nodes on the network are replaced, the network system shall automatically identify the replacement equipment and establish its network communication links.

Portable Test Units (PTUs) provided for with the networks shall be capable of performing detailed diagnostics and real-time monitoring of network activity. The equipment shall have the capability to disable and enable nodes on the network within either a car or the entire consist, and to directly communicate with any node on the network within either a car or the entire consist. As an aid to troubleshooting, the diagnostic tool shall be able to identify, diagnose and announce any subsystem on the car or in the entire consist that has a faulty network node. During vehicle or train revenue operation, the PTU shall be limited to real-time monitoring and diagnostics of the received data. The diagnostic equipment shall translate all data, both in and out of the diagnostic units, into engineering units. Any hexadecimal presentation of data shall be in addition to the engineering units. Protocol analyzers shall be provided for any network supplied. Refer to Section 18 for tester deliverable requirements.

### **9.6.3.3 Future Adaptations**

**Replaceability/Upgradeability:** Additions and/or changes to any vehicle system shall be easily incorporated into the existing architecture without modification to other portions of the train control system. Interfaces shall be documented as described in other portions of the Specifications.

**Scalability:** The architecture shall allow for additional subsystems and for additional functions within initial subsystems. The architecture shall allow for additional trainline functions without degrading network operation.

Trainline control and monitoring data formats shall be structured in an integrated fashion suited to safe, effective and efficient control of the vehicle. The data formats shall not be dictated by the needs of a single Supplier. The data formats shall be fully documented.

## **9.7 Monitoring and Diagnostics System**

### **9.7.1 General**

The Monitoring and Diagnostics System (MDS) shall consist of hardware and software consistent with the Sound Transit maintenance philosophy. The maintenance philosophy on which the hardware and software depend shall be defined at the system level during the earliest Design Review meetings. A wide variety of accurate operating (status) information and current and historical fault data shall be made available from all subsystems whether or not they utilize microprocessor controls. The system level maintenance philosophy shall clearly define which information is of interest under the operating conditions, which will apply to the vehicle fleet. The intelligent subsystems will each have their own requirements for internal self-testing, diagnostics and fault logging, and some of those requirements may be of greater interest during the design and testing of the subsystems than they are when the fleet is in service. Sound Transit's interest is in data that supports operation and maintenance of the fleet. The purpose of the MDS is to minimize the time required to troubleshoot and repair the cars. The system shall make it possible for the Operator or other field personnel to immediately be aware of an existing or serious problem and take the necessary prescribed action. The MDS, in conjunction with the MDL (below), shall make it possible for maintenance personnel to troubleshoot any problems to the Lowest Level Replacement Unit (LLRU) without the need to use external test equipment.

MDS data and Automatic Passenger Counting (APC) system data shall be automatically transmitted from the vehicle MDS and APC via wireless LAN technology to the vehicle MMIS at the maintenance facility. The Contractor shall submit a design report on the MDS system to Sound Transit within 180 days after NTP. (CDRL 9-18)

The Contractor is encouraged to integrate the APC, Communications, and MDS functions to permit the sharing of hardware and simplification of car wiring. Refer to Section 13.

### **9.7.2 On-Board Equipment**

Each vehicle shall be provided with an on-board MDS. The system shall collect, analyze, and report information to the crew and maintenance personnel regarding the vehicle subsystems.

The MDS shall consist of Monitoring and Diagnostic Logic (MDL) located in an electric locker inside the vehicle. The function of the MDL is to gather, process, and record information from the monitored systems, and report its findings through the TOD and via wireless communications link to the maintenance shop. It may also have data collection and transfer modules in each car, which facilitate interface with the subsystems of that car. It shall report information by way of the Train Operator Display (TOD) located in the cab console of each cab. Alternatively, it can report information by way of a separate, dedicated display located in sight of the operator in the cab. If this alternative is proposed, the indications of the Operating Screen (Refer to Operating Screen section, below) shall also be made available on the TOD. (CDRL 9-18 in this Section). Each individual vehicle subsystem shall perform its own diagnostics and shall log data

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appropriate to every fault. A subset of this fault information, as determined by the Contractor, along with selected operating status information, shall automatically be provided to the MDL. It shall be possible for a maintainer to address any fault log and display on the TOD with all data available on the system PTU.

The MDL shall be a robust, independent subsystem using the data networks described in this Section to efficiently, rapidly and accurately relay its information to its display. The data rate for the MDL shall be selected to reflect the real-time needs of the operator for operational and diagnostic information.

### **9.7.2.1 Monitoring and Diagnostics System Physical Requirements**

The MDS shall be subject to all design and documentation requirements in Section 17 that apply to microprocessor-controlled systems, including spare hardware input and output and spare memory provisions. The system shall have sufficient memory capacity to save fault data for the time intervals between periodic maintenance without losing data to overwrites.

### **9.7.2.2 Interface with Train Operator Display (TOD)**

The Operating Screen, the Trouble Screen and the Maintenance Screens on the TOD shall obtain the information to be displayed from the MDL. Each screen may employ one or more levels of subsidiary screens which present more extensive information. No subsidiary screen shall be employed unless the complexity and scope of the information to be presented precludes its presentation directly on a higher level screen. Subsidiary screens shall be arranged hierarchically, with a consistent interface to facilitate moving up and down the hierarchy. Where the same information is provided on several different screens, it shall be presented the same way (text, graphics, color) and in the same location, but not necessarily the same size. The interface for screen selection shall be consistent among all of the screens described in this Section and Section 5.

All screens shall display the following information:

- Time and date: Indication of hh:mm in the 24-hour system and MM-DD-YY format.
- Consist: Graphical indication of up to four vehicles in a consist, with vehicle numbers shown in order with lead vehicle indicated, and indication of which cab is the “active cab”.

It shall be possible for Sound Transit to edit all fault and message text that is displayed on the TOD. All screen content and layout shall be subject to Sound Transit review and approval.

#### **9.7.2.2.1 Operating Screen**

The purpose of the Operating Screen is to provide pertinent information to the Operator during normal operation of the train.

Information provided on the Operating Screen shall be a subset of information collected from the train and vehicle subsystems and analog sensors.

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The Operating Screen shall present, as a minimum, the following train information and functions:

- Indicator of new information (unacknowledged) on the Trouble Screen
- Passenger Emergency Intercom: activation and location for all vehicles in the train on the graphical indication of the train
- Pantograph voltage for that vehicle
- Pantograph current for that vehicle
- HVAC status for all vehicles in the train on the graphical indication of the train
- Auxiliary Inverter status
- Friction Brake status for all vehicles in the train on the graphical indication of the train
- Sanders active status for all vehicles in the train on the graphical indication of the train
- Track brake status for all vehicles in the train on the graphical indication of the train
- Door status for all vehicles in the train on the graphical indication of the train
- Any active bypass

Operating screen content shall be submitted to Sound Transit. (CDRL 9-19)

### **9.7.2.2.2 Trouble Screen**

The purpose of the Trouble Screen is to provide pertinent information to the Operator or field personnel concerning conditions that affect the immediate operation of the train.

Items with agreed urgency shall flash on the Operating screen to catch the Train Operator's attention. Flashing of such items shall be canceled by the user's activation of a Fault Acknowledge control.

Information provided on the Trouble Screen shall be a subset of information being collected from the train and vehicle subsystems and analog sensors. Providing the trouble information to the TOD shall have priority over other activities of the Monitoring and Diagnostics System.

The Trouble Screen shall present, as a minimum, the following train information and functions:

- Manual door release activation: location by car and doorway
- Door Not Closed and locked: location by car and doorway
- Door Open Enroute: location by car and doorway
- Door Cut Out: location by car and doorway
- Friction Brake: applied; location by car truck, and truck side;
- Brake in Emergency: location by car and truck
- Propulsion fault: location by car and truck
- Auxiliary Power fault: location by car and car half

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- Air or Hydraulic Supply fault: location by car and truck
- Air or Hydraulic Suspension fault: location by car and truck
- Network fault: location and ID by car
- HVAC fault: location by car and car half
- ATP fault by car]
- NVR fault
- Acknowledgement: reset indicator on operating screen

"Location" information shall be graphical to show which vehicle in train, supplemented by text including vehicle number and enough additional detail to isolate the fault to the subsystem or component.

If corrective action must be taken immediately, the suggested corrective action shall be listed.

Trouble screen content shall be submitted to Sound Transit. (CDRL 9-20)

### **9.7.2.2.3 Maintenance Screens**

Access to the maintenance screens shall require the use of a maintenance key. There shall be a selection of Maintenance Screens, arranged to provide access to all MDL functions and capabilities. In addition, it shall be possible for a maintainer to request additional data from the fault log in any system connected to the MDS for presentation on the TOD. Maintenance screen content shall be submitted to Sound Transit. (CDRL 9-21)

Status screens shall display real time status information from system, subsystem, and intelligent sensors (not part of a subsystem) at the train and vehicle level. Status shall include "active" faults.

Fault logging screens shall display the major failures of the car's subsystems. The fault data shall include the time, vehicle number, the system and all information contained in the individual subsystem's fault log. Format of the individual subsystem fault logs shall be consistent regardless of the source of the fault data. The Maintenance Screens shall allow scrolling through all logged faults by subsystem. Provision shall be made to identify the most important fault modes in each vehicle system, including time keyed in and out and consist coupling history. Provision shall be made to allow the user to scroll through the content of individual subsystem fault logs resident in the subsystems. All fault logs shall be available to the maintenance personnel for review on the screen or to be downloaded to the PTU or storage card. Provision shall be made to conserve fault log memory by incrementing a counter for repetitive faults rather than making a new entry. Alternatives to this scheme will be considered.

One of the Maintenance Screens shall allow a maintainer to select customized subsets of historical or status data, such as a time frame of interest or specific data from different subsystems for display on the same screen.

One of the Maintenance Screens shall allow the maintainer to initiate self-tests of all subsystems and view the results without changing screens. Testing shall be disabled unless the cab reverser is in neutral.

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A Maintenance Screen shall allow access to the MDL's internal fault logs. It shall be possible to use one vehicle's MDS as a PTU for any other MDS in a consist.

### **9.7.2.3 Monitoring and Diagnostics Logic (MDL) Functions**

The MDL shall collect and process information from the microprocessor-controlled subsystems and from other subsystems and sensors. The MDL shall have embedded within it a subset of the PTU functions that are essential to troubleshooting and accessing and downloading faults for every subsystem on the vehicle.

It shall be possible to set up real time data gathering parameters in advance for a specific test run or revenue service run for which the minimum sampling intervals shall be no greater than 100 ms. Such parameters include selecting signals, setting triggers and sampling rates to be captured. The data capture shall be accomplished without additional equipment on board during the test or revenue service runs and sufficient storage shall be provided to investigate any foreseeable problems.

The MDL shall be capable of capturing the system level and subsystem operating status data, which shall then be saved in case of a major fault. The MDL shall include a buffer for all faults such that key associated technical and operational data at the time of the fault, and no less than 2 seconds prior to, and after, the fault, shall be saved in each fault log file. It shall be possible to view this data in 100 ms increments (or less, if recommended by the system or subsystem manufacturer) for the 2 seconds prior to, and after, the actual fault occurrence.

Provision shall be made for adding temporary or permanent analog or digital sensors for use in troubleshooting. The MDL shall be capable of handling the additional inputs in the same way as it handles any other data.

The MDL shall collect information at the system level and pertaining to subsystems on all vehicles in a train. Each MDL shall be capable of accessing the data collected by the MDL in any other vehicle coupled into the same train. When vehicles are uncoupled, the fault information of each vehicle shall be resident in the vehicle of origin. Each vehicle MDL shall retain a record of other vehicles to which it has been coupled but it does not have to retain the fault history of other vehicles.

The MDL shall transmit maintenance data, vehicle mileage data, and passenger count data to the shop maintenance data workstation by means of a wireless communications link when interrogated by the shop system. The shop system shall be able to interrogate any vehicle that is powered up in the maintenance shop and storage yard. The wireless communications system shall be designed to prevent communications signals from being available to receivers located outside of the yard and shop boundaries.

Each time the vehicle is keyed up at the master controller, the MDL shall update its master clock from the GPS clock described in Section 14 and synchronize all microprocessor based systems in the vehicle with the exception of the event recorder.

Collecting and presenting Trouble Screen information shall have priority over other MDL functions.

Downloading the fault information to a laptop PC using either a USB or Ethernet connection shall not automatically clear the log. A separate action shall be taken from the PTU to clear the log and reset faults.

#### **9.7.2.4 Monitoring and Diagnostics System Interfaces with Other Systems**

The MDS shall be designed and suitably buffered such that a failure of the system does not adversely affect the systems it is monitoring, and failures of monitored systems and sensors do not adversely affect the MDS.

Wherever possible, the MDS shall be capable of distinguishing between a complete failure of a specific system and a failure to communicate with it.

The MDS shall communicate with other parts of itself and with other systems and sensors through the network described in this Section. The coding structure(s) shall be defined during the first MDS design review meeting. Automatically transmitted fault information shall not be transmitted as text messages, but responses to special searches initiated by a maintainer may be transmitted as text messages.

The system shall be capable of providing a specific subset of trouble data to off-board data collector modules if such modules are added at a future date. This capability shall consist of an output data port suitable for connection to a radio link or transponder to be added at a future date, along with the necessary software for data port control and access. The transmission (broadcast) technique shall not interfere with, or be interfered with, by any other system on the train or wayside.

The following interfaces with other systems (also called subsystems) are required:

- **Time Stamp Coordination:** The MDS clock shall provide the official time stamp for information from all subsystems. Any subsystem internal clock shall be updated on key up by the Monitoring and Diagnostic System clock except for the event recorder.
- **Exception Reporting:** Conditions outside of specified parameters shall be reported to the MDS.
- **Failure Indications:** All major system failures during operation or during the self-test shall be reported to the MDS.
- **Diagnosis Documentation:** All parameters associated with failure indications and exception reporting shall be clearly documented. This includes the identification of the parameters, the relationship(s) among parameters, filtering, time delays, levels, and counting and reset requirements.
- **Historical Data Storage:** All subsystem reports shall be stored in a non-volatile memory for diagnostic use. Records shall include time stamp, condition and associated data. At a minimum, data shall be recorded and retrievable for the period from 2 s before the fault event to 2 s after the event at a sampling rate that is appropriate for the application, but in not greater than 100 ms intervals. Identical log formats shall be used for all vehicle systems. This data shall be accessible at the system, using the PTU (Section 18) and

through the MDS. The Contractor shall determine the amount of memory required for the Historical Data Storage based on a 30 day preventative maintenance schedule.

- Test on Demand: Each system shall respond to MDS commands for controlled self-test and shall report the results to the MDS. The MDS shall also be capable of initiating self-tests of the individual subsystems and displaying the results. Tests will not be allowed unless the active cab reverser is in neutral.
- Real Time Data: Each system shall provide specific pre-determined operating (status) data to the MDS at sampling rates appropriate to the rate of change and priority of the sampled signal, and also respond to MDS requests for updated data. Sampling rates shall be menu selected. Transmission time delays shall be defined and identifiable.

#### **9.7.2.5 Additional Subsystem Diagnostics (Data/Fault Loggers)**

The diagnostics for each subsystem (data/fault loggers) shall meet the following requirements for microprocessor controlled subsystems, and shall apply to non-microprocessor controlled subsystems to the extent appropriate. The information is expected to correlate directly with and be more extensive than that reported to the MDS:

- Failure Indications: As described in this Section.
- Diagnosis Documentation: As described in this Section.
- Historical Data Storage: As described in this Section.

The Contractor shall prepare a report for each subsystem listing the parameters that will be recorded, events to be recorded, self-tests, sampling rates, and other related items. (CDRL 9-22)

A description of the data/fault logger functions shall also be included in the Software Requirements Specification for each subsystem. Refer to Section 17.

An LED display on each system shall allow visual verification of the health of the system without the use of either the MDS or a PTU.

### **9.7.3 Monitoring and Diagnostics Data Collection and Management**

#### **9.7.3.1 Diagnostic Test Equipment**

There shall be a conveniently located USB or Ethernet connector in the cab for a PTU to fully test the MDL, to download faults and to make any needed changes to user settings.

The portable testers shall comply with all of the requirements for PTUs specified in Section 18.

#### **9.7.3.2 Vehicle Monitoring and Diagnostics System Data Management**

The vehicle MDS shall be equipped with a wireless communications transceiver for the purpose of transmitting MDS data to the vehicle maintenance workstation in the OMF and OMSF shops installed by the Contractor. Communications shall be secure and encrypted to prevent unauthorized users from accessing the data or system.

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A Data Management Work Station equipped for wireless communications shall be provided to interrogate vehicles when they are in the maintenance shop and storage yard. It shall store and analyze the data collected from the MDS. Refer to Section 18.

### **9.8 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 9-1 Single-line power distribution diagrams (Section 9.1)
- 9-2 Load analyses for the ac and dc systems (Section 9.1)
- 9-3 Grounding scheme (Section 9.1.2)
- 9-4 Pantograph design report (Section 9.2.1)
- 9-5 Lightning arrestor rating selection analysis (Section 9.2.2.1)
- 9-6 High speed circuit breaker design report (Section 9.2.2.2)
- 9-7 Shop power connection design report (Section 9.2.2.3)
- 9-8 Ground fault protection design report (Section 9.2.2.4)
- 9-9 Alternative power return and safety ground arrangements (Sections 9.2.3.1, 9.2.3.2)
- 9-10 Line filter system design report (Section 9.2.4)
- 9-11 Auxiliary power supply design report (Section 9.3.1)
- 9-12 Load management design report (Section 9.3.3)
- 9-13 Low-voltage power supply design report (Section 9.4.2)
- 9-14 Forced ventilation approval request (Section 9.5)
- 9-15 Equipment ventilation air filter design (Section 9.5.1)
- 9-16 Trainline and local signal architecture plan (Section 9.6)
- 9-17 Network protocols and transmission methodology (Section 9.6.3.1)
- 9-18 Monitoring and diagnostics system design report (Section 9.7.1)
- 9-19 Operating screen report (Section 9.7.2.2.1)
- 9-20 Trouble screen report (Section 9.7.2.2.2)

## *General Electrical Equipment*

9-21 Maintenance screen report (Section 9.7.2.2.3)

9-22 Data/fault logger report for each subsystem (Section 9.7.2.5)

### **9.9 Cited References**

The following standards or references were cited in this Section at the referenced location:

IEC 60310	Railway applications - Traction transformers and inductors on board rolling stock (Section 9.2.4)
IEC 60349	Electric traction - Rotating electrical machines for rail and road vehicles (Section 9.5.2)
IEC 61133	Railway Applications – Rolling Stock - Testing of rolling stock on completion of construction and before entry into service (Section 9.2.1)
IEC 61373	Corrigendum 1 - Railway applications - Rolling stock equipment - Shock and vibration tests (Section 9.2.4)
IEEE Std 11	IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles (Sections 9.3.1, 9.4.2.1)
IEEE Std 1476	IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces (Sections 9.3.1, 9.4.1)
NFPA 130	Standard for Fixed Guideway Transit and Passenger Rail Systems (Section 9.4.3.6)

**END OF SECTION 9**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 10  
PROPULSION SYSTEM AND CONTROL**

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## **SECTION 10: PROPULSION SYSTEM AND CONTROL**

### **10.1 General**

The propulsion system includes power modulation devices, traction motors, drive gear units, control logic, wheel spin-slide correction, circuit protection devices, dynamic brake resistors, and all accessories necessary to meet the specified requirements of propulsion and dynamic braking.

Provide one traction motor for each axle of each end truck. Provide at least one ac inverter drive for each end truck. The equipment shall be of a service proven design as defined in Section 2. For equipment that does not meet the requirements of Section 2, the Contractor shall provide the location and duration of the equipment's revenue service operation showing that it has been operated for at least one year in revenue service on a rail vehicle, with the names and addresses of references at the operating authority, a detailed description of the development process showing how preceding service proven equipment designs have been modified, and a detailed description of any additional modifications that will need to be made to comply with the Specifications.

The inverter switching and grounding scheme shall guarantee that current leakage paths from the traction motor to the primary power ground brush return assemblies are eliminated to the extent that no components of the drive train are damaged by leakage current. The propulsion system qualification laboratory test described in Section 16, Testing shall expressly include measurements to verify that no leakage current is flowing along the drive train components from traction motor to ground.

Within 180 days of NTP the Contractor shall prepare a propulsion system design report. When data is requested in this Section for design review, it shall be included in this report unless otherwise specified. (CDRL 10-1)

### **10.2 System Requirements**

#### **10.2.1 Propulsion System Configuration**

Power modulation in both propulsion and dynamic braking shall be accomplished by microprocessor-controlled, three-phase ac inverters.

Two independent inverter drive units shall be provided, one for each powered truck. The drive unit for each truck shall perform its functions, including propulsion, dynamic braking, and wheel spin-slide correction, even if the other truck's drive unit is not functioning. The inverter drive units shall be identical and interchangeable between trucks.

Power collection and primary protection equipment may be shared between the two truck-control systems.

Power switching devices shall be located on the car roof near their respective trucks with motor cable lengths kept as short as practical. Control electronics for each truck shall also be located

near that truck, either in the propulsion container on the roof or in an electric locker inside the vehicle. Drive Configuration

Drive configuration shall be one motor per axle (two motors per truck). The traction motor shall drive its associated axle through a gear drive. The arrangement shall minimize unsprung weight on the driven axles and shall provide resilience to absorb the shocks resulting from running through special trackwork. All motors, gear units and couplings shall be interchangeable between motor trucks and from axle to axle.

### **10.3 Equipment Thermal Capacities**

#### **10.3.1 Normal Duty**

The continuous thermal rating of all propulsion system components shall exceed the rating that is necessary to operate with the normal duty cycle, over the allowable range of overhead contact system voltage as specified in Section 2. All propulsion system components shall function as specified and without damage under these conditions. Component life and reliability shall meet or exceed the specified minimum overhaul cycles and reliability requirements, respectively.

Rheostatic braking resistors shall be sized for the specified duty cycles, as if there were no regenerative braking and the resistors must dissipate all braking energy.

#### **10.3.2 Worst Case Duty**

The worst case duty cycle shall be based on consideration of the following three cases: towing requirements, operation with one truck cut-out, or the normal duty cycle, all as defined in Section 2, whichever is worse. If the normal duty cycle provides the worst case, all equipment shall be thermally rated as specified in the Normal Duty section, above.

If the towing requirements or operation with one truck cut-out present the worst case, then the traction motor abnormal duty rating may be based on the temperature rises allowed for its actual insulation class.

The Contractor shall submit the simulations and component thermal ratings for both duty cycles as part of the CDRL 10-1 Propulsion System Design Report.

#### **10.3.3 Equipment Temperature Control**

Equipment may be cooled by natural convection or forced air. Refer to Section 9 for forced air ventilation requirements.

Equipment cooling shall be provided on a per-truck basis so that continued operation is possible in the event of a single cooling system failure.

Propulsion equipment, including traction motors and power modulation devices, shall be protected from damage due to cooling failure. Detection of cooling failures shall illuminate the appropriate propulsion fault indicators and automatically reduce performance of the affected components. If temperatures continue to rise during reduced performance operation the

propulsion unit shall be shut down. Cooling failures confined to a single truck's drive equipment shall not disable the other truck's drive equipment. Actual or calculated temperature measurements shall be used to control any equipment ventilation blowers (refer to Section 9 for equipment ventilation blower requirements).

#### **10.4 Switching Line Transients**

All vehicle-borne equipment shall withstand all vehicle and wayside generated transients without damage or reduction in life.

Refer to Section 2 for details regarding the overhead contact system voltages.

#### **10.5 Electromagnetic Interference**

Electromagnetic interference (EMI) limits as specified in Section 2 shall not be exceeded as a result of propulsion system operation. In addition, the propulsion system shall be designed to operate in an environment of high ambient electrical noise. Such electrical noise could be self-generated, generated by other vehicle systems, or generated off-vehicle. Coordinated with the reporting requirements of Section 2, the Contractor shall prepare a design report on EMI produced by the propulsion system and the system's noise immunity. The report shall be submitted as part of the propulsion system design documentation. (CDRL 10-2)

Brake choppers in the ac inverter systems shall have a fixed firing frequency which shall be established in coordination with Sound Transit so that electromagnetic interference with other vehicle systems and non-vehicle equipment shall not inhibit or adversely affect normal functioning and safety of such systems and equipment.

#### **10.6 Performance Characteristics**

The propulsion system shall provide train acceleration and deceleration rates as specified in Section 2. The command signals shall be the master controller trainline signals (both discreet trainline and data communications bus signals) specified in Section 5 and the load compensation signals. The output of the system shall be the train acceleration or deceleration tractive effort corresponding to the commanded rate value.

##### **10.6.1 Accuracy and Response Times**

The propulsion system time response shall be sufficiently fast to:

- Provide the specified vehicle acceleration and deceleration rates, jerk rate, and mode change dead times with accuracy as specified in Section 2
- Provide the specified wheel spin and wheel slide correction efficiencies as defined in Section 2

The specified accuracies and response times shall be independent of ambient temperatures within the range, variations of the low-voltage supply within the limits, and variations in the wayside power supply voltages as specified in Section 2.

### **10.6.2 Load Compensation**

The propulsion control system shall adjust tractive effort to compensate for varying passenger loads on a per-one-half vehicle basis, with the system for a truck providing the tractive effort for load on that truck and one-half of the load on the adjacent center truck. Compensation shall be provided by measurement of passenger loading on a per-truck basis in both propulsion and braking. Sensors and associated circuits shall be continuously or periodically checked to verify that they are functioning properly. Refer to Section 2.

In the event the load compensation signal is not within the allowable range, the system shall default to the load weigh signal of the adjacent truck.

Load compensation may use signals processed by the propulsion control or signals that have been processed by the friction brake system. However, in either case the same signal shall be used by both propulsion and friction brake systems.

Alternative methods for load compensated tractive effort may be proposed.

### **10.6.3 Friction Brake Control**

The propulsion control logic shall provide signals to the friction brake control logic for modulation of disc braking effort during dynamic braking and under wheel slide conditions.

#### **10.6.3.1 Dynamic Brake Effort Feedback Signal**

Dynamic braking effort feedback signals, one for each powered truck, shall be supplied to the disc brake control logic system to indicate the braking tractive effort being produced on that truck. The calibration and error checking schemes for these signals shall be jointly developed by the propulsion and brake equipment suppliers under supervision of the Contractor. (Include in CDRL 10-1)

#### **10.6.3.2 Wheel Slide Control Signals**

The wheel spin-slide system shall produce an independent correction signal for each of the three trucks to modulate the dynamic and/or friction brake effort under sliding conditions such that the wheel slide system performance requirements of Section 2 are met. The wheel spin/slide logic may be located entirely within the propulsion systems on the vehicle or may be shared with the friction brake control logic. The center truck shall be provided with independent pressure control for each pair of wheels and separate wheel-slide correction signals shall be provided for each of these pairs of wheels. Appropriateness of wheel spin-slide detection values and control times shall be verified during car performance testing and shall be modified as required to provide the performance specified in Section 2.

The spin/slide control function shall be jointly developed by the propulsion and brake equipment suppliers under supervision of the Contractor, with final review and approval by Sound Transit. The spin/slide signal type and distribution shall be approved by the friction brake and propulsion suppliers. (Include in CDRL 10-1) Data and signals used as input to the spin/slide control system shall be selected and structured to minimize signal propagation delays caused by signal

conversion and transmission to the greatest extent possible such that the signals arrive in real time at the propulsion and friction brake Electronic Control Units. The design shall be fault tolerant such that failures will result in application of full commanded braking effort.

The wheel spin-slide control shall also be interfaced with the sanding trainlines to provide automatic sanding for control of spins and slides. Approximately 0.5 s after a spin or slide is detected, the leading sanders on every power truck in the train shall be activated by the sanding trainline, with sanding continuing until the spin or slide is corrected or no-motion is detected. Include the criteria for automatic sanding activation. (Include in CDRL 10-1)

### **10.6.3.3 Maximum Brake Control**

The propulsion control system shall respond to the maximum brake trainlines by inhibiting the drive mode and producing a load-weighted dynamic braking effort so that the vehicle achieves the braking performance specified in Section 2. The amount of braking effort shall be coordinated with the friction brake equipment such that the propulsion system effort complements a fixed braking effort applied by each friction brake component. The propulsion system for each truck shall have an interface with the friction brake system on that truck to indicate the proper operation of dynamic braking on that truck. The carbuilder shall submit a report on the maximum brake control scheme and how braking effort will be distributed between the propulsion and friction brake components to achieve the specified Maximum Brake rates. (CDRL 10-3)

### **10.6.4 Dynamic Brake Capability**

Dynamic braking effort shall be produced by the propulsion system as specified in Section 2.

The dynamic brake shall be combined regenerative and rheostatic and shall be available from maximum vehicle speed down to a vehicle speed of 6 mph (9.7 km/h) or less. The dynamic brake control system shall continuously monitor line voltage, shall supply to the line the maximum amount of energy possible within the line voltage limits prescribed, and shall divert to the braking resistors only the generated energy in excess of that accepted by the line. Once initiated, dynamic braking shall be available independent of the presence of line voltage.

The propulsion controls may be configured to use a low level of regenerative braking to maintain the line voltage at the input filter and for auxiliaries during line gaps or other discontinuities in the primary power supply regardless of commanded operating mode (motoring, coast).

### **10.6.5 Mode and Rate Selection**

The propulsion system shall directly utilize both the trainlined (rate, direction, brake, and power mode selection signals generated by the master controller), and the network bus signals, as specified in Section 5.

The propulsion control equipment in each vehicle shall passively interpret the trainlined commands without loading the trainlines beyond their design limits.

The drive mode shall be inhibited, at a minimum, by the following:

- Maximum Brake Applications, as indicated by de-energized Maximum Brake Trainlines. Refer to Sections 2 and 5.
- Overspeed ATP tractive effort removal. Refer to Section 14.
- Service brake applications, parking brake applications, low hydraulic fluid level, and low hydraulic accumulator supply volume and pressures (inhibited on a timed basis) as may be indicated by a de-energized Friction Brakes Released trainline. Refer to Section 12.
- Doors Open or Unlocked as indicated by the Door Status Interlock trainlines. Refer to Section 6.
- Direction Out-of-Correspondence, on a vehicle basis as described in the Direction Change section, below.

### **10.6.6 Train Operation**

The propulsion system in each vehicle shall correctly respond to the trainline commands, including mode command, direction command, and rate command.

The propulsion system shall respond smoothly, predictably, and safely under all conditions.

The propulsion control logic shall coordinate propulsion and brake efforts in order to avoid rollback.

### **10.6.7 Direction Change**

Direction change shall be provided by traction motor phase rotation reversal. The reversing logic shall respond to the trainlined direction control signals as indicated in Section 5. A change of direction shall be possible only when no-motion is detected. Correspondence between the trainline command and the motor phase rotation shall be monitored, with out-of-correspondence conditions annunciated as a propulsion system fault. The propulsion mode shall be inhibited on the truck with the fault.

### **10.6.8 Cut-Out Control**

Provisions shall be included for each powered truck of a vehicle to be independently disabled and isolated from the primary power supply independent of the auxiliary power supplies. This isolation will be referred to as "propulsion cut-out". With one truck cut out on a single vehicle, or with one or both trucks cut out on one vehicle in a consist, it shall be possible to operate the vehicle or consist in either direction as described in Section 2 at speeds up to 25 mph (40 km/h) with no damaging effects. An overspeed limit—of 25 mph (40 km/h) shall be automatically applied when any truck in a train is cut out. Refer to the Motor Overspeed Protection section, below. All other systems shall remain operational and propulsion cut-out shall not affect the operation of the master controller on the cut-out vehicle.

The propulsion cut-out switch(es) shall be mounted in an electric locker in each cab. Activation of the propulsion cut-out switch shall be monitored by the MDS and the appropriate status indications shall be displayed on the Train Operator Display (TOD). Additional status indications shall be as required in Section 5.

### **10.6.9 Wheel Spin-Slide Correction**

A wheel spin-slide detection and correction function shall be provided as an integral part of the propulsion control system. The system shall provide the spin and slide correction signals for the propulsion system and shall provide slide control signals for the friction brake systems if the friction brake system has no wheel-slide detection logic. Arrangements with wheel spin-slide control in both the propulsion and friction brake systems are acceptable provided that they function in coordination, such that they do not compete for control, and such that all functional requirements are provided for the vehicle. The wheel spin-slide system shall maximize the use of dynamic braking during a stop; systems that cut-out dynamic brake when a slide is detected are not permitted; refer to the Wheel Slide Control Signals section, above. The wheel spin-slide correction system shall meet the requirements of Section 2.

The control logic shall take full advantage of vehicle's three-truck configuration in developing the estimated vehicle ground speed used in the spin-slide control calculations. Wheel spin-slide control logic design shall be submitted. (Include in CDRL 10-1)

### **10.6.10 Motor Overspeed Protection**

The propulsion control system shall include overspeed protection logic to limit train speed to set values by means of tractive effort control. This function shall be independent of the vital train overspeed protection imposed by the ATP system specified in Section 14.

The speed information shall be derived from a source that is corrected for wheel wear.

The motor overspeed protection logic shall remove propulsion tractive effort when the vehicle speed exceeds the overspeed protection set point. Power shall be restored when the speed drops 3 mph (4.8 km/h) below the set point, or as recommended by the propulsion supplier. This function shall be provided on an individual propulsion system basis and shall be annunciated to the cab by the MDS:

- The motor overspeed protection set point for the system shall be 58 mph (93 km/h)  $\pm$  1 mph (1.6 km/h) when systems are normal or when the Speed Restriction Bypass Switch has been placed in the BYPASS position and ATP is cut-out.
- The motor overspeed protection set point for the system shall be 25 mph (40 km/h), with a tolerance of  $\pm$  1 mph (1.6 km/h), when in ATP bypass mode, when any propulsion or brake equipment has been cut-out, or when a propulsion or brake system failure has been detected.

### **10.6.11 Circuit Protection and Visual Annunciation**

Circuits powered from the primary power wire system shall be protected as required by Sections 2 and 9.

Control circuits shall be protected by low-voltage circuit breakers.

A dynamic brake failure detection function shall be provided for each motor truck. Whenever dynamic brake is commanded, this function shall verify that adequate dynamic braking effort is being produced; if it is not being produced, a local propulsion fault shall be indicated for that truck and the location of the propulsion fault shall be indicated on the Train Operator's Display. The dynamic brake feedback signal to the friction brake system shall be clamped at zero under dynamic brake failure conditions. Dynamic brake failure detection design shall minimize nuisance fault annunciations due to transient events, including momentary loss of primary power when braking is initiated.

Visual annunciation of all propulsion system faults including cut-out, general faults, ventilation failure, and overheating shall be provided on both a trainline and local basis, as specified in Sections 5 and 9, and shall cause the reduced overspeed set point to be imposed as specified in the Motor Overspeed Protection section, above.

The propulsion system shall interface with the MDS by means of the vehicle data bus as specified in Section 9.

An integrated fault management function shall be provided for the propulsion system, including but not limited to, fault detection and annunciation, system protection, fault data collection, and automatic fault reset capability.

### **10.6.12 Routine Switching**

Traction motor input power conditioning, including motoring, braking, and direction reversal, shall be accomplished by suitably rated IGBT devices. The brake chopper shall utilize an IGBT switching device on the primary side with a freewheeling diode across the brake resistor.

### **10.6.13 Line Switch**

A high-speed line switch shall be provided for each inverter to make and interrupt power during normal or faulted conditions, and to isolate the inverter from primary power when the inverter is cut-out. Operation of the line switch shall be coordinated with the HSCB described in Section 9. Line switch capability shall be coordinated with input protective device capability. The line switch may be either a contactor or a solid state device.

If a solid state line switch is used, it shall operate with bi-directional current flow. The semiconductor selection and application for this purpose shall be submitted. (Include in CDRL 10-1)

If a contactor is used it shall comply with the requirements of the Contactors section, below.

The line switch, its control, and associated equipment shall be arranged to limit instantaneous inrush currents under all operating conditions to a value that will not cause failure or deterioration of any component, including fuses, and will not cause nuisance tripping of wayside substation breakers. Any means adopted to achieve this capability shall not materially interfere with car performance under conditions of intermittent collector contact, as with an icy contact wire.

#### **10.6.14 Adjustability**

Propulsion system operating characteristics, including tractive effort and jerk limit, both in motoring and braking, shall be fully adjustable by Sound Transit within the specified performance range. The system shall be adaptable such that adjustments shall not be necessary to compensate for component wear, aging, and similar phenomena.

Compensation for a reference wheel's diameter shall be provided using software commands from Portable Test Units. Adjustments shall be made in 0.04 in (1 mm) increments of wheel diameter, covering the full range between new and fully worn diameters. Other required wheel size compensation shall be automatic, except ATP wheel wear compensation described in Section 14.

Except where otherwise specified, adjustments shall be by updating microprocessor flash memory.

#### **10.6.15 No-Motion Logic**

The propulsion system shall include the vital no-motion logic specified in Section 2.

### **10.7 System Components**

#### **10.7.1 Traction Motors**

All motors shall be identical and completely interchangeable.

Ac traction motors shall have the following basic design features:

- Motor type: Three phase, squirrel cage induction motor, with copper cage, and formed stator coils.
- Ventilation: Totally enclosed self-ventilated. Splash-proof, self-vented motors shall be required.
- Duty: Thermally rated in accordance with the duty cycles as defined in Sections 2 and 10.
- Load Sharing: The motor characteristics shall allow all performance characteristics to be met with wheel diameter differences which vary between 0 and 0.24 in (6 mm) between axles on a truck, and with the wheels on one axle being the fully worn wheel diameter. For trucks that do not have an axle with fully worn wheels, the motor characteristics shall allow all performance characteristics to be met with wheel diameter differences of 0.24 in (6 mm) multiplied by the actual minimum wheel diameter on the truck, and then divided by the allowable fully worn wheel diameter.

- **Motor Standards:** The traction motor shall be designed in accordance with IEC 60349-2.
- **Insulation:** The motor, when operated under the conditions specified in Section 2, shall remain within the Class F temperature designated in IEC 60349-2, Section 8, Type Tests, with Class H winding insulation, or within the Class H temperature range with Class C insulation, except for towing as noted in this Section. Under towing conditions motor temperatures may increase to the thermal class of the motor insulation. The motor stator coils shall be Vacuum Pressure Impregnated (VPI) in the complete stator frame assembly. The Contractor shall manufacture sample sections of the stator and winding assemblies to verify the VPI process. These sample stator assemblies shall undergo the VPI process simultaneously with production stators. The Contractor shall section the simulated stator assemblies to establish freedom from voids and to verify that there is good bonding. This VPI verification shall be conducted with the first two stators and two other selected at random by Sound Transit. If voids are found, as determined by Sound Transit, then the process shall be modified until corrected and the quantity of samples shall be increased as determined by Sound Transit. All VPI verification costs, and subsequent corrections to production motors, shall be borne by the Contractor. Alternative VPI verification procedures may be proposed, if successful manufacturing experience is provided.
- **Enclosure:** Shall be splash-proof self-ventilated as appropriate.
- **Mounting:** Each traction motor shall be resiliently mounted, either directly to the truck frame or to both the truck frame and gear unit, as described in this Section. Alternatively, the motor may be mounted directly to the gear unit with a membrane coupling. The unsprung mass of the motor-gear unit assembly shall be kept to a minimum. Safety straps, tabs or hangers shall be provided as required to prevent damage in the event of motor or gear unit mount failure (refer to Section 11 for safety hangers).
- **Shaft Coupling:** A splined or taper fit, flexible coupling shall be provided between traction motor and gear unit shafts. The coupling design and motor-gear unit mounting arrangement shall minimize coupling dynamic angular displacement. An arrangement in which the traction motor is rigidly mounted to the gearbox and the traction motor drive shaft shares the gearbox input shaft bearing is acceptable. If this arrangement is provided, access to the membrane coupling shall be from the top side of the assembly.
- **Maximum Safe Speed:** The motor shall be designed to run continuously, with no damage, at a speed corresponding to a car speed of 60 mph (97 km/h) with fully worn wheels.
- **Bearings:** Grease lubricated, NFL, antifriction bearings shall be provided. Grease cavities shall be large enough to hold a five year supply of lubricant, and designed to force grease through the bearing(s) when grease is applied under pressure. Arrangements which use gear lubricant for the traction motor bearing at the pinion end are acceptable. Ball bearings shall be rated according to ANSI/ABMA 9. Roller bearings shall be rated according to ANSI/ABMA 11. Bearings shall have an ANSI/ABMA L10 rating life equivalent to 1,000,000 mi (1,609,000 km) of service or greater. (Note that the L10 life rating value is not a guaranteed performance value, but a rating to allow for bearing comparison.) Access to the grease fittings shall be possible without removing the trucks from the car body.

- Service Life to Overhaul: Traction motors shall have a minimum service life to overhaul of not less than 800,000 mi (1,287,500 km).
- Rotor Balance: The traction motor rotor cage shall be of copper alloy bars with brazed or welded rings. The rotor and cooling fan shall be dynamically balanced separately so that, after they are assembled, vibration does not exceed the requirements below, without any balancing following assembly. Balance correcting weights shall be metal, and shall be welded in place, secured in retention grooves, or bolted in place.
- Vibration Limits: The vibration of any traction motor shall not exceed the vibration requirements of IEC 60349-2.
- Noise: Motor shall meet the requirements of Section 2.
- Markings: Terminals, leads, and motor frames shall be clearly marked for positive identification.
- Electrical Connections: Motor connections to vehicle wiring shall conform to the requirements of Sections 9 and 17. Leads shall be secured to avoid insulation chafing and shall be routed to accommodate all truck motions without interference or excess strain. The current value used in determining the minimum size of motor leads shall not be less than 50% of the maximum load current seen under the most severe normal duty, or as determined by the root-mean-square method, and shall conform to NFPA 130. All connectors and related hardware shall be rated for the peak voltages and currents present.
- Traction motor over temperature protection shall be provided. If the winding temperature rises 27°F (15 K) above the designed operating temperature limit, the control unit shall decrease the motor duty cycle by removing the electrical braking and converting into friction braking on the affected truck. The decision shall be made by calculating the power that the motor is consuming. The measurement of winding temperatures with embedded sensors is not permitted. A motor overheating fault shall meet the indication requirements of Section 5 and shall cause the reduced overspeed set point to be imposed as specified in the Motor Overspeed Protection section, above.
- End bell castings shall be of ferrous material. Non-ferrous materials such as aluminum shall not be permitted.

### **10.7.2 Gear Drive**

Each motored axle shall be driven by a parallel, single-reduction or double-reduction drive gear unit designed and manufactured for bi-directional service. The gear drive chosen shall be a service proven design as defined in Section 2.

Gear units shall be equipped with anti-friction bearings throughout. Bearing design and selection shall require inspection no more frequently than once every 500,000 mi (804,700 km). Ball bearings shall be rated according to ANSI/ABMA 9. Roller bearings shall be rated according to ANSI/ABMA 11. Bearings shall have an ANSI/ABMA L10 rating life equivalent to 1,500,000 mi (2,500,000 km) or more of service. External bearing shaft seals shall be the labyrinth type,

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with supplemental sliding contact seals or deflectors, to preclude high velocity splashed water from entering the gear units.

Gears shall be designed and applied to require inspection no more frequently than once in every 800,000 mi (1,287,500 km) and have a life of at least 1,000,000 mi (1,609,000 km).

The gear unit shall be oil lubricated and provided with sufficient baffles, dams, and passages to ensure an adequate flow of lubricant to all bearings and gears under all combinations of acceleration, speed, direction, load, and environment. The gear unit shall prevent infiltration of moisture into the lubricant from any and all sources and shall not require replenishment of oil in between oil change intervals. If rubbing seals are provided, a breather resistant to water intrusion is required.

The gear unit shall have openings with removable plugs located with easy access for filling and draining. Plugs shall be of a type or be located to prevent damage by obstacles on the track and the resultant loss of lubricant. Plugs shall be secured by lock wires to prevent loosening in service. The gear case shall be provided with a readily accessible glass sight gauge protected by an approved captive cover for use by the maintenance department.

The filler plug opening shall be arranged to provide an indication of oil level and also prevent overfilling. Drain or filler plugs shall have magnetic particle collectors.

Removable and accessible oil-tight and airtight inspection covers shall be provided on the gear housing for visual inspection of the gears.

Gear units shall conform to the noise requirements in Section 2.

Gear unit pinion shaft and coupling shall be balanced if an arrangement in which the traction motor is rigidly mounted to the gearbox and the traction motor drive shaft shares the gearbox input shaft bearing

The Contractor shall provide tools required for the removal of the pinion shaft coupling as part of Special Tools.

All gear units shall be given an approved routine test before application. Two gear units, one from the initial five gear units and another from mid-production shall be qualification tested. (Refer to Section 16)

### **10.7.2.1 Gear Unit Mounting**

One of the following motor and gear unit drive and mounting arrangements shall be provided.

- Parallel drive with the motor and gear unit rigidly attached together. Mounting shall be a combination of resilient attachment to the truck frame and gear unit suspension from the axle by an elastomeric coupling. This elastomeric coupling shall also couple the gear unit output to the axle.

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- Parallel drive with the motor attached resiliently to the gear unit with the gear unit hard-mounted to the axle. Resilient mounting of the opposite end of the assembly to the truck frame shall be provided.

Elastomeric axle couplings shall not require lubrication and the elastomeric application shall be at stress levels providing a service life of at least 800,000 mi (1,287,500 km). The elastomer elements shall be shielded from heat radiation from friction brake discs. The coupling design shall provide sufficient clearance between the axle and the inside of the gear unit output quill to prevent contact between them with one wheel of a truck raised 2 in (50 mm) with a vehicle weight from AW0 to AW4. All critical parts of the coupling shall be visible for inspection without disassembly or removal of any part.

The friction brake hub may be attached to the gearbox output shaft as discussed in Section 12.

The motor and gear unit drive and mounting arrangement provided shall meet the specified noise, vibration, ride quality, shock loading and maintenance requirements.

### **10.7.3 Ventilation System**

Ventilation equipment shall conform to the requirements of Section 9.

### **10.7.4 Dynamic Brake Resistors**

Dynamic brake resistors shall be edge-wound ribbon, flat wound ribbon, or stamped sheet metal types. The application design shall conform to NFPA 130.

The resistors shall have sufficient capacity to provide full power dissipation during operation at full service braking over the specified profile and passenger loadings up to, and including, AW3, assuming no regeneration into the line. This shall be demonstrated by the propulsion system qualification test (refer to Section 16) and by on-site testing (Propulsion Performance tests; refer to Section 16.) Maximum active element temperature under these conditions shall be limited to 1022°F (550°C).

Dynamic brake resistor grids shall be electrically isolated from their frames, and the frames shall be electrically isolated from the vehicle body and heat shield or enclosure with high temperature insulation. Provision shall be made for grid expansion to prevent warping. The resistor grids shall be convection air ventilated and roof mounted. Exhaust air and radiated heat from the resistors shall be controlled to prevent damage to closely mounted overhead contact wire and associated messengers and feeder cables. Screens shall be provided to protect convection cooled resistors from overhead vandal damage. The screens shall be strong enough to resist damage due to persons working on the roof. Convection cooled resistors shall be rated for cooling in still air unless the Contractor demonstrates to the satisfaction of Sound Transit via analysis and test that a certain minimum contribution from the car motion may be considered.

All resistor elements, resistor frames, heat shields, screens, enclosures, and hardware shall be made of stainless steel. All resistor components shall be selected both for their thermal and mechanical properties, and corrosion resistance. Refer to Chapter 17 for material requirements.

### **10.7.5 Static Power Devices**

Propulsion power semiconductor assemblies shall be functionally grouped, keyed, and mounted in modular form to facilitate maintenance and easy removal. Power semiconductors shall be applied and installed per the manufacturer's recommendations.

All propulsion system power circuit control components and the insulators associated with such components, other than braking resistors, shall be mounted in sealed cabinets to prevent dirt and moisture from affecting the components and from reducing the insulation rating of the equipment. If necessary to avoid ozone build-up, the enclosures where power contactors are mounted may be connected to the atmosphere via screened and filter-protected openings. Any filters used for this purpose shall be designed to preclude snow and water ingestion into the enclosure and shall be self-cleaning.

Forced air may be used where required for heat sink temperature stabilization, but shall not be used to ventilate the inside of the equipment cabinets. Cooling air shall be routed through channels free of high-voltage stress to avoid arc-over at dirt build-up zones. Inclusion of heat sinks at voltage potentials other than ground is prohibited. The ventilation air supply shall conform to the requirements of Section 9. Refer also to the Equipment Temperature Control section, above.

The Contractor shall provide Sound Transit with all information necessary to maintain the power device assemblies, including device replacement and reassembly.

### **10.7.6 Contactors**

The use of contactors for propulsion control shall be minimized to the greatest possible extent. All contactor applications shall be submitted for Sound Transit consideration. (Include in CDRL 10 -1)

In normal operation contactors shall be operated under no load conditions only.

All propulsion system power circuit control contactors shall be capable of safely interrupting the maximum possible load current in case of a control malfunction. Contactor rating and operation shall be coordinated with circuit protection elements. The contactors shall be designed for a minimum of 1,000,000 mechanical operations. The arc chute design shall permit the arc to be safely guided away from the operating contacts, independent of the direction in which current is flowing. Venting shall be provided to prevent ozone buildup in the contactor compartments, as described in the Static Power Devices section, above. The arrangement of arc chutes, blowout coils, and venting, along with the contactor tip size, shall allow safe continued operation upon reset after a malfunction.

Contactors shall be installed for easy accessibility for routine inspection and maintenance. Access to the contactors shall require only opening an enclosure cover. Access to the contact tips shall require only removal of the arc chute, which shall be retained by spring catches or similar devices. Refer to Section 17 for additional requirements for contactors.

### **10.7.7 Propulsion Line Filters**

The propulsion apparatus for each motor truck shall be protected by a separate input filter that conforms to the requirements of Section 9. Each input filter shall be provided with a charging circuit that shall limit charging current and input voltage overshoot to approved levels. Input filters shall be designed to preclude the generation of EMI in excess of that which will provide safe and reliable operation. It is also essential that filter resonance frequencies, considering filter coupling with wayside inductances and capacitances, be far removed from all wayside signaling frequencies.

### **10.7.8 Speed Sensing**

Speed sensing devices shall be provided to measure all axle and separate wheel speeds. They shall be installed on the axles or wheel assemblies, or incorporated as integral with traction motor or gear box if higher resolution is desired. The number of speed sensors shall be sufficient to continue normal operation with one speed sensor failed on each motor truck.

Speed sensor types and mountings shall be identical between motor trucks and within the center truck. An exception may be if special, dedicated speed sensors are required by the ATP supplier. Mounting shall be such as to avoid lubricant loss when removed and shall be arranged to minimize the need for mechanical adjustment

All speed sensing gears, toothed wheels, or similar devices shall be mounted on their shafts via keys, splines, or press fits. The mounting method shall be selected to guarantee that the speed measuring device cannot indicate speeds other than the actual axle speed under all conditions except massive drive train damage.

Speed sensor wiring shall be enclosed in conduit on the vehicle body and shall be run to a terminal box located above the speed sensor location on the truck. Speed sensors shall be connected to the vehicle body by shielded wires terminated in waterproof multi-pin connectors at each end. Refer to Section 17 for cable connector requirements.

All speed sensors shall be easily accessible for inspection, adjustment, and replacement both with trucks attached to vehicles over maintenance pits, on jacks, and with trucks sitting by themselves on the floor.

The sensors shall be the active magnetic pick-up type. The face of each speed sensor shall be smooth with no protruding elements. The sensor shall be hermetically sealed in a stainless steel case. The face shall be encased in a seamless stainless steel cover unless the sensor is guaranteed, and proven in service, to be immune to damage or inaccurate operation caused by continuous exposure to the intended lubricating fluids and temperatures. Optical encoders may only be used with approval of Sound Transit.

#### **10.7.8.1 Odometer**

An electronic odometer with permanent non-volatile memory or non-resettable electromechanical odometer shall be provided to display the total number of miles accumulated by the vehicle, as specified in Section 5. The odometer shall register miles to the nearest mile

and shall have a minimum of eight digits. The odometer shall be incremented by the propulsion system ECU or the Event Recorder.

When a GPS signal is not available the propulsion system shall provide backup distance signaling to the automatic station announcement and automatic passenger counting system specified in Section 13. Refer to the Dead Reckoning section in Section 14.

### **10.7.9 Control Logic**

The propulsion system control logic units shall be microprocessor-based with associated peripherals and I/O as required to meet all of the specified functions and performance criteria. The control units shall provide self-diagnostic routines, fault monitoring of internal and external devices, and user programmable operating characteristics. Refer to the Adjustability section, above, and Sections 9 and 17.

Each inverter shall be controlled by a dedicated control logic, integrated with the inverter in a protected compartment. The foundation of the control logic shall be a minimum 32 bit microprocessor with other processors and peripherals as necessary to meet all required functions and performance criteria. The control logic shall operate the propulsion inverter to produce positive or negative tractive effort as commanded by the trainlines and/or vehicle bus. The control logic shall interface with the controls of the friction brakes to provide brake blending, interface with spin-slide operation and additional functions as are necessary to provide a complete design.

The Contractor may propose a speed-sensor-less drive or a traditional inverter control with a speed sensor for each motor. The loss of one speed sensor shall not disable the affected truck.

The inverter drive control system shall be a modern vector control system utilizing space vector modulation technology, with sufficient accuracy to provide stable operation at any speed, including standing still on a grade. The space vector modulation control shall be configured so as to minimize traction current harmonics to the greatest extent possible. Sinusoidal PWM controls are not allowed.

The control logic shall provide all the necessary control functions to safely operate the vehicle in any operating mode. It shall also detect and respond safely to any abnormal operating conditions and provide ample diagnostic information regarding those incidents as described in Section 9.

Fully independent control logic units and logic power supplies shall be provided for each truck such that one truck can function if the propulsion equipment for the other has failed.

If the no-motion function is provided as checked redundant signals from the separate propulsion logic units, no-motion shall continue to be provided by the other propulsion logic unit when one propulsion logic unit has failed. The condition shall be annunciated to the operator by the MDS. No-motion bypass shall not be required until both channels fail. Refer to Section 5 for bypass circuitry requirements.

## *Propulsion System and Control*

Electronic control equipment shall be segregated from the power equipment. Control circuitry and control voltage sources shall be galvanically isolated from power circuitry and high-voltage sources.

The control unit shall provide continuous monitoring of critical parameters, including motor currents, switching device currents, and component temperatures. The control unit and all related software and devices shall be sufficiently responsive to detect and remedy all erroneous or potentially damaging conditions such that equipment damage is prevented or minimized. The detection and response times of these anticipation circuits and software routines shall permit detection and corrective action before other protective devices, including the HSCB, react. The fault monitoring schemes and response performance shall be submitted. (Include in CDRL 10-1)

The control unit shall provide the interface with the Monitoring and Diagnostics System by means of the vehicle data bus as specified in Section 9, or by connection to the Ethernet communications bus. Propulsion system time setting shall be performed each time the train is keyed on by the Master Controller key.

Each control logic shall be provided with an Ethernet network connector for communication with the portable test units (PTU). The PTU shall be capable of initiating self-test of the system and isolating failures to Lowest Level Replaceable Unit level. The PTU shall also be capable of monitoring the propulsion system during vehicle operations. All commands and displays on the PTU shall be in English and standard engineering units (volts, amps, etc.). All time shall be presented in month/day/year and h/min/s formats. Refer to Section 18 for general requirements for portable test equipment. Fault isolation and self-test capabilities shall also be available via the MDS.

Each control logic shall be provided with a data/fault logger that complies with the requirements of Section 9. The data/fault logger shall create a record of at least eight relevant signals and time of recording whenever an unusual or erroneous condition is encountered during operation. Signals shall be converted to real units, e.g., volts, amps, time of day, etc. The fault information shall be stored locally and transmitted via the vehicle data bus to the MDS for storage and retrieval. Refer to Section 9 for MDS requirements. The signals specified in this paragraph will be provided through the PTU. The sampling rate shall be not less than 100 Hz for each channel.

Refer to Section 17 for general electrical and electronic design standards.

### **10.7.10 Wire and Cable**

All propulsion system wire, cable, and terminations shall conform to Section 17. Cables and connectors shall be keyed or grouped to prevent incorrect connection and adequately supported to prevent chafing, undue stress, and fatigue.

Traction motor cabling shall be kept as short as practical, designed and routed to minimize external electromagnetic fields and interference with other equipment. The cables shall be positioned a sufficient distance from ATP and TWC antennae and cables to avoid interference. As a minimum, a ground wire, connecting inverter ground to traction motor ground, shall be bundled with the three phase cables. There shall be no other ground connections of this cable between inverter and traction motor.

Quick-disconnects meeting the requirements of Sections 9 and 17 shall be provided for traction motor wires, including the ground cable, between the power trucks and car body, to facilitate removal of trucks. The connection method and hardware data shall be submitted. (CDRL 10-4) Ground wires shall conform to the requirements of Section 17.

## **10.8 Packaging**

### **10.8.1 Underfloor and Roof Mounted Equipment**

The propulsion system control, inductors, capacitors, and power devices shall be housed in enclosures suitable for roof or underfloor mounting, as applicable.

Refer to Section 2 for maintainability requirements, Section 15 for equipment enclosure requirements and Section 9 for ventilation requirements and restrictions.

Corrosion resistant stainless steel screens and guards shall be provided to protect roof mounted and underfloor equipment and ducts from wheel splash, flying ballast, dropped objects, or other similar items, and to prevent accidental employee contact of hot or electrically live equipment. Guards shall be designed or located so that they will not collect debris. Screens and guards shall be easily removable for maintenance and shall not prevent adequate cooling of equipment.

High velocity air exiting from any ventilation equipment shall be directed away from station platforms, the track, tunnel ceiling, or roof, so as not to disturb snow, dirt, and debris. Exhaust air from equipment shall not be directed to the air intake of other equipment.

### **10.8.2 Equipment Located in the Vehicle Interior**

Equipment located in the vehicle interior shall be installed in electric lockers in the cab or under seats. Under seat mounting shall be approved by Sound Transit on a case-by-case basis.

Equipment location and enclosure construction shall protect the equipment from dirt, conductive dust, and spilled liquids, including corrosive cleaning fluids. Additional requirements for console, roof, and floor mounted equipment are specified in Sections 2, 5, 15, and 17.

## **10.9 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 10-1 Propulsion system design report (Section 10.1)
- 10-2 EMI design report (Section 10.5)
- 10-3 Maximum brake control and distribution of efforts report (Section 10.6.3.3)
- 10-4 Traction motor/truck to car body wiring connection data (Section 10.7.10)

## **10.10 Cited References**

The following standards or references were cited in this Section at the referenced location:

ANSI/ABMA 9	Load Ratings and Fatigue Life for Ball Bearings (Sections 10.7.1, 10.7.2)
ANSI/ABMA 11	Load Ratings and Fatigue Life for Roller Bearings (Sections 10.7.1, 10.7.2)
IEC 60349-2	Electric traction – Rotating electrical machines for rail and road vehicles – Part 2: Electronic converter-fed alternating current motors (Section 10.7.1)
NFPA 130	Standard for Fixed Guideway Transit Systems (Sections 10.7.1, 10.7.4)

**END OF SECTION 10**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 11  
TRUCK ASSEMBLIES**

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## **SECTION 11: TRUCK ASSEMBLIES**

### **11.1 General**

This Section specifies the design and functional requirements for the truck assemblies. The "trucks" are defined as all components from the rail to and including the first components rigidly fastened to the car body. Gear boxes, motors, wiring, brake system components, cab signal antennae, and associated mounting brackets for these components are part of truck assemblies but are not included in this Section, except that any mechanical interface requiring welding or drilling on the truck frame shall be considered part of the truck.

Each vehicle shall be equipped with three, four-wheel trucks: a non-motored truck mounted under the center body section center lines, a motored truck under the "A" body section, and a motored truck under the "B" body section. The truck frames may be of either inboard or outboard bearing design. The non-motored truck shall include a dropped frame portion on the car longitudinal centerline, designed to clear the low floor interior passageway of the center "C" car (articulation) body section, and may use individual stub axles at each wheel location.

The trucks shall be designed and the truck frames manufactured by a supplier(s) who has designed and manufactured the same trucks previously, or shall be an adaptation of a design manufactured by the supplier. Adaptations are limited to changes in dimensions, materials or procedures necessary to comply with the Specifications.

The motor trucks and components shall be of a design or adaptation of a design meeting the service-proven requirements specified in Section 2. The service proven fleet shall have operated in the same or more unfavorable climatic conditions over track meeting FRA Class 4 requirements at the same or higher maximum speed. Four adjustable track clearers (two per truck) shall be provided. The track clearers shall be located at the outboard corners (adjacent to cab end) of the truck frame.

The non-motored truck and components shall be based on service-proven designs where possible. The design capabilities shall meet all Specification requirements at the specified speeds and track curvature, over track meeting FRA Class 4 requirements and in the specified climatic conditions. This shall include as a minimum, theoretical methods to predict the dynamic behavior of the trailer truck/articulation section, test methods to verify theoretical predictions during the design phase, and either method to ensure the proposed design will meet all Specification requirements.

Truck weight shall be kept to a minimum consistent with the strength, performance, and maintenance accessibility requirements of the Specifications.

The trucks shall be designed to minimize resonant vibrations when in operation. Surface contact between truck components, except suspension stops, shall be made through fabric reinforced, service-proven, non-metallic materials to impede the transmission of vibration and noise.

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The trucks shall be suitable for safe operation at speeds up to 65 mph (105 km/h) and shall provide the specified ride quality up to 55 mph (88 km/h) over the entire range of wheel wear and car loading.

The center truck shall provide the required ride quality and tracking capability without the need for periodic realignment of the wheel assemblies. The center truck and articulation design shall prevent sustained flanging of center truck wheels on tangent track. Sound Transit requires that vehicle dynamic simulations which demonstrate high speed stability, ride quality and center truck performance requirements be included in the Wheel to Rail Interface Study (WRIS) required by Section 2.

Any parts of either truck type requiring removal to permit truck removal, as described in the Clearance Considerations section, or otherwise, shall be mounted with accessible bolts, pins, or other approved fasteners which can be removed using common hand tools.

### **11.2 Truck Design Report**

The Contractor shall submit a truck design report that addresses all subsections of TS 11, in sufficient detail for review and approval. The Contractor shall submit a preliminary and one final version of the truck design report. The submittal dates shall be in accordance with the approved project schedule. (CDRL 11-1) Refer to the Documentation Requirements section, below, for content requirements.

### **11.3 Design Considerations**

#### **11.3.1 Service Life**

The truck structure shall have a service life of 30 years minimum, without the need for structural repairs.

#### **11.3.2 Wheel Base**

The truck wheel base shall be limited to the ranges specified in Section 2.

#### **11.3.3 Interchangeability**

Motor trucks shall be identical and fully interchangeable between either end of a vehicle, and among any vehicles furnished under this Contract, without modification. Center trucks shall be interchangeable among any vehicles furnished under this Contract, without modification. All components shall be interchangeable among all trucks.

#### **11.3.4 Wheel Truing Provisions**

The trucks shall be designed to be compatible with the existing Sound Transit wheel profiling machine such that it will be capable of truing wheels of both types of trucks without removal of trucks from the car or disassembly of any part of the truck or the carbody except the plugs or caps at the ends of the axle and end-of-axle ground brush equipment if used. (Include in CDRL 11-1) If required, hold down provisions shall be provided on the truck frame or journal

bearing housing that do not apply eccentric loads on the journal bearings. The Contractor shall coordinate with Sound Transit to ensure that the Sound Transit wheel profiling machine will be capable of truing wheels of both types of trucks. The Contractor shall identify and resolve all interface issues between the wheels, trucks, car body, and wheel truing machine. (Include in CDRL 11-1)

If the standard AAR wheel-measuring tape cannot be applied for inspection measurements of wheel diameter, the Contractor shall demonstrate an alternative method of measuring wheel diameter. (Include in CDRL 11-1) Should special measuring devices be necessary for this measurement, the Contractor shall supply three such devices.

### **11.3.5 Clearance Considerations**

The complete truck assembly shall clear the car body and car body-mounted equipment by not less than 1.5 in (38 mm). For center trucks which do not swivel under the center car body section, this clearance may be reduced to 0.5 in (13 mm). All truck parts, except wheels and track brakes, shall clear the plane of the top of rails by not less than 2 in (50 mm).

These clearance limits shall be met when full allowance is made for the most unfavorable combinations of:

- Wheel tread or flange wear;
- Static and dynamic primary and secondary spring deflection;
- Primary and secondary suspension failure;
- Static and dynamic suspension stop deflection, including possible wear of the suspension stops to the condemning limit;
- The full specified range and worst case combination of horizontal and vertical curves; and
- Any other possible movement of the trucks and associated parts including possible movement caused by the maximum excursions of any truck-mounted parts.

The design shall permit removal of the motor trucks from under the car in areas of minimum headroom. It shall not be necessary to raise the car body more than the minimum distance required for the motor truck and traction motors to pass beneath the coupler and draft gear.

The Contractor shall perform a clearance considerations study. (Include in CDRL-1)

### **11.3.6 Wheel Lubricators**

The trucks shall include interfaces to permit future installation of solid, dry stick flange lubricators.

### **11.3.7 Train Control System Antennas**

The trucks shall include interfaces for mounting and cabling to antennas for the ATP equipment, and for the TWC equipment if the vehicle design results in the TWC transponder being mounted on the truck. The Contractor shall supply, mount and wire the antennae as described in Section 14.

## **11.4 Suspension System**

### **11.4.1 General Requirements**

Motor trucks shall support the car body on the truck bolsters using ball or roller bearing rings, or other approved methods. Ball bearings shall meet ANSI/ABMA Standard 9, and roller bearings shall meet ANSI/ABMA Standard 11. If the ball or roller bearings are used, the maintenance cycle shall coincide with the motor truck maintenance. Center, non-motored trucks shall support the center body section on the secondary suspension. All truck attachment methods shall meet the service-proven requirements of this Section and Section 2.

The maximum change in car floor height due to car loading changes from AW0 to AW4, with suspension failure, shall be limited by the safe operating requirements, clearance requirements, and prevention of interference between the doors and wayside loading platforms during door opening. Under normal conditions, the suspension system shall keep the car floor height above top-of-rail to the value and tolerance specified in Section 2.

### **11.4.2 Primary Suspension**

Primary suspension shall be by means of chevron, Clouth elastomeric springs, or similar elastomeric spring elements. The vertical resonance frequency of the primary suspension system shall not exceed 12 Hz. The longitudinal spring rate shall be selected such that all the requirements of the Specifications are met, but shall permit the axles to align in curves down to a radius of 600 ft (183 m) without flanging. The longitudinal spring rate shall not exceed 90,000 lb/in (15,760 kN/m). Sound Transit requires that vehicle dynamic simulations which demonstrate the primary suspension longitudinal stiffness requirements be included in the Wheel to Rail Interface Study (WRIS) required by Section 2.

Refer to Section 17 for elastomeric material requirements.

### **11.4.3 Secondary Suspension**

Each end truck bolster and the center car body section shall be supported by a secondary suspension system consisting of air or hydraulic springs designed also to resist the lateral forces experienced in rail service. The springs shall be augmented by horizontal and vertical shock absorbers (refer to the Shock Absorbers section, below) to achieve the ride quality specified in Section 2. Longitudinal forces shall be transmitted between the truck frame and truck bolster by radius rods (refer to the Radius Rods section, below).

The secondary suspension springs shall be installed between the truck frame and the truck bolster for the motor truck, and between the truck frame and the center body section for the non-motored

truck. Air or hydraulic springs shall be augmented by elastomeric stops or coil springs to support the carbody in the event of failure. The car shall operate safely at all design speeds with any or all of the secondary air or hydraulic springs inoperative. Sound Transit requires that vehicle dynamic simulations which demonstrate safe operation with inoperative secondary suspension be included in the Wheel to Rail Interface Study (WRIS) required by Section 2. In the event the contractor elects to use a pneumatic secondary suspension system, the air compressor crank case shall be designed with a block heater and moisture removal valve.

Refer to Section 17 for material requirements.

#### **11.4.4 Load Leveling**

Air or hydraulic spring pressure shall be controlled by leveling valves or equivalent sensors on each truck connected around the secondary or secondary and primary suspensions as required to meet the specified performance. These valves shall control the height of the floor to compensate for changes in passenger load and distribution.

The suspension system shall maintain the top of the car floor at the height specified in Section 2. Leveling valves or sensors shall have a response deadband commensurate with the floor leveling requirements, but shall not be susceptible to spring pressure oscillation.

Sudden loss of suspension air or hydraulic pressure on either side of a truck shall initiate rapid venting of the opposite spring on the same truck.

The Contractor may offer alternative leveling valve arrangements that provide the specified leveling performance. Alternative arrangements shall be submitted as part of the preliminary design review and shall be subject to Sound Transit review and approval. (Include in CDRL 11-1) If a single leveling valve is used at any truck, it shall be located as close as possible to the centerline of the car, and shall be readily accessible for maintenance.

##### **11.4.4.1 Load Compensation**

Passenger load indication shall be provided to the vehicle data bus, to be used by propulsion, friction brake, HVAC controls and other system controls as required. The load compensation system design shall meet the accuracy and safety requirements described in Section 2. Each air or hydraulic spring assembly shall have a suitable connection to pressure transducers for load compensation signals provided to the vehicle data bus for use by other systems. Transducers shall not be mounted to the truck frame or bolster.

Transducers shall be mounted in a manner to prevent direct contact with water spray such as alignment with wheel flange way or direct rain vehicle wash exposure.

##### **11.4.4.2 Electronic and Hydraulic Control Units**

Electronic and hydraulic control units provided as part of the load leveling system shall comply with the requirements stated in Section 12 for friction brake system control components. The load leveling control components may be combined with the friction brake controls, provided that separate control hardware is used for each function.

#### **11.4.5 Shock Absorbers**

Lateral shock absorbers shall be of the hydraulic type. Vertical shock absorbers may be either hydraulic or friction type as required by the truck design.

The Contractor shall be responsible for determining the proper parameters for the shock absorbers to meet the specified performance requirements.

#### **11.4.6 Suspension Stops**

Lateral and vertical suspension stops shall be designed with a progressive rate to produce a lower force at initial contact and a progressively higher force as the stop is compressed. The stops shall be provided with replaceable elastomeric cushions. Stops shall develop sufficient force to limit motion within clearance requirements.

#### **11.4.7 Wear Adjustment**

Provision shall be made in the truck design for vertical mechanical adjustment of the primary and secondary suspension to compensate for maximum wheel wear and wear or settlement of other truck parts. The adjustments shall be accomplished with standard maintenance shop equipment, and shall not impair the operation of the truck. Adjustment at any level shall not cause the vehicle to exceed the specified dynamic envelope. The adjustment range shall be 10% greater than the full range of tolerances plus wear.

#### **11.4.8 Body Roll Stabilization**

The suspension of each truck shall be designed to minimize car body roll. The exact value is to be defined by the Contractor and approved by Sound Transit, but shall not exceed 3 degrees for each side. Roll control to keep the car body within the dynamic clearance outline of the vehicle shall be by torsion bars or other service-proven method.

#### **11.4.9 Truck Swiveling**

The Contractor shall provide a truck assembly that will resist hunting (nosing) at all speeds up to 65 mph (105 km/h) and be sufficiently free to turn such that wheel treads do not exhibit double groove type wear patterns or flange wear below the condemning thickness (thin flange) before reaching condemnable high flange condition. High speed truck stability shall remain acceptable for all normal wheel wear and truck assembly wear or aging. Truck stabilizing measures and turning stiffness, which includes articulation joint stiffness for the center truck, shall not cause abnormal wheel or rail wear. Sound Transit requests that vehicle dynamic simulations which demonstrate the truck swiveling requirements shall be included in the Wheel to Rail Interface Study (WRIS) required by Section 2. (Include in CDRL 11-1)

## **11.5 Truck Frame and Bolster**

### **11.5.1 General Requirements**

Truck frames and bolsters shall be of a service-proven design fabricated by welding, casting, or a combination of the two. Materials shall be according to Section 17. All welding shall be in accordance with welding and brazing requirements specified in Section 17.

Pedestal tie bars, if used, shall be attached to the truck frame pedestals in a manner that provides a positive, metal-in-bearing path for loads which may be taken through the tie bars. A pedestal tie bar attachment design that depends solely on clamping friction to transmit loads between it and the pedestals will not be acceptable.

There shall be no sliding surfaces involved in the method of retaining the journal bearings in their proper positions. The design of the truck shall have sufficient compensation for normal creep or settlement of the primary suspension springs to achieve the full rated life of the suspension springs, plus an additional 1/4 in (6.4 mm).

Where pockets or partially enclosed spaces exist, adequate drainage shall be provided so that no moisture collects anywhere within the truck frame and bolster.

Threaded fasteners, adjustment points, and structurally critical locations shall be accessible for inspection and work using conventional means and tools.

### **11.5.2 Connection**

A positive mechanical connection shall be provided between the car body and trucks, such that the trucks will be raised with the car body, without disengaging any part of the suspension system. These connections shall be detachable by conventional hand tools to permit de-trucking. The strength of the connection shall provide a safety factor of not less than two times the yield strength of the material when lifting a fully assembled truck. These connections shall be designed and located such that damage to car body, car body subsystem components and trucks is minimized during derailments. These connections shall not chaff or wear against itself or any part, bracket or component of the truck or car body.

The ultimate strength of the truck-to-car body connection for motor trucks shall be sufficient to secure the entire truck to the car body under conditions in which a horizontal load of 90,000 lbf (400 kN) is applied in any direction at any point on the truck through the center of rotation, without separation of the truck and car body. The ability of the truck-to-car body connection to sustain this load shall be independent of the presence of vertical load. The horizontal load may be transmitted from the truck to the car body through structural members, positive stops, or other rigid, mechanical safety devices. Bolster-locating radius rods shall not be used to provide any portion of this strength. The connection between the truck frame and the truck bolster must also meet this requirement as it is in the load path from the bottom of the truck frame to the car body.

### **11.5.3 Radius Rods**

Radius rods or similar devices shall withstand a longitudinal load equal to the required design load, without permanent deformation. The design load shall be two times the weight of a complete motor truck, including motors, gear units, brake equipment and all other truck-mounted apparatus, but excluding the truck bolster assembly. Any bracket by which a radius rod is attached to the truck, truck bolster, or the car body, the member to which the bracket is attached, and any intermediate connection shall, as a minimum, withstand a longitudinal load equal to 175% of the required design load without permanent deformation. The brackets or the connections shall fail (deform permanently or break) before the members to which the connections are made fail.

Clearance shall be provided between the radius rods and all parts of the car body and apparatus under all operating conditions.

Propulsion and braking forces shall be transmitted between the truck and the truck bolster in a manner which minimizes weight transfer between axles of a truck; maximizes adhesion; and minimizes stress levels, wear, and displacements in the truck. To this end, radius rods, if used, shall be positioned as low as allowed by clearance, and shall be elastomerically cushioned at both ends.

### **11.5.4 Tram and Axle Parallelism**

The motor truck frame assembly, when loaded with its share of the AW2 car weight, shall maintain the axles parallel to within 0.080 in (2 mm) on each side at the journal centers and shall limit the difference between diagonally opposed bearing locations to 0.40 in (10 mm), both as measured on the truck alone, and on the complete AW2 car stationary on level tangent track. Motor truck frame tram marks located within 0.03 in (0.76 mm) of their true position shall be provided. The center truck shall have axles parallel within 0.040 in (1.0 mm) at the journal center.

The Contractor shall provide tools required for the inspection of tram and axle parallelism as part of Special Tools.

### **11.5.5 Equalization**

Truck equalization shall be such that with the car on level track under an AW0 load, lifting or dropping any wheel of a truck 1.50 in (38 mm) shall not change the load on any wheel of the car more than 60%. Raising or lowering any wheel on a truck up to 2 in (50 mm) shall not result in loss of contact between any of the other wheels and the rail. Sound Transit requires that vehicle simulations which demonstrate the wheel load equalization requirements be included in the Wheel to Rail Interface Study (WRIS) required by Section 2. (Include in CDRL 11-1)

### **11.5.6 Lifting Provisions**

Each truck side frame shall be fitted with two diamond plate or similar slip-resistant lifting surfaces approximately 6 in (150 mm) long by 4 in (100 mm) wide to support the truck and car during wheel machining, for propulsion check-out, or for re-railing. Lifting plates shall be

located to allow for balanced jacking of the truck. Additional lifting provisions shall be provided to allow lifting using overhead cranes.

## **11.6 Journal Bearings**

Journal bearings shall be grease lubricated, tapered roller bearings with an L10 life probability, as defined by the American Bearing Manufacturer's Association (ANSI/ABMA Standard 11) of not less than 1,000,000 mi (1,609,000 km) at any car weight up to AW4 with the shock and impact loads typical of rail car service. Bearings shall be NFL (No Field Lubrication) with seals designed and service-proven for use on Light Rail Vehicles. The center truck journal bearings may be oil lubricated if assembled with a pre-load on the bearings and shall be NFL sealed type bearings. There shall be no sliding surface involved in the method of retaining the journal bearings in their proper positions.

Journal bearing housings shall be electrically insulated from the truck frame by the primary suspension or other means. The method used to insulate journal bearings from the truck frame shall be submitted as part of the preliminary design review. (Include in CDRL 11-1) Journal bearings shall not be electrically insulated from the journal bearing housings.

## **11.7 Wheels**

### **11.7.1 General Requirements**

The trucks shall use SAB type V wheels, Bochum 2000 type wheels, or approved equal, with a steel center. New and fully worn wheel diameters shall be as described in Section 2. Tires shall meet the requirements of ASTM A551/A551M, Class DHT, with a maximum carbon content of between 0.67% and 0.72% weight percent, or approved equivalent. All wheels shall be of the same AAR hardness class.

Wheel profile for motor trucks shall be as shown in Figure 2-2 unless otherwise approved by Sound Transit. Wheel profile for the center truck wheels shall be specified by the Contractor and shall be designed to meet the ride quality requirements per Section 2. Center truck wheel hubs shall have provisions for outside brake disk mounting, if chosen for the truck and brake configuration. Actual wheel profiles shall reflect the results of the Wheel to Rail Interface Study described in Section 2.

It is the responsibility of the Contractor to ensure that their proposed wheel profile operates in a reliable and safe manner with the specified rail profile described in Section 2.

The wheel assembly shall also serve as the electrical interface for grounding the car to the running rails for the return of propulsion and auxiliary current, and to shunt the signal system track circuits from rail to rail. Conductive paths of a capacity to conduct all specified currents shall be provided by external hub-to-tire flexible copper shunts. Shunts shall be arranged to be easily inspected for integrity, and shall be readily removable and replaceable for maintenance purposes and for tire replacement. A minimum of three shunts per wheel shall be provided. These shunts shall not interfere with wheel truing, and shall be mounted to avoid damage from wayside obstructions. Refer to the Pressing or Mounting Requirements and Tolerances section, below.

Provisions shall be made for hydraulically-assisted wheel removal including an internal annular groove in the hub, a port connecting the groove to the outside of the hub, a threaded connection for the pressure application device at the outer end of the port, and a secure closure for the threaded connection. The secure closure device shall be removable with standard tools and be of non-metallic, non-corrosive material.

The Contractor shall provide hydraulically assisted tooling required for the removal of wheels as part of Special Tools.

Sound Transit shall be furnished with copies of all reports required by ASTM A551/A551M, Class DHT and copies shall be incorporated in the Car History Book for each car.

### **11.7.2 Wheel Diameter Tolerance**

Tolerance for the new wheel diameter shall be +0.2 in (5 mm), -0 in (0 mm). Wheels for the motor trucks shall be supplied in marked sets of two, matched in diameter to within 0.012 in (0.30 mm). Wheels for the center truck shall be matched in diameter in accordance with the truck manufacturer's recommendations in the order to meet the required ride quality and tracking capability.

### **11.7.3 Identification**

Tire marking shall be in accordance with ASTM A551/A551M, Class DHT. Both tires and hubs shall be serialized, and hub marking in accordance with AAR MSRP, Section G, Standard M-107/M-208.

## **11.8 Axles**

### **11.8.1 General Requirements**

Full length and stub axles shall be of the solid design. The axle shall be designed to have a fatigue life of not less than 30 years. For all interference fits on the axle, the pressed-on part shall overhang its respective seat on the axle. Both ends of each full length axle and the outboard end of stub axles shall be chamfered and furnished with standard 60 degree lathe centers.

The axle assembly components shall be designed to be usable with Sound Transit's wheel press and wheel truing machine.

Sound Transit shall be furnished with copies of all reports required by AAR MSRP, Section G, Standard M-101. Reports shall be incorporated into the Car History Book for each car.

### **11.8.2 Design Considerations**

For full-length axles used with inboard bearing trucks, the calculated maximum static unit stress at the bearing center shall not exceed 6,000 lbf/in<sup>2</sup> (41,400 kPa) when the axle is considered a simple beam under AW4 load. Full-length axles used with outboard bearing trucks shall conform to the requirements of APTA PR-M-RP-008-98 (formerly AAR Standards S-014 and S-042).

The Contractor shall submit to Sound Transit, as part of the preliminary design review, a load diagram and static and dynamic stress calculations for the axles, that shall show, as a minimum, the maximum value of stresses to which the axles are expected to be subjected in service, and a prediction of the axle's fatigue life using a cumulative damage or other approved calculation method. (Include in CDRL 11-1) The Contractor shall consider in the axle bending fatigue stress calculations the effect of the bending loads induced by the presence of restraining rails.

### **11.8.3 Manufacturing Requirements**

Solid axles shall be manufactured in accordance with AAR MSRP, Section G, Standard M-101, Grade F except as otherwise required by the Specifications. Hollow axles, if used, shall be manufactured in accordance with AAR M-101, Grade H or approved equal. All axles shall be given a sub-critical quench heat treatment. Solid axles shall meet Grade F yield strength requirements after sub-critical quench. Steels containing chromium or molybdenum, with or without nickel, are acceptable provided they are vacuum degassed and meet Grade F or H properties, as required.

Wheel seats, bearing seats, gearbox resilient coupling seats, brake disc seats, and ground brush ring (if used) seats shall be free from tool marks and scratches, and shall provide for interchangeability of axle mounted components. The finish of the axle at the bearing seats shall not exceed 32  $\mu\text{in}$  (0.8  $\mu\text{m}$ ) RMS surface roughness. The finish of the axle at the wheel seats shall not exceed 63  $\mu\text{in}$  (1.6  $\mu\text{m}$ ) RMS surface roughness. Hollow axles shall have a machined interior finish not exceeding 250  $\mu\text{in}$  (6.4  $\mu\text{m}$ ) RMS surface roughness. All other areas of the axle shall have a machined surface finish not exceeding 125  $\mu\text{in}$  (3.2  $\mu\text{m}$ ) RMS surface roughness.

There shall be approved stress-relief profiles and/or radii at the ends of seats, and stress-relief grooves between adjacent seats. All stress-relief radii and grooves shall be cold-rolled to a bright surface by an approved process.

### **11.8.4 Axle Tolerances**

The tolerance on the wheel, bearing, and coupling seat diameters shall not exceed +0.001 in (0.025 mm), -0 in (0 mm). Wheel, bearing and coupling or gear seats shall be concentric, with run-out not exceeding 0.001 in (0.025 mm).

### **11.8.5 Identification**

Each axle shall be permanently marked with the information required by AAR M-101. Motor truck axles and center truck stub axles shall have different numbering sequences. The Contractor shall furnish Sound Transit with a record of the manufacturer's serial and heat numbers listed together with the appropriate serial numbers of the cars and trucks on which they have been installed to be included in the Car History Book.

## 11.9 Wheel-Axle Assembly

### 11.9.1 General Requirements for Motor Trucks

For motor trucks, the wheels, journal bearings, gearbox couplings, ground brush rings (if used), and disc hubs shall be fitted to the axle by pressing. The disc hub may be bolted to the gearbox output shaft, as approved by Sound Transit. The wheel hub and gearbox couplings shall be installed with a press fit in accordance with standard AAR practice.

Journal bearings shall be pressed on and seated firmly against axle stops. Axle-bearing fits and pressing forces shall conform to AAR standard practice in MSRP Section G, Part II, except that the bearing press-on and seating force shall be 25 to 30 tons (249 to 299 kN) total pressing tonnage. Disc hub, gear coupling, and ground ring (if used) fits and pressing forces shall be as recommended by the equipment manufacturer. Bearing press-on and seating forces shall be evident in the pressure graph. Wheel pressing tonnages shall conform to AAR standard practice, except that the maximum pressing force shall be 80 tons (797 kN), and a residual clamping load on the bearing assembly shall be obtained by a spike force on the wheel of between 25 and 37 tons (249 and 369 kN). This spike force shall be clearly visible on the pressure graph. Pressing procedures shall be submitted as part of the preliminary design review. (Include in CDRL 11-1)

### 11.9.2 General Requirements for Trailer Trucks

For trailer trucks without conventional axles the wheels, bearings, ground brush ring (if used), and disc hubs shall be fitted to the axle by pressing, or mounting, or by being bolted to the wheel for trucks with non-rotating stub axles. The fit tolerances and pressing forces shall be as recommended by the equipment manufacturers.

### 11.9.3 Pressing or Mounting Requirements and Tolerances

Pressure graphs of all gear coupling, disc hub, grounding ring (if used), journal bearing, and wheel-to-axle pressings shall be furnished to Sound Transit and are to be included in the Car History Book. The graphs obtained for the wheel pressing shall meet the requirements described in AAR MSRP, Section G-II, Standard RP-631, Paragraph 2.3.5, and Standard RP-633, including the following figures:

- Figure 4.19, Identification of wheel fit pressure diagram
- Figure 4.20, Constructing and using a typical wheel mounting template
- Figure 4.21, An example of an ideal mount
- Figure 4.22, Example of an acceptable amount
- Figure 4.23, Example of an acceptable mount
- Figure 4.24, Example of a misfit where the final tonnage is not concise
- Figure 4.25, Example of a misfit whose peak tonnage exceeds the minimum tonnage
- Figure 4.26, Example of a misfit where tonnage does not build up to the 75% fit line
- Figure 4.27, Example of a misfit caused by an obstruction or by excessive positive taper
- Figure 4.28, Example of a misfit indicating an alignment problem

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Prior to pressing on either wheels or gear couplings, the seats and couplings shall be prepared as described in the MSRP Section G, Part II.

The wheel-axle assembly shall meet the following requirements after all pressing and mounting operations are completed:

- For full-length axles, the mounted wheel back-to-back dimension shall be as specified in Section 2. The center truck stub-axle-wheel units assembled in the truck frames shall meet these requirements.
- Each full-length tire-wheel-axle assembly shall provide a maximum shunting resistance of 0.01  $\Omega$  when measured from tire tread to tire tread. Maximum wheel tire tread-to-axle resistance for assembled stub-axle-wheel units shall be 0.005  $\Omega$ .
- The assembled and wired center truck tire, wheel, ground brush, cable, ground brush, wheel, tire assembly shall provide a maximum shunting resistance of 0.05  $\Omega$  when measured from tire tread to tire tread. The journal bearings shall be excluded from the shunting circuit.
- Each full-length wheel-axle assembly shall be supported and rotated on its bearings. Concentricity, when measured as near as possible to the center and at each end of each axle, shall not exceed 0.003 in (0.075 mm) TIR at each location.
- When the wheel-axle assemblies, full-length or stub, are rolled on its journal bearings, the wheel treads shall have less than 0.028 in (0.70 mm) TIR radial run-out and less than 0.040 in (1.0 mm) TIR lateral run-out.
- After mounting, motor truck journal bearings shall meet AAR requirements for "installed" lateral clearance.
- Center truck journal bearing clearances or preload shall be as determined by the Contractor, shall be submitted as part of the preliminary design review. (Include in CDRL 11-1)

Axle assemblies not meeting the above requirements shall be rejected. Axles shall also be rejected if they are galled or otherwise scarred when pressing to mount wheels, bearings, or gear couplings. In the absence of visible evidence of such galling or scarring, the use of pressing force in excess of that specified shall be taken as cause for rejection of the assembly.

### **11.10 Track Brake Supports**

The track brakes shall be supported from the journal bearing housings or similar unsprung element of the truck in accordance with the requirements of the Specifications. The track brake support arrangement shall maintain positive lateral alignment of the track brake with the running rail. Track brake supports that depend solely on clamping friction between the brackets and journal housings (or other supportive element) to maintain alignment shall not be permitted. Track brake forces shall be transmitted to the truck frame as near to the top of rail as practical to minimize the moment on the track brake unit. Refer to Section 12 for a description of track brake requirements.

### **11.11 Safety Bars**

Adjustable safety bars shall be provided at the outboard ends of the end trucks and shall be arranged to deflect debris on the track and prevent such material from getting under the wheels. These bars shall be at least 5.5 ft (1680 mm) wide (centered on the truck) and 6 in (150 mm) high, and shall be made of steel or other approved material. They shall be mounted with a maximum clearance of 4 in (100 mm) to top-of-the rail when all truck parts are new. Clearance shall not be less than 2 in (50 mm) for the worst-case combination of conditions specified in the Clearance Considerations section, above. The safety bars and mounting arrangement shall have sufficient strength to withstand the impact of built-up snow at highway grade crossings, with the car or train operating at normal speeds. Safety bar arrangement and mounting shall not adversely affect the function of the ATP and TWC antennae.

Safety bars shall be arranged and mounted for replacement with common hand tools, and without disturbing the ATP and TWC antennae in the event of damage.

### **11.12 Safety Hangers**

Safety hangers shall be provided to support the motors and gearboxes in the event of failure of their attachments. In addition, if the motor and gearbox suspension bolts or links are longer than 6 in (150 mm), a safety device of approved design shall be provided which prevents a failed bolt or link from dropping to an extent which would create a hazardous operating condition.

### **11.13 Grounding Device**

Each axle of both motor trucks and each wheel assembly of the center truck shall be provided with grounding devices to meet requirements for electrical grounding specified in Section 9. This grounding device may be an end-of-axle grounding assembly, radial brush assembly with a ground ring applied to the axle, or as proposed by the Contractor and approved by Sound Transit. Ground rings applied to axles by press fit shall be steel or other approved alloy with thermal expansion coefficients compatible with the axle steel. Ground brush life shall be a minimum of 130,000 mi (209,000 km). End-of-axle devices shall be removable with common hand tools for access to axle centers during wheel truing operations. Electrical requirements including current capacity and voltage rise shall be as specified in Section 9.

### **11.14 Design Data Requirements**

#### **11.14.1 Design Loads**

In addition to those loads identified elsewhere in the Specifications, the truck frame and all truck parts, including motor, gear unit, and friction and track brake equipment supports shall be capable of withstanding the maximum load variation imposed by the forces acting on the frame. The basis for determining maximum load variation shall include forces resulting from passenger load, track shocks and forces, motor torque, friction brakes, track brakes, and any possible combination of these forces when operating under all possible conditions on track meeting the minimum requirements of the FRA Class 4 "Track Safety Standards", per 49 CFR Part 213, at speeds up to and including 65 mph (104 km/h).

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The static strength design condition for the truck frame and bolster shall be based on the trucks share of a design load weight equal to the AW4 weight less the weight of the trucks.

- The vertical load on the truck shall not be less than the truck's share of the design load, augmented by the weight transfer effects such as tractive effort reactions.
- The longitudinal load, applied at the center of gravity of the car, shall not be less than the maximum possible instantaneous braking effort (friction and dynamic plus track brake) with AW4 loading and 50% adhesion.
- The lateral load, applied at the center of gravity of the car, shall not be less than that developed at car overturning.
- Accessory loads, such as those from brake units, track brakes, and traction motors, shall represent maximum steady state conditions; for example, maximum motor torque and brake unit weight, and maximum brake unit reaction and motor weight, or the worst combination (brake blending) of both.

Under these conditions combined, the maximum stresses at any location in the truck frame and bolster shall not exceed 50% of the yield strength of the material.

The fatigue design of the truck frame and bolster shall be based on the above conditions with a design load equal to the AW2 weight less the weight of the trucks. The mean vertical load on a truck shall be the truck's share of the design load and the vertical load shall vary about the mean vertical load by  $\pm 25\%$ . The lateral load shall vary between 15% of the mean vertical load acting towards one side of the truck and 15% of the mean vertical load acting towards the other side of the truck. The longitudinal load shall vary between 15% of the mean vertical load acting towards one end and 15% of the mean vertical load acting towards the other end. The lateral and longitudinal loads shall act as if they were applied at the center of gravity of the car body at AW2 with resulting vertical loading applied to the bolster or truck frame as appropriate. Accessory loads shall vary between  $\pm 100\%$  of their maximum steady-state values: motor under maximum braking torque and brake unit tractive effort reaction under Full Service Brake application plus maximum track brake tractive effort load. All loads shall be applied with the phasing to produce the worst possible stress combination. Under these conditions, stresses shall not exceed the allowable fatigue values.

Fatigue allowable stress levels for truck materials shall be limited to published endurance stress values for smooth, flat, tension-tension specimens or recent Contractor tests with sufficient individual tests to establish the endurance stress value for 95% survival at the 84% confidence level as defined in ASM Metals Handbook, 9th Edition, Volume 8: Mechanical Testing, "Fatigue and Fracture," pages 695-720. (Note that this is a description of the statistical treatment of the fatigue data; the Contractor is responsible for finding or developing data to establish the fatigue properties.). Fatigue allowable stress levels for welded connections shall not exceed the requirements of AWS D1.1/D1.1M for Dynamic Structures or Contractor tests of the specific connection establishing its endurance stress (load) value for 95% survival at 69% confidence level. The Contractor shall submit its chosen static and fatigue allowable values, whether published or test values, to Sound Transit for review and approval with the Truck Stress Analysis

and Testing Plan, finalized in the Stress Analysis Report, before truck static and fatigue tests (Include in CDRL 11-3).

The use of UIC 515-4 and UIC 615-4 as a basis for design conditions of the trucks may be permitted at the discretion of Sound Transit provided it is shown that the truck design conditions will aim to produce a truck that will meet the more severe track conditions, speeds, and truck weights in the U.S. In no case will the requirements of 11.4.2 be exempted.

#### **11.14.2 Stress Analysis**

A Truck Stress Analysis and Testing Plan shall be submitted no later than 90 days after NTP. (CDRL 11-2) It shall include an outline of the procedure the Contractor will use to analyze and test the design of the truck. It shall be discussed during the truck design review meeting.

The Truck Stress Analysis and Testing Plan shall include the following:

- Table of loads to be used for static analysis and test, with load magnitudes and points of application;
- Derivation of the static loads to be applied;
- Table of loads to be used for fatigue analysis and test, with load magnitudes, points of application, and phasing;
- Derivation of the fatigue loads to be applied;
- Diagrams of load applications; and
- Table of allowable stress levels.

The Truck Stress Analysis and Testing Plan must be approved prior to the submittal of the Truck Stress Analysis Report required by this section.

The Contractor shall submit, prior to truck and bolster static and fatigue testing, a stress analysis of the motor truck frame and bolster and the center truck assembly. (CDRL 11-3) The stress analysis shall show the calculated stresses, allowable stresses, and margins of safety for all elements for all specified loading conditions. The stress analysis shall consist, as a minimum, of a finite element analysis of the global structure and a classical analysis of all connections, supplemented as necessary by manual or computerized calculations.

The Contractor shall submit and receive approval of its finite element model prior to performing the FEA. (CDRL 11-4) The Finite Element Model Report shall include the element grid, all assumptions, and all input data, such as loads, section properties, boundary conditions and material properties. This information shall be included as part of this preliminary submittal and again as part of the complete analysis. The input shall have each page numbered, and columns of data shall be clearly labeled on each page using terms, symbols, abbreviations, and units defined in the report. A key to all symbols and colors shall be included. Boundary reaction forces of the truck under its own weight shall be included.

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The Contractor shall submit a separate analysis of welds and welded connections that includes the fatigue classifications of each weld according to AWS D1.1/D1.1M. This analysis shall account for all welding on the finished truck frame, including welds attaching brackets, studs, and holders for all truck accessories. It shall include drawings of the truck welding locations, or FEM mesh plots with the weld locations indicated, with the AWS classification indicated. (CDRL 11-5)

The FEA input data and output data shall also be submitted on electronic media in ASCII format or as approved by Sound Transit. (CDRL 11-6) Submittal of the input files is required with the model and at any time the file is changed, but not more often than monthly. Submittal of the output files is required with the FEA report and at any time the file is changed. Criteria for final approval of the stress analysis shall include the Contractor's submittal of the fully configured input data files as required by this paragraph. Each revision shall be accompanied by detailed revision notes that explain each change and indicate where changes were made in the report as a result of the change.

All Reports shall have each page numbered, and columns of data shall be clearly labeled on each page using terms defined in the analysis.

The FEA report shall include color plots showing the following:

- Deflections in all three axes separately plotted and imposed over the deflected shape;
- von Mises, or other approved combination stresses;
- Maximum and minimum principal stresses;
- Direction of maximum and minimum principal stresses; and
- Meshing accuracy index.

The analysis shall also include at least the following:

- Table of Contents.
- A structural diagram (layout) of the truck frames and bolster showing all member locations and shapes, and indicating the material and thickness of each. The methods of joining shall be completely defined, including AWS D1.1/D1.1M weld classifications for fatigue for all welds. Connections between the truck, bolster and car body shall also be clearly shown.
- Diagrams displaying external loads and supports applied to the truck frames and bolster.
- A summary of the results of calculations of stresses in all members. The locations where calculated stress levels equal or exceed 85% of the allowable stress criteria approved by Sound Transit in this Section shall be shown in a separate table along with the design or operating conditions (loads) which cause them. Calculated stresses shall be supported, where available, by the results of actual tests of trucks of identical design.

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- An analysis of all critical connections of the truck frames and bolster major structural elements under all specified loading conditions.
- A tabulation of the Contractor's selection of allowable truck frame and bolster static and fatigue stresses and assumed applied fatigue stress ranges for the truck frames and bolster members that are fatigue critical. Allowable stress levels shall be substantiated by the Contractor's test data or by citing published sources.
- Critical welds shall be as identified by the truck manufacturer and approved by Sound Transit, and shall include, as a minimum, all welds or portions of welds which, based on the results of the stress analysis and truck tests, are expected to be critical in fatigue.
- A table showing the engineering properties of each grade and temper of each material. This table shall include the material designation, yield strength, ultimate strength, elongation, Young's modulus for tension and compression, and shear elastic moduli. In each case, minimum-guaranteed values from the specifications for the corresponding grade and heat treatment of the material shall be used.

For those portions of the proposed designs which are based on a service-proven truck, the Contractor may, with Sound Transit's approval, provide data from previous tests, historical data from operations, or stress analysis, as required above, to satisfy the corresponding portion of these requirements. (CDRL 11-7)

The information derived from the analysis shall be used to determine strain gauge locations and other criteria for the truck tests. The locations of all strain gauges shall be shown on plots of the FEA truck and bolster mesh with dimensions. The analysis shall be updated as the truck design progresses.

### **11.15 Truck Serial Number**

Each truck shall be provided with a permanently attached serial number plate located on the right hand side of the truck in a conspicuous place. The figures shall be not less than 0.75 in (20 mm) in height.

### **11.16 Documentation Requirements**

The truck design report shall include but not be limited to the following information:

- Wheel to Rail Interface Study (Section 2)
- Wheel truing provisions. (Section 11.3.4)
- Identification and resolution of interface issues between the wheels, trucks, car body, and wheel truing machine (Section 11.3.4)
- An alternative method of measuring wheel diameter (if proposed) (Section 11.3.4)
- Clearance considerations study (Section 11.3.5)
- Truck swiveling. (Section 11.4.9)

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- Wheel load equalization. (Section 11.5.5)
- Journal bearing insulation method. (Section 11.6)
- Axle design considerations. (Section 11.8.2)
- Wheel pressing procedures. (Section 11.9.1)
- Center truck journal bearing clearances or preload. (Section 11.9.3)

### **11.16.1 Contract Deliverables**

In addition to the truck design report, the following contract deliverables shall be submitted to Sound Transit for review and approval. Refer to Section 19 for contract deliverables requirements.

- 11-1 Truck design report that conveys the design and shows compliance with the requirements of the Specifications (Section 11.2)
- 11-2 Truck stress analysis and testing plan. (Section 11.14.2)
- 11-3 Stress analysis report prior to truck and bolster static and fatigue testing. (Sections 11.4.1, 11.14.2)
- 11-4 Request for approval of the Finite Element Model Report. (Section 11.14.2)
- 11-5 Separate analysis of welds and welded connections. (Section 11.14.2)
- 11-6 FEA input data and output data on electronic media. (Section 11.14.2)
- 11-7 Data from previous tests, historical data from operations, or stress analysis for a service-proven truck (Section 11.14.2)

### **11.17 Cited References**

The following standards were cited in this Section at the referenced location:

AAR MSRP Section G	Manual of Standards and Recommended Practices, Wheels and Axles (600 Series) (Section 11.7.3, 11.8.1, 11.8.3, 11.8.5, 11.9.3)
AAR M-101	Axles, Carbon Steel, Heat Treated (Sections 11.8.1, 11.8.3, 11.8.5)
AAR M-107/208	Wheels, Carbon Steel (Section 11.7.3)
AAR RP-631	Recommended Wheel Shop Practices (Section 11.9.3)
AAR RP-633	Figures (Section 11.9.3)

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AAR MSRP Sect G Part II	Manual of Standards and Recommended Practices, Wheel and Axle (Shop) Manual (Sections 11.9.1, 11.9.3)
ANSI/ABMA Standard 9	Load ratings and bearing life for ball bearings. (Section 11.3.1)
ANSI/ABMA Standard 11	Load ratings and fatigue life for roller bearings (Sections 11.3.1, 11.5)
APTA PR-M-RP-008-98	Recommended Practice for Passenger Car Axle Design (Section 11.7.2)
ASM	Metals Handbook (Section 11.13.1)
ASTM A551/A551M	Standard Specification for Steel Tires (Sections 11.6.1, 11.6.3)
AWS D1.1/D1.1M	Structural Welding Code – Steel (Sections 11.13.1, 11.13.2)
49 CFR Part 213	Track Safety Standards (Section 11.13.1)

**END OF SECTION 11**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 12  
FRICTION BRAKE SYSTEM**

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## **SECTION 12: FRICTION BRAKE SYSTEM**

### **12.1 General**

This Section establishes the requirements for vehicle friction brake system and control, and air supply for the suspension system, if pneumatic.

The friction brake system and air supply shall conform to the service-proven requirements and the safety requirements specified in Section 2. Equipment whose basic service-proven design requires modifications to conform to Sound Transit requirements may be recommended to Sound Transit by the Contractor. The Contractor shall demonstrate, in detail, what modifications must be incorporated and shall demonstrate, to Sound Transit's satisfaction and approval, that such changes will not adversely affect operation in the Seattle environment. This information shall be included in the friction brake system design report required by the next paragraph.

Within 180 days of NTP or as part of the Preliminary Design Review (PDR), whichever comes first, the Contractor shall prepare a friction brake system design report that includes all of the design submittals required by Sections 12.2 thru 12.6. (CDRL 12-1)

### **12.2 Brake System Description**

The friction brake system shall be an electro-hydraulic disc brake system that functions in coordination with the propulsion system described in Section 10. The system shall provide independent pressure control of the hydraulic braking equipment on each truck, as specified in detail in the remainder of this Section.

The disc brake system shall perform the following basic functions:

- Supplement dynamic brake to provide service braking under vehicle loading and speeds as specified in Section 2
- Supplement dynamic brake to provide maximum braking with the assistance of track brakes and sanding
- Provide service and maximum braking in the event of dynamic brake failure
- Act as a parking brake system

### **12.3 Brake System Configuration**

The friction brake system shall have the following configuration:

- Friction braking shall be controlled by electronic control units (ECUs) completely independent of the propulsion system electronics. Refer to the Disc Brake Electronic Control Units section, below. Each truck shall be controlled by a separate control unit, independent to the extent that the other trucks braking is fully operational if the ECU for one truck has failed. The center truck ECU shall have two independent channels, one

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each to control each wheelset on the center truck, to provide required wheel spin/slide correction as specified in Section 2.

- Separate, independent hydraulic pressure control units (HPCUs) shall be provided for each truck. The HPCUs shall be resiliently mounted to the car body.
- Brake disc(s) and calipers shall be provided on each axle of the motor trucks and on each wheel of the center truck. The calipers for each truck shall be controlled independently by their respective ECU, and powered by their respective HPCU. Disc braking shall use spring pressure to apply the service brake and hydraulic pressure to release the service brakes; the parking brake shall use spring pressure. Brake discs shall be mounted inboard of the wheels and truck frame on motor trucks and outboard of wheels on the center truck.
- Independent pressure control of each pair of center truck wheels is required to improve wheel-slide control.
- Two electromagnetic track brakes shall be provided per truck, for a total of six per vehicle. The track brakes shall function in the full service brake plus track brakes mode (FST) (refer to Section 5), in maximum braking (refer to Section 2), and by manual control from the cab console (refer to Section 5).
- A sanding system shall be provided that deposits sand immediately in front of the leading wheels on both motor trucks. Alternate arrangements may be proposed. Sanding shall be automatically provided during maximum braking and after detection of severe spin or slide conditions as described in Section 10.
- Pressure controls, transducers, indicators, and auxiliary valves shall be provided as necessary to provide specified functions.

### **12.4 Power Source**

The friction brake control equipment and hydraulic pumps shall use the vehicle low-voltage dc system as the power source. Brushless dc motors shall be used.

### **12.5 Performance and Control**

The friction brake system shall provide braking rate, slide efficiency, and duty cycle performance specified in Section 2.

All interfaces between systems shall be jointly developed by the system suppliers and brake equipment suppliers under the supervision of the Contractor, with final review and approval by Sound Transit, to ensure that proper operation and conformance to the Specifications is achieved. (Include in CDRL 12-1)

#### **12.5.1 Trainline Control**

Each ECU shall directly and independently interpret the trainline signals (including the data communications bus), propulsion interface signals, load compensation signals, wheel spin/slide

signals and the maximum brake signal to provide the desired brake system response. Refer to Sections 5 and 10.

### **12.5.2 Load Compensation**

Load weighing shall be used as the primary load compensation control input for all braking modes, including maximum brake tractive effort control, except track brake. The friction braking system shall adjust the braking effort to compensate for varying passenger loads on a per truck basis. Sensors and associated circuits shall be continuously or periodically checked to verify that they are functioning properly. In the event a load sensor failure is identified, the system shall default to AW0 braking effort on the affected truck. Alternatively, if the Contractor can demonstrate reliable and accurate performance by the Automatic Passenger Counter (APC) system, the APC output may be used for the purposes of load compensation in the event of a load weighting failure. Refer to Sections 2, and 10 for further information.

Load compensation may use signals independently processed by the friction brake system or signals that have been processed by the propulsion control system; however, both systems shall use the same signals.

Load compensation/load weighing signal shall also be provided to the vehicle data bus, specified in Section 9, for use by the HVAC system to control the variable fresh air intake.

### **12.5.3 Dynamic Brake Interface**

A dynamic brake feedback signal shall be utilized by the ECU for each end truck to reduce disc brake effort in response to the presence of dynamic braking on that truck. Refer to Section 10.

The ECUs shall proportionately reduce disc braking levels in response to dynamic brake signals such that the total contribution of disc and dynamic braking always results in the brake rate requested by the trainline rate request for any given vehicle speed and passenger load condition. The disc brake control logic shall process the dynamic brake signal effort as required to accommodate any disc brake system non-linearities.

Center truck braking shall also be available to supplement dynamic braking as needed. Since dynamic brake may not be able to provide the full requested braking tractive effort above passenger load state AW2, and/or above 45 mph, center truck braking may be required in addition to end truck friction braking in order to provide the requested brake rate under all specified passenger load states and from all specified speeds. The Contractor shall prepare a Friction Brake Effort Allocation Report detailing, for each passenger load state, and for all speeds above and below 45 mph, what the dynamic brake and friction brake tractive effort contributions will be from each of the end and center trucks. The report shall address maximum service brake and maximum brake tractive effort allocations separately.

See Section 2 for blending requirements.

#### **12.5.4 Parking Brake Control**

A spring-applied parking brake function shall be provided for each motor truck axle, and for each center truck wheel, by utilization of the service brakes.

The parking brake trainline shall be utilized by the friction brake system for parking brake control. The trainline shall be energized to command a release of parking brakes.

The parking brake shall automatically be applied when all reversers in the cabs of a train are in the “NEUTRAL” position, or when more than one reverser in a train is not in the “NEUTRAL” position.

A parking brake applied anywhere on a train for more than 7 s after the application of propulsion shall inhibit propulsion and the brake release indication on a train-wide basis. Refer to the Disc Brake - Propulsion System Interlocks section, below.

#### **12.5.5 Wheel Slide Control**

Analog or digital wheel slide control signals from the propulsion system shall be utilized by the disc brake system to reduce disc braking effort in response to wheel slides. Alternative arrangements with wheel spin/slide controlled by both the propulsion and brake control system are acceptable, provided that all specified performance requirements are complied with, and that it can be demonstrated that the two systems do not compete with one another for control. In addition, power level, digital (battery level energize to release) wheel slide control signals shall be used, if needed, to provide the performance required by Section 2. Refer to Section 10.

Wheel slip control shall activate sanding during a severe spin or slide on a train-wide basis. Refer to Section 10. The degree of spin or slide considered “severe” shall be adjustable by the PTU.

The ECU shall reduce disc braking levels, on a per truck basis, and per axle set on the center truck, in response to analog or digital wheel slide signals such that disc brake effort is reduced to a level deemed to be appropriate for the slide correction by the friction brake supplier. Reapplication of the braking effort following a slide correction shall be at a rate no faster than the allowable jerk limit. The disc brake control logic shall process the analog or digital wheel slide signal, as required, to accommodate any disc brake system non-linearities.

The disc brake system response times shall be sufficiently short to permit the vehicle to achieve performance requirements specified in Section 2 using the control scheme specified in Section 10.

Friction brake modulation shall be arranged in such a manner that system or wiring failures that remove power will not result in loss of disc brakes.

### **12.5.6 Track Brake Control**

Track brakes shall be applied when the master controller is in the FST position and MXB is requested (either by the master controller or emergency pushbutton), or when the operator's track brake switch is in the "ON" position.

FST and MXB commanded track brake applications shall be interlocked with the no-motion system so that the track brakes are released when no-motion is detected.

A track brake cut-out shall be provided on a per-truck basis by low-voltage dc breakers located in the cab electrical locker. When a track brake circuit breaker is off, a local friction brake fault for that truck shall be annunciated, and the cab System Fault light shall be illuminated (refer to Section 5).

If the track brakes on one side of a truck are non-functional, the track brakes on the other side of that truck shall be disabled, to eliminate the potential for derailment during a track brake application.

Track brake control and logic shall be provided by relays and contactors separate from the friction brake ECU. Each truck's track brakes shall be controlled by a separate relay and contactor circuit, fed from the separate circuit breaker described above.

Any track brake application shall activate the cab annunciators as described in Section 5.

### **12.5.7 Maximum Brake Control**

The disc brake system shall respond to a maximum brake request by producing a load weighed friction braking effort on each truck such that the vehicle achieves the braking performance specified in Section 2. The amount of braking effort applied per truck shall be coordinated with the propulsion system dynamic brake equipment, and shall be consistent with the planned friction brake contributions from each truck as given in the Contractor's Friction Brake Effort Allocation Report for the specified variety of passenger load weigh states and brake entry speeds. (Include in CDRL 12-1) The friction brake system for each truck shall receive a signal from the propulsion system, which shall indicate the level of dynamic brake tractive effort provided on that truck. If the appropriate level of dynamic brake tractive effort is not being provided, and maximum brake is commanded, the friction brake fault monitor shall cause a fixed brake application on that truck. The maximum brake trainline shall override all other trainline inputs.

### **12.5.8 Weight Distribution**

The disc brake system shall perform as specified over the range of vehicle loading from AW0 to AW4. The service brake control system and the maximum brake control system shall be designed to allow for weight differences between trucks due to uneven passenger loadings and vehicle weight distribution.

### **12.5.9 Thermal Capacity (Duty Cycle)**

The disc brake system shall have thermal capacity to provide continuous operation with the duty cycle specified in Section 2. Operation shall be verified at full schedule speeds with dynamic brake functional. During this operation the system shall maintain accuracy and time response requirements specified in Section 2, and the disc brake temperature shall not exceed the design limit determined by the disc or brake pad manufacturer. Operation shall also be verified with a passenger loading of AW2, top speeds limited to a nominal 25 mph (40 km/h) and with dynamic brake nonfunctional as described in Section 2. During this operation the system shall maintain accuracy and time response requirements specified in Section 2, and disc brake temperature shall not exceed the design limit determined by the disc or brake pad manufacturer.

The capability of providing this performance shall be verified by dynamometer or flywheel test and an LRV qualification test as described in Section 16.

### **12.5.10 Storage Capacity**

Under all specified environmental conditions, the disc brake system shall have sufficient storage capacity after loss of hydraulic pump power to permit three full brake applications and releases, keeping the brakes applied for at least 30 s per application, and brakes released for 2 min between applications, with car stationary and without dynamic brake assistance. Full brake applications shall be at the FSB level for an AW3 car weight. It shall be assumed that the power loss occurs when the accumulator hydraulic volume is at the minimum hydraulic pump cut-in pressure level.

The brake controls shall be provided with means to detect and alarm when the fluid level in the hydraulic fluid supply reservoir is below the level recommended by the friction brake supplier for continued safe operation. Means shall also be provided to detect whenever any hydraulic accumulator supply volumes and pressures are below the minimum values necessary to achieve an all-friction MXB AW3 stop. The pressures shall be sensed with non-adjustable pressure transducers and volumes by sensing devices in the accumulators, pump rate check or by use of pressure measurements by system transducers and charging time calculations.

When a low fluid supply reservoir level or low accumulator supply volume or pressure is detected, the controls shall:

- Inhibit propulsion by means of contacts in the Friction Brakes Released Trainline
- Indicate a Friction Brake Fault for that truck on the Local Indicator Panel (Refer to Section 5)
- Indicate a System Fault for the train on the console Annunciator Panel with details shown on the TOD (refer to Section 5)

### **12.5.11 Disc Brake - Propulsion System Interlocks**

The disc brake system shall be interlocked with the propulsion system such that propulsion is removed if any disc brake remains applied on any truck in a train for more than 7 s after the application of propulsion, and as specified elsewhere. Refer to this Section and Section 10.

Complete disc brake release shall be possible at all vehicle speeds down to zero mph.

### **12.5.12 Annunciation**

Refer to Section 5 for friction brake system annunciation.

#### **12.5.12.1 Friction Brake Fault or Cut-out**

The local “FRICTION BRAKE FAULT” indicator shall be illuminated red when any brake equipment failure is sensed or when brake equipment is cut out, on a per truck basis for the end trucks, and a per wheelset basis for the center truck. The SYSTEM FAULT indicator on the annunciator panel shall be illuminated red when any brake equipment failure is sensed. The local BYPASS/CUTOUT ACTIVE indicator on the annunciator panel shall be illuminated red when any brake equipment is cut out. The Monitoring and Diagnostics System shall also provide indication to the operator when brakes are malfunctioning or cutout. Refer to the Brake Failure Monitoring Feature section, below.

#### **12.5.12.2 Disc Brakes Released**

The “DISC BRAKES RELEASED” indicator shall be illuminated green on the console annunciator when all disc brakes on a train, including the parking brakes, are released as indicated by a series circuit using brake cylinder pressure transducers, parking brake pressure transducers and relays as described in this Section, and fluid level is acceptable and interlocked as described in this Section. This information shall also be supplied to the propulsion controls to suppress the propulsion mode if the brakes are not released within 7 s after the start of propulsion mode, as specified in this Section and Section 10.

#### **12.5.12.3 Track Brake On**

The “TRACK BRAKE ON” indicator shall be illuminated yellow on the console annunciator when the track brakes are applied on any truck of a vehicle or train.

### **12.5.13 Disc Brake Cut-out**

The disc brake system shall include a method to release and cut-out the disc brakes on a truck, allowing the vehicle to be moved in the case of a failure.

#### **12.5.13.1 Disc Brake Cut-out of Pressure-Released Brakes**

A two-position, three-way manual valve with indicating switch shall be provided for each truck that will pressurize the brake cylinder lines to release and prevent subsequent applications of the disc brake on that truck. Cut-out valve handles shall have a locking design, and shall have

## *Friction Brake System*

provisions for a lock wire and seal. The valve shall be positioned between the HPCU and the brake actuators. The handle of this cut-out valve shall be accessible from one side of the vehicle on the exterior as approved by Sound Transit. (Include in CDRL 12-1) The set-up shall allow for the release of each single truck, any combination of two trucks, or all three trucks. The indicating switch shall be arranged to annunciate when the brakes are cut-out in accordance with the Friction Brake Fault or Cut-Out section, above.

A manual hand pump, permanently plumbed into the hydraulic system (non-portable), shall be provided to pressurize the hydraulic system when the cut-out valves are in the cut-out position. The pump location in the vehicle interior shall be approved by Sound Transit and shall be accessible using the crew key. The pump shall have the capacity to release all eight actuators on a vehicle. A pressure gauge, calibrated in bars, shall be provided to indicate release line pressure. Instructions for operating the system brake release valves and pump, with appropriate pressures, shall be provided at a convenient location near the pump. A tray shall be provided under the pump to contain any leakage or spillage.

When the service brakes are cut-out and released, the normal brake release indication, for the disc brakes on that truck only, shall be provided to the friction brake-propulsion system interlocks described in this Section. Cutting in the service brakes shall automatically reset this feature to normal operation.

An electrically-operated remote release shall be provided on the cab upper control panels with separate control valves and truck selector valves for each truck. The remote release shall pressurize the service and parking brake lines to cause the release all friction brakes on the selected trucks. The electrical circuit for each valve shall be treated as a vital circuit with switching of both positive and negative feeds to each valve, so that no single point failure can cause false energization of a valve.

Additionally a mechanical release shall be provided for releasing individual spring brake actuators. The device shall be operable from the side of the vehicle as approved by Sound Transit (Include in CDRL 12-1). The mechanical release feature shall automatically reset upon the next normal service brake release.

### **12.5.14 Sanding System Control**

The control for sanders shall be powered from the low-voltage dc power supply and shall function properly over the range specified in Section 2. Separate low-voltage dc circuit breakers shall be provided for the sanding control on each truck. Sand shall be applied automatically during maximum braking, and during severe (as determined by the Contractor) spins or slides. Refer to the wheel slide control interface description in this Section. Automatic sanding resulting from a wheel slip, slide or maximum brake application shall be interlocked with the no-motion detection circuitry and disabled below the no-motion detection point. Sanding control and logic may be provided by relays separate from the friction brake control logic.

The sanding nozzles shall be heated, and designed such that they will not clog under any specified environmental conditions. The heater design and application shall be justified by

successful previous application in a similar environment or by other means subject to Sound Transit review and approval.

## **12.6 Brake Failure Monitoring (BFM) Feature**

A friction brake failure monitoring feature shall be provided which shall recognize and respond to all friction brake system failures. The monitoring system shall conform to safety requirements specified in Section 2.

The feature shall monitor the status and operation of each disc brake ECU and HPCU, trainline commands (including the data communication trainline), propulsion system dynamic brake status, and track brake and sander system circuit breakers to determine proper operation of each. Each disc brake ECU and HPCU shall provide the hardware and software necessary for the failure monitoring feature.

Serious brake faults that occur during maximum brake applications, including the loss of power, control command or loss of the dynamic brakes, shall, on a per truck basis, cause a fixed level of hydraulic pressure to be applied to the friction brakes on that truck.

Brake fault information shall be transmitted to the Monitoring and Diagnostic System specified in Section 9 by means of the vehicle data bus or the vehicle Ethernet communications bus specified in Section 9, and to the local fault indicators described in Section 5.

## **12.7 Friction Brake System Components**

### **12.7.1 Disc and Hub**

All discs and hubs shall have thermal characteristics and strength to resist warping and cracking due to thermal stress resulting from the specified duty cycle.

The power truck discs supplied on the car shall be a two-piece design attached to a hub. Split discs shall be provided as spare parts. The hub shall be pressed on the axle or may be attached to the gearbox output shaft, as approved by Sound Transit. (CDRL 12-2) The disc and hub together shall statically balance within 40 ozf-in (0.28 N-m).

The center truck discs shall be a one-piece design that bolts to a hub pressed on the axle outboard of the wheel, or mounted directly to the outboard side of the wheel assembly. The disc and hub together shall statically balance within 40 ozf-in (0.28 N-m).

All discs shall be vented with radial or circular ribs separating the two friction surfaces to provide sufficient cooling between stops. The ribs shall be arranged to avoid generation of pure tone noise.

Wear indication grooves shall be provided on both edges of each disc to indicate the minimum allowable disc thickness.

Brake discs shall be interchangeable among all power truck axles and among all center truck wheels.

### **12.7.2 Calipers, Actuators, and Pads**

Brake actuators shall be mounted to floating calipers designed to follow the disc regardless of lateral axle motion. Fixed, saddle mount calipers may be used on the center truck if they are mounted in a location with little relative lateral motion with respect to the disc. The calipers shall also accommodate all other relative motions between the brake discs and the truck frame without binding, causing accelerated wear, overhanging the disc beyond the brake system supplier's recommendation or damage to truck or brake components.

Each brake actuator shall include an automatic slack adjustment feature, which shall compensate for brake pad wear as well as ensure drag-free running.

The brake pads and holders shall be designed for quick pad replacement without disassembly of the caliper unit. Brake pads shall be interchangeable between all axles of the same type.

Motor truck actuators and calipers shall be interchangeable among all motor truck axles. Center truck actuators and calipers shall be interchangeable among all center truck wheel-axle assemblies, except as required to accommodate speed sensors or hose locations required by the truck design.

See Section 11 for brake caliper location limitations and other brake-related truck requirements.

The brake pad, caliper, and disc assembly shall not emit audible squeal, chatter, or other undesirable sounds.

### **12.7.3 Disc Brake Electronic Control Unit**

The disc brake system for each truck shall be provided with a disc brake electronic control unit (ECU). Refer to the Brake System Configuration section, above. The disc brake control logic shall be microprocessor-based with associated peripherals and I/O ports as required to meet all of the specified functions and performance criteria. Refer to Section 17 for software systems design requirements.

Each disc brake ECU shall determine the level of disc braking corresponding to the trainline rate command signal. Wheel slide control signals for that truck may be obtained from the propulsion system or wheel slide control of the disc brake may be a function of the disc brake ECU. Dynamic braking effort signals for that truck shall be obtained from the propulsion system. In all braking modes, including maximum braking, load compensation shall be used to adjust the braking effort.

The disc brake ECU shall also provide the necessary measurement points, hardware, and software for the brake failure monitoring feature to determine proper system operation.

Each ECU shall be provided with a data/fault logger that complies with the requirements of Section 9. The data/fault logger shall create a record of at least eight relevant signals and time of recording whenever an unusual or erroneous condition is encountered during operation. Signals shall be converted to engineering units, (e.g. volts, amps, time of day, etc.). The fault information

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shall both be stored locally and transmitted via the vehicle data bus, or the vehicle Ethernet data communications bus, to the Monitoring and Diagnostic System for retrieval. Refer to Section 9.

Friction brake system time setting shall be performed each time the train is keyed on by the Master Controller key.

Each disc brake ECU shall be equipped with an Ethernet interface for communicating with portable test units (PTU) to permit static testing and diagnoses, and dynamic monitoring of the disc brake system during vehicle operations. Refer to Section 18 for general requirements for PTUs.

### **12.7.4 Hydraulic Pressure Control Unit**

Each truck shall be provided with a Hydraulic Pressure Control Unit (HPCU). Each HPCU shall be mounted near the truck or wheelset that it controls in order to minimize brake response time. The units shall be mounted in a protected location to prevent damage from dirt, dust, wheel splash, and unusual heating conditions such as cooling air outlet from propulsion equipment or radiant heat from brake discs. Refer to the Protection section, below, for additional mounting requirements. The hydraulic secondary suspension system for that truck (if used) may be integrated with the friction brake hydraulic system.

The HPCU shall contain a hydraulic fluid reservoir, motor-driven pump, accumulator (may be separately mounted), and all necessary control valves and pressure controls. All control valves and pressure controls shall be mounted on a common manifold to minimize piping within the HPCU. All external connections shall be made directly to the manifold plate using self-sealing, quick-connect couplings.

The hydraulic fluid reservoir shall be designed to minimize the potential for contamination from particles or moisture. A breather-filter and pressure release valve shall be provided (opening at approximately 3 lbf/in<sup>2</sup> gauge (0.2 bar)). The reservoir shall be provided with a drain plug, fluid level sight glass, and a self-sealing, quick-connect coupler for filling.

The pump shall be driven by a brushless dc motor operating from the vehicle low-voltage power supply. The motor shall function properly over the range specified in Section 2. The pump shall charge an accumulator with fluid from the reservoir for service and maximum braking applications, including multiple applications and releases during wheel slide activity. Designs in which the pump motor operates continuously to maintain pressure will not be permitted. The pump motor shall use sealed bearings, and shall be totally enclosed, non-ventilated, and rated for wash-down applications. The motor mounting shall preclude the ingestion of hydraulic fluid or fumes.

A nitrogen-charged accumulator shall be provided to store the hydraulic energy. The pressure levels, volumes, and pressurized fluid levels shall be sufficient to meet the required performance, response times, and capacity for brake applications and wheel slide control specified in Section 2, at all ambient conditions.

The HPCUs shall provide for the use of either an electronically-controlled pressure servo system that consists of separate Pulse Width Modulated (PWM) controlled application and release

## *Friction Brake System*

magnet valves, plus a pressure feedback transducer and appropriate auxiliary components, or an analog servo valve with appropriate auxiliary components.

Pressure transducers shall be utilized for feedback, testing, and the failure monitoring system. Transducers shall be low drift, temperature-compensated devices that shall not require calibration more often than once every 5 years. The hydraulic control system shall include regular, internal self-checks of correlation between commanded and measured pressures.

### **12.7.5 Pressure Sensors**

Pressure transducers with test fittings shall be provided to perform the functions described below. The pressure transducers shall be independent of the pressure transducers used for feedback and other basic system control functions.

#### **12.7.5.1 Brake Cylinder Pressure Sensors**

Brake cylinder release indication pressure transducers shall be provided in the brake cylinder line for each truck, located downstream of the disc brake cut-out valves, such that a cutout brake cylinder will read zero pressure. The transducers shall control circuits to operate the propulsion interlocks and annunciators described in this Section.

#### **12.7.5.2 Accumulator Low Pressure and Volume Sensors**

Non-adjustable pressure and accumulator volume sensors, or an alternate method, subject to approval by Sound Transit, shall be used to monitor the accumulator for each truck for the purpose of inhibiting propulsion, as described in the Storage Capacity section, above.

#### **12.7.5.3 Pump Motor Controls**

Transducers shall be used to monitor accumulator pressure or accumulator volume for each truck for the purpose of operating the motor-driven pump as described in the Hydraulic Pressure Control Unit section, above.

#### **12.7.5.4 Brake Failure Valves**

The hydraulic pressure control unit shall include brake failure valves which shall cause a fixed hydraulic pressure to be applied to the brake actuators when commanded by the brake failure monitoring system. An adjustable pressure regulator shall provide a fixed pressure to the brake actuators by means of a three-way magnet valve when the magnet valve is de-energized. When the magnet valve is energized it shall connect the pressure servo system to the brake actuators.

### **12.7.6 Test Points and Fittings**

Pressure test fittings shall be provided in all hydraulic lines that are monitored by pressure sensors. The fittings shall allow for testing without removing the sensor being tested from the vehicle. Self-sealing quick-connect couplings shall be mounted directly to the manifold plate in an accessible location.

## **12.8 Hydraulic Fluid System**

### **12.8.1 Hydraulic Fluid**

Hydraulic fluid shall be fire-resistant and meet all requirements of MIL-PRF-83282. Wide temperature range commercial hydraulic fluids with equivalent or better fire characteristics may be proposed and shall be subject to Sound Transit review and approval. (CDRL 12-3) See Section 17 for additional smoke and flammability requirements.

### **12.8.2 Operating Pressures**

The maximum pressure in the hydraulic system shall be limited to 2500 lbf/in<sup>2</sup> gauge (172 bar). Maximum brake cylinder pressure shall be no greater than 1500 lbf/in<sup>2</sup> gauge (103 bar).

### **12.8.3 Filtration**

Filters shall be strategically located in the hydraulic system to prevent damage to system components. As a minimum, the following filters shall be provided:

- A maximum 74 micron filter between the reservoir intake and the pump
- A maximum 10 micron filter between the high pressure pump outlet and the accumulator

Additional filters and/or alternate filtration ratings recommended by the brake equipment supplier may be proposed.

Filters shall have an internal bypass, except as otherwise justified by the brake equipment supplier. (Include in CDRL 12-1)

All filters shall be provided with replaceable filter elements. The filtering capability, flow rate capability, and overall size shall maintain system function and hydraulic fluid quality within the equipment manufacturer's specifications throughout the filter replacement interval, which shall be greater than one year.

### **12.8.4 Hydraulic Seals**

Hydraulic seals shall be applied according to recommendations of the seal manufacturer, including: surface finishes, clearances, dimensions and tolerances, minimum and maximum pressures, velocities, ambient and operating temperatures, fluid properties and cleanliness, back-up rings, assembly instructions and lubricants, and all other criteria as may be specified. Deviations from the manufacturer's recommendations will be permitted only with the expressed concurrence of the manufacturer.

Seals shall provide leak-free operation for a period not less than twice the approved overhaul period.

The seal manufacturer shall confirm that the seal's application is acceptable. This confirmation shall be submitted to Sound Transit. (Include in CDRL 12-1)

### **12.8.5 Piping**

All hydraulic piping shall comply in all respects with Section 17 and the hydraulic brake supplier's design and installation requirements, whichever are more restrictive.

Within 180 days of NTP, and prior to manufacture of production cars, the Contractor shall provide Sound Transit with a report containing the following (include in CDRL 12-1):

- All critical line sizes and materials including internal HPCU piping and brake cylinder piping.
- Installation details of all critical lines including routing, total length and volume, and major joint and direction change locations. A list of all proposed bend radii shall also be provided.
- Pipe processing details including cleaning, welding, brazing, and fabrication methods.
- Locations of all major hydraulic brake control components, electrical control relays, and auxiliary devices plus the proposed location and volume of all accumulators.
- A listing of all hosing and seals showing the compatibility with the hydraulic fluid and the smoke, flammability, and toxicity data required in Section 17.
- A friction brake usage analysis, justifying the proposed accumulator and reservoir capacities.

### **12.9 Magnetic Track Brake**

Articulated track brakes shall be selected to provide the performance indicated in Section 2. Track brakes other than articulated may be considered if it can be proven that they would be beneficial to Sound Transit.

Control of track brakes shall be as described in the Track Brake Control section, above. Track brake supports shall be as described in Section 11.

The track brake system shall be effective at all speeds from the maximum down to a full stop over all conditions of curves and grades. Track brake force shall not be modulated by blending, load compensation, or other means.

The track brakes shall be fully watertight. Coils shall be enclosed in a non-magnetic, corrosion-resistant case with all coil voids filled to form a hermetically-sealed unit. Coils shall be electrically isolated from all grounds and shall be terminated in a built-in two-pin connector or other approved connection. Connection to vehicle wiring shall be via flexible cable(s) with waterproof connectors at both ends.

All track brake forces shall be transmitted to the truck through bonded rubber elements. If it is necessary to remove the track brake to renew the rubber elements, they shall be applied to the track brake assembly rather than the truck. Track brake mounting which does not require rubber

## *Friction Brake System*

elements, but which provides for quiet operation, will be considered for approval by Sound Transit. (Include in CDRL 12-1)

Track brake shoes and the pole filler material shall be readily replaceable. The wear surfaces shall be smooth and shall not wear grooves or ridges in the rail head throughout the life of the track brake shoe.

Track brakes shall not interfere with track, wayside, or truck components under all normal conditions and combinations of wear. In the area between the railhead and 2 in (50 mm) above top of rail, the track brake shall not extend laterally beyond the wheel tire cross section with fully worn track brake shoes.

In a de-energized state, the track brake shall be suspended above the rail by springs and shall be located laterally by resilient stops. Track brake motion while suspended shall not produce audible noise under any normal operating condition. Vertical clearance above top of rail, when de-energized, shall be maintained under all loading conditions. Provision for adjustment, if necessary, shall be provided to maintain proper clearances.

A separate track brake contactor and circuit breaker shall be provided for each truck. Tripped or open track brake circuit breakers shall cause annunciation of a friction brake fault as described in the Brake Failure Monitoring Feature and Friction Brake Fault or Cut-out sections, above.

### **12.10 Sanding System**

Each vehicle shall be provided with eight electrically-heated sandboxes, eight pneumatic sand traps, and heated sanding nozzles arranged to deposit sand on both rails immediately in front of each motor truck on each vehicle of a train. Alternative design of the sanding system may be considered if it can be proven that it would be beneficial to Sound Transit.

Sanders may be constructed of conventional parts as described below, or may be unitized sanding systems with integral pressurized sandbox, compressor, heater, and controls that provide the sanding functions described below.

Sanders shall be operated pneumatically and shall include sand reservoirs, traps, piping, and nozzles for each of the sander locations. They shall operate successfully over the full normal pressure range of the air supply system.

Sandboxes shall be contained within underseat enclosures, which shall conform to the general design of all other underseat enclosures. The boxes shall be made of stainless steel or cast aluminum and shall be arranged to permit easy filling from both inside and outside the vehicle. The bottom of the sandbox shall be sloped towards the floor outlet with the slope angle greater than the angle of repose of the sand. Each sandbox shall have a sight gauge, visible from inside the vehicle, to indicate sand level. Capacity shall be at least 0.7 ft<sup>3</sup> (0.02 m<sup>3</sup>) per box and the design shall be such that moisture or foreign matter cannot enter into the box under normal operation. The inside access cover shall be the seat bottom. The seat shall be hinged and shall be equipped with a spring latch to hold the seat down. A Sound Transit crew key shall be required to release the latch and raise the seat. The outside access cover shall be locked using the Sound Transit's crew key.

## *Friction Brake System*

The sandboxes shall gravity feed into pneumatic sand traps, which shall have a successful railroad or transit service history. The traps shall be initially adjusted to apply sand at a flow rate of approximately 1 lb/min (0.45 kg/min) with a supply air pressure of 120 lbf/in<sup>2</sup> gauge (8.3 bar). The flow rate shall be mechanically adjustable by shop personnel by at least +/- 25% of the nominal setting

The output of the trap shall be through piping or hose selected and arranged to permit the free flow of sand to the nozzles under all conditions of environment and truck rotation. Tees, elbows, or other restrictive fittings shall not be used. Sanding nozzles shall not clog under any specified environmental conditions.

Heated sanding nozzles shall be fastened to the truck frame and connected to the sand traps by flexible hoses. The nozzles shall be shaped and located to deposit sand directly in front of, and as close as possible to, the wheel/rail contact point. Nozzles shall be designed to reject water caused by wheel splash.

Control of sanders shall be as described in the Sanding System Control section, above.

The sandbox heaters shall be self-regulating sheet-type heaters powered from the low-voltage system through an independent circuit breaker per truck.

Air for the sanding system shall be provided by the vehicle air supply system. Cut-out valves for the sanders of each truck shall be provided.

The sanders for each motor truck shall be fed by a separate circuit breaker, which shall also function as the sander cut-out switch. Tripped or open sander system circuit breakers shall cause annunciation of a brake fault as described in the Friction Brake Fault or Cut-out section, above.

### **12.11 Air Supply System**

A source of clean, dry, compressed air shall be provided for use by the sanding and other pneumatic car systems. Alternatively, if a hydraulic suspension system is used, unitized sanders with internal air compressors may be used instead of a central air supply.

#### **12.11.1 Air Compressor**

If a pneumatic suspension system is used, an air compressor shall provide a centralized air supply for suspension and other functions. The air compressor shall be an approved design (CDRL 12-4) and shall be a high quality two- or three-cylinder two-stage compressor, or rotary screw compressor, direct-driven by a three-phase ac induction motor, powered from the ac power supply described in Section 9 or from a dedicated variable voltage variable frequency inverter fed from the 1500 Vdc line, and furnished complete with suspension frame. Compressor shall not overload the motor during starting under cold ambient conditions, as described in Section 2.

## *Friction Brake System*

The air compressor unit shall operate safely and quietly at all line voltages specified in Section 2, and include the following:

- Compressor capacity shall be sufficient for the normal and continuous operation of two coupled cars, with compressed air transferred via the main reservoir equalizing pipe, with all equipment functioning normally on both cars. Except for initial charging of the reservoirs, air delivery shall be sufficient to keep the air systems of both cars above the low air annunciation point at all times, and as specified in this Section.
- The compressor capacity shall be sufficient to supply all air system needs as described above under all operating conditions when operating anywhere within its normal operating pressure range, at minimum auxiliary inverter output or input voltage. The air compressor shall be designed and demonstrated to operate continuously at maximum capacity without damage.
- The compressor unit shall be resiliently mounted on the car roof and shall not conduct noise or vibration into the car. Resilient mounts shall be of a quality adequate to allow a minimum of five years of service before replacement. The suspension frame shall pass under the compressor and motor, and shall safely support the compressor in the event of failure of mounting bolts, or resilient mounting.
- The compressor motor shall be equipped with anti-friction bearings of the sealed lubrication type. Grease cavities in each bearing shall contain sufficient lubricant to allow operation for the greater of three years, or the recommended overhaul period, without re-lubrication.
- Compressor crankshaft bearings may be of the sealed grease lubricated type, or may be designed to use crankcase oil for lubrication.
- The air compressor cooling system shall consist of a finned tubing after-cooling unit, included within the compressor unit, and arranged to drain into a heated sump reservoir in the compressor unit.
- The after-cooler shall provide a discharge air temperature suitable to achieve the desiccant dryer capacity and service interval, but within 20°F (11 K) of ambient.
- The sump reservoir shall be equipped with a thermostatically-controlled, heated, pneumatically piloted drain valve. The drain valve shall be controlled in conjunction with the compressor start-stop cycle.
- The drain valve discharge shall be muffled to meet the steady state sound level limits of Section 2, and shall be heated and arranged to drain to the undercar area.
- Piping from the compressor to the dryer unit shall be arranged to drain into the sump reservoir.

### **12.11.2 Dryer Unit**

Moisture shall be removed from the air supply by an approved twin tower desiccant dryer assembly, (CDRL 12-5). The dryer shall have sufficient capacity to provide a minimum 30°F (17 K) dew point depression with the compressor operating on a 100% duty cycle.

Desiccant service intervals shall be no less than one year, and the dryer shall maintain the specified minimum capacity during the entire service interval.

The purge discharge shall be muffled to meet the steady state sound limit requirements of Section 2. The dryer and purge discharge shall be heated and the discharge routed to drain to the undercar area.

### **12.11.3 Main and Supply Reservoir Arrangement**

A main reservoir shall be provided on the roof of each car.

The main air reservoir shall be provided with a manual drain cock constructed of non-corroding materials. The drain cock shall be heated and arranged to drain to the undercar area.

All reservoirs shall be mounted so as to provide a 1 in (25 mm) difference in mounting height from end to end, with the drain cock located at the lowest point. Alternative arrangements may be proposed. (CDRL 12-6)

All reservoirs shall be supplied by the manufacturer with drilled "telltale" holes per 49 CFR 229.31(c), with a head thickness and shell designed to withstand at least five times the maximum working pressure. Alternative designs may be submitted. (CDRL 12-7)

### **12.11.4 Main Reservoir Equalizing Pipe**

A main reservoir equalizing pipe and valve arrangement shall be provided so as to permit one car to charge and supply an adjacent coupled car whose air compressor is inoperative.

### **12.11.5 Operating Pressures**

Maximum pressure in the air system shall be limited via a main reservoir pressure relief safety valve. A compressor governor control cut-out pressure shall be at least 10 lbf/in<sup>2</sup> gauge (0.7 bar) lower than the safety valve setting.

### **12.11.6 Code Requirements**

Design and installation of all air system components shall conform in all respects with the ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels.

## **12.12 Packaging and Installation**

### **12.12.1 Components**

Design and installation of all hydraulic brake system and air supply system components shall conform in all respects to Section 17.

### **12.12.2 Piping**

The hydraulic braking system piping and air system piping shall conform to Section 17. Tapered pipe threads will not be allowed.

### **12.12.3 Component Fastening**

Brake components mounted to manifolds shall be fastened with standard threaded fasteners that do not rely on prevailing torque to prevent bolt loosening in service. Refer to Section 17.

Other brake components mounted to the vehicle body or trucks shall be fastened with vibration resistant fasteners.

### **12.12.4 Hydraulic and Air Line Support**

Hydraulic and air hoses, pipes and tubes shall be supported to prevent interference, vibration, rubbing and chafing. Routing that uses other piping or cables as the sole means of support is not acceptable.

### **12.12.5 Protection**

All brake control equipment shall be mounted so that it is protected to the greatest extent possible against damage due to minor collisions, automobile sideswipes, derailments, dirt, dust, ballast, and water.

All cut-out cocks shall be mounted in protected locations.

### **12.12.6 Labeling**

All friction brake apparatus, cut-out cocks and brake release devices shall be clearly labeled in a permanent manner. Operating instructions, including safety warnings, for cut-out valves and brake release devices, shall be provided in the compartments that enclose the cocks or devices or on panels adjacent to the cocks or devices. Refer to Section 15.

## **12.13 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer also to Section 19 for CDRL requirements.

12-1 Friction Brake System Design Report (Section 12.1)

## *Friction Brake System*

- 12-2 Mounting of disc brake hub (Section 12.7.1)
- 12-3 Wide temperature range commercial hydraulic fluid [if applicable] (Section 12.8.1)
- 12-4 Air compressor design [if applicable] (Section 12.11.1)
- 12-5 Desiccant dryer assembly [if applicable] (Section 12.11.2)
- 12-6 Alternative air reservoir mounting arrangement [if applicable] (Section 12.11.3)
- 12-7 Alternative air reservoir designs [if applicable] (Section 12.11.3)

### **12.14 Cited References**

The following standards or references were cited in this Section at the referenced location:

ASME	Boiler and Pressure Vessel Code (Section 12.11.6)
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, NATO Code Number H -537 (Section 12.8.1)
49 CFR 229.31(c)	Part 229 – Railroad Locomotive Safety Standards: Main Reservoir Tests (Section 12.11.3)

**END OF SECTION 12**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 13  
VEHICLE COMMUNICATION, PUBLIC ADDRESS, PASSENGER INTERCOM,  
RADIO, AUTOMATIC PASSENGER INFORMATION,  
CLOSED CIRCUIT TELEVISION,  
AND  
AUTOMATIC PASSENGER COUNTING SYSTEMS**

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**SECTION 13: VEHICLE COMMUNICATION, PUBLIC ADDRESS, PASSENGER INTERCOM, RADIO, PASSENGER INFORMATION, CLOSED CIRCUIT TELEVISION, AND AUTOMATIC PASSENGER COUNTING SYSTEMS**

**13.1 General**

**13.1.1 Scope**

The on-board communication system includes the Audio Control Head (ACH), and the public address (PA), passenger intercom, on-board train radio subsystems, and the passenger information system, which includes the destination signs and automated announcement and display equipment. In addition, this Section includes Closed Circuit Television (CCTV) equipment for rear viewing and car interior surveillance, and the Automatic Passenger Counting (APC) equipment.

The Contractor shall furnish all specified communications, PA equipment, passenger information equipment, intercom equipment, CCTV equipment, APC equipment and the voice radio set described in this Section. The Contractor shall install and test all communication, PA equipment, radio, passenger information, intercom equipment, CCTV equipment, and APC equipment. All trainlined communications functions shall be fully compatible with other trainline functions being installed in these cars.

**13.1.2 Audio and Radio Communications**

All digital communications equipment, PA equipment, radio, passenger information equipment, intercom equipment, CCTV equipment, and APC equipment shall be rated for continuous duty. Control and power circuits for all such equipment shall be isolated from the chassis and cabinets and shall be rated to pass the insulation tests specified in Section 16.

Within 180 days of NTP the Contractor shall prepare an initial communications system design report that addresses all audio and passenger information systems. It shall identify all design submittals that are necessary to demonstrate compliance with the requirements of this Section. The report shall be updated as actual submittals are tendered for review and approval, but no less frequently than every 60 days. The Report shall summarize the content and approval status of each submittal. (CDRL 13-1)

**13.1.3 Communications Functional Description**

Each car shall have communication and other equipment designed, installed, and tested by the Contractor to provide the following vehicle functions:

- One-way communication from the train operator to passengers (PA System) via the interior and exterior speakers
- Two-way communication between the train operator and the Sound Transit Central Controller and/or Sound Transit rail supervisors

- Two-way Passenger Emergency Intercom for passenger initiated communication between a passenger inside the train and the train operator
- Automatic announcements including route, destination, and next station
- Special recorded announcements to the passengers (PA System)
- Two way cab-to-cab communication
- Destination and passenger information message signs
- Wireless communication to download route and message information at the depot and terminal locations (Wireless communication to download system software updates shall only be done at the depot.)
- Detection of communication system faults and the functional means to report them to the MDS
- Provision of an Automatic Passenger Counting function

## **13.2 Audio System Control Head (ACH)**

### **13.2.1 General**

The ACH shall be furnished and installed in each cab as an integral part of the cab console. (Include in CDRL 13-1.)

The ACH shall consist of:

- Gooseneck microphone or approved alternative (mounted separately from the ACH);
- Mode or function switches with indicating lights (PA, Cab-to-Cab Intercom, and Passenger Emergency Intercom)
- PA mode selector switch (interior, exterior, or both)
- Intercom chime
- Two loudspeakers per cab: one for two-way radio and one for PA/Intercom, mounted independently in the operator's cab
- Speaker volume control for cab speakers
- Push-to-Talk (PTT) switch on the operator's handhold
- Automatic Announcement Control Panel (AACP) (may be integrated into the ACH or mounted separately)
- Circuitry to implement the specified functional requirements

The momentary pushbuttons shall be vandal resistant and shall be designed and type tested for one million failure-free mechanical operations.

Alternative arrangements that integrate the control panel functionality with the train operator's display console may be proposed. (Include in CDRL 13-1.)

### **13.2.2 Gooseneck Microphone**

The Contractor shall furnish a gooseneck microphone in each cab. The gooseneck microphone shall be usable for all intercom and PA modes. The gooseneck microphone shall comply with the following requirements:

- It shall be of rugged, weatherproof construction and shall be designed and constructed for transportation applications
- It shall employ a noise-canceling, close-talking style of dynamic microphone
- The microphone cable shall be enclosed in the flexible gooseneck microphone mount, which shall be securely attached to the console. The mounting at the panel shall be secured from the interior of the cab console. Twisting and flexing of the gooseneck cable to suit each train operator's ergonomic needs shall not result in a loose mounting fixture on the console, and shall not cause signal interruptions due to a loose connection.
- The gooseneck length shall permit a seated train operator in the fifth female to ninety-fifth male percentile height range to speak into the microphone without leaving the normal operating position or losing sight of traffic in front of the vehicle
- The microphone cable shall terminate at a circular, extremely robust, transit-grade connector on the back of the ACH
- The microphone shall be vandal resistant

As an alternative, Sound Transit will consider a boom style microphone or "hands-free" in-dash mounted microphone, meeting the above requirements. (Include in CDRL 13-1.)

### **13.2.3 Push-to-Talk Switches**

A push-to-talk (PTT) switch for use in all PA and intercom modes shall be provided in each cab. A rugged, transit-grade momentary-contact switch to function as the system PTT switch shall be installed on the console switch panel as specified in Section 5. Pressing the PTT switch shall also silence the local cab PA and intercom speakers. The PTT shall not be used as part of the two-way radio communications.

### **13.2.4 Radio Interface**

Interface connections shall be provided for the radio loudspeaker if the loudspeaker is mounted as part of the ACH.

### **13.3 Public Address System**

#### **13.3.1 General**

The public address (PA) system shall permit the operator to make announcements to passengers in all cars of a train through use of loudspeakers connected by a system of trainlines, relays, switches, and amplifiers.

The PA system is also used by the automatic passenger information system (APIS) to make announcements to passengers.

Sets of loudspeakers shall be strategically located inside and outside the car. Whether the interior set of loudspeakers, the exterior set of loudspeakers, or both, are to be used for public announcements shall be determined by switches at the ACH of the controlling cab.

The operator PA function shall be activated by selecting PA mode at the ACH. The operator shall be able to make an announcement through the gooseneck microphone when the PTT switch is depressed.

Operator-initiated PA messages shall override passenger information system messages.

Each car shall be provided with both preamplifier, digital transceiver, and power amplifiers, which shall drive that car's loudspeakers. In trainlined operation, the announcement circuitry shall be Ethernet-based. The Ethernet trainline shall provide PA announcement information to all cars. The head end car controller shall drive the power amplifiers in that car, and the PA speakers in the succeeding cars shall be powered from the amplifiers in those cars. Preamplifiers and power amplifiers shall not be connected in series or cascaded from car to car.

All messages shall be intelligible and acoustically pleasing under all operating conditions at all train speeds. The minimum Speech Transmission Index (STI) level of the PA system, when the train is not moving and the HVAC system is off, shall be 0.72 when tested according to IEC 60268-16, using the Bedrock STIPAmeter SM50 or an approved equivalent. All STI measurements shall be made following the practices recommended in the Embedded Acoustics White Paper EA-WP-2014-199-1. Alternative or additional STI measurement techniques from other standards or white papers may be proposed.

The PA system shall include an equalizer, and upon installation, equalizer optimization efforts shall be made to tune the PA system in order to maximize the STI across the car. When the train is moving and all typical noise sources are on (including the HVAC system), the PA system shall have an average STI rating greater than or equal to 0.5. STI measurements shall be made at no fewer than nine interior locations per car at no fewer than three different heights, and there shall be at least three STI measurements made at each measurement location.

All STI measurements, calculations, and tuning efforts shall be documented. No measurement shall be discarded and replaced by a repeated measurement, with two exceptions:

- (1) If one of the measurements deviates by more than 0.05 from the average, then this measurement may be repeated once, discarding the original measurement.

- (2) If a unique audible acoustic event occurs that possibly interferes with the measurements (door slamming, noisy train passing by outside, etc.), then the corresponding measurement may be discarded and repeated.

In all STI tests, the volume of the test announcements shall approximate the volume of typical PA system announcements.

Preceding any public audio announcement, including automatic announcements, a local tone annunciator shall be energized to alert passengers that an announcement is forthcoming. The tone volume shall be 3 dB above the normal speech level. The annunciator shall possess a pleasant, chime-like quality.

### **13.3.2 Equipment Requirements**

#### **13.3.2.1 Interior Loudspeakers**

Interior loudspeakers shall be subject to Sound Transit review and approval and shall meet or exceed the following criteria (include in CDRL 13-1):

- Provide a minimum of one speaker for every 2400 mm (8 ft) of vehicle length
- Select speaker dispersion and other characteristics to provide sound levels within 3 dB of one another, and intelligible audio (as specified elsewhere in this Section), at all seating locations and under all vehicle operating conditions
- Provide speakers with a continuous power rating of minimum 5 W
- Arrange speakers to eliminate feedback from any audio input source
- Provide audio fidelity specified in this Section at all power levels
- Mount speakers in the ceiling, or other approved locations
- Grilles shall be flush mounted, finished to match the panel, perforated, removable for access to the speaker, and held in place with tamper-proof screws
- Provide a volume adjustment control for the operator's cab PA speaker that can be adjusted by the operator

#### **13.3.2.2 Exterior Loudspeakers**

Exterior loudspeakers shall be subject to Sound Transit review and approval and shall meet or exceed the following criteria: (Include in CDRL 13-1)

- Provide a minimum of four external speakers per vehicle, two per side
- Speakers shall be impervious to environmental conditions as specified in Section 2, Design and Performance Criteria
- Provide speakers with a continuous power rating of minimum 15 W

- Mounting of speakers and routing of speaker wires shall be waterproof
- Speaker locations shall not violate the vehicle's dynamic outline
- Speakers shall be immune to the chemicals and detergents normally used during vehicle washing, shall not interfere with nor damage mechanical vehicle wash brushes, and shall be designed to withstand all forces generated by these brushes

### **13.3.2.3 Amplifiers**

Provide network-connected amplifiers driving one or more speakers, with sufficient power to drive all connected speakers at maximum levels, simultaneously, without distortion. The frequency response of power amplifiers below 100 Hz shall fall off at a rate of maximum 6 dB per octave.

The radio output amplifier shall be used for driving the cab radio loudspeaker only.

### **13.3.3 Performance Requirements**

#### **13.3.3.1 Uniformity of Coverage**

Interior loudspeakers shall be arranged so that the sound pressure level throughout the passenger compartment at a height of 64 in (1625 mm) does not vary by more than  $\pm 3$  dB for a pink noise signal over the octave band centered at 4 kHz.

#### **13.3.3.2 Sound Level**

The public address system's output level shall be automatically set in accordance with the ambient noise level in each individual car prior to activation of the system. The range of automatic adjustment shall be a minimum of 15 dB. The maximum output level shall be a minimum of 15 dB above the interior ambient noise level resulting from vehicle operation at full speed in a tunnel.

#### **13.3.4 Audio Power Supply**

The audio equipment shall be powered from the vehicle low-voltage power supply by a transformer-isolated, dc-to-dc power converter, which may be integrated into the audio amplifier case. The circuit supplying power to the converter shall supply no other loads, and the input circuit shall have a dedicated circuit breaker.

The output voltage, power level and regulation shall be as needed to permit the audio system to provide the performance specified elsewhere in this Section.

The converter shall include as a minimum the following protective features: Input voltage transient protection with energy levels up to 140 J and peak currents of 2000 A; input-to-output isolation of 1500 Vdc; and the output shall be short circuit-proofed by including automatic current limiting.

The unit shall be enclosed in a dust tight anodized aluminum heat sink case and shall be convection cooled.

### **13.4 Vehicle Intercom System**

The communication system shall include an intercom feature to allow two-way communications between the operator's cab and any passenger emergency intercom (PEI) station, and between operator's cabs (IC) in a vehicle consist as described in this Section.

A lighted pushbutton on the console shall control the intercom system and provide status indication as follows when the cab is active:

- Incoming page from PEI or IC. A visual indication shall be provided by flashing the light on the pushbutton and an audible indication shall sound a distinctive intercom ring tone over the cab speaker. By pressing the control pushbutton, two-way communication shall be established and the caller shall be heard on the cab speaker. The light on the pushbutton shall turn steadily on and the operator shall be able to respond to the call using the push-to-talk (PTT) switch on the console switch panel and the gooseneck microphone.
- Pressing the steady lighted pushbutton shall terminate the call and the status light shall extinguish returning the communication system to normal.
- If an intercom call is initiated while one is already in progress, the audio paging shall be heard over the cab speaker and the status light on the pushbutton shall flash at a high rate. The operator shall acknowledge the newest call by pressing the fast flashing control button. This action shall return the status light to steady and initiate a standard "hold" message to be played where the call was initiated followed by a muted "busy" signal. Such calls shall be stored in a buffer, in the order received, and accessible to the operator at the conclusion of the present call.
- If the call is not acknowledged by the operator within 15 seconds the call will time out and be canceled and the next call in the cue will be activated this will apply to all calls in cue.

In cases where a call is terminated and there are one or more calls waiting, queued in order they were made, pressing the control button shall in addition to terminating the first call change the busy signal at the next caller's location to the ring tone at normal volume. The action shall also cause the status light in the cab to start flashing and the ring tone shall sound over the cab speaker. The call will now be processed as an incoming page from PEI or IC as described in the first bullet. Subsequent calls are answered, acknowledged and terminated similarly until there are no more calls in the queue.

Selecting another function on the console shall cause any intercom call to be placed on hold and permit the selected mode to be used, after which the operator shall be able to return to the intercom mode by pressing the intercom control pushbutton. An intercom call put on hold shall cause the status light in the cab, and at the location the call was made from, to flash at a high rate while also playing the "hold" message at that location followed by the muted busy signal.

Cab speaker volume for the ring tone and conversation shall be adjustable using PTU software only.

The queue shall be cleared when the cab is deactivated.

Alternatively the intercom user interface can be integrated with the TOD; however, the operator shall have means to respond to and cancel PEI calls and to initiate, respond to and cancel IC calls in the event that the TOD has failed.

#### **13.4.1 Passenger Emergency Intercom Stations**

The passenger emergency intercom (PEI) system shall allow calls to be initiated from any PEI station in the consist. PEI stations shall be located in each wheelchair area (refer to Section 2) so as to be easily accessible for wheelchair patron's use. The units shall be flush mounted at a height of 48 in (1220 mm) above the floor, and shall be submitted to Sound Transit for review. (CDRL 13-2)

The PEI station shall incorporate a "press-to-latch" feature enabling immediate communication with the operator via the paging loudspeaker without having to continue to press the call button. When the call button is pressed, the communication system shall initiate the intercom function, play the paging audio, and flash the status light on the console in the controlling cab and at the PEI station that initiated the call.

Communication between one PEI station and another shall not be possible.

The PEI station shall consist of a panel enclosure constructed from stainless steel, which shall enclose a loudspeaker, microphone, large call button, an indicator light (which may be part of the call button), and any necessary auxiliary components to make the system function as specified. The units shall be resistant to moisture from indirect rain and normal cleaning with a moist cloth, and shall be vandal resistant. Electrical connections shall be by means of concealed multi-pin connectors; refer to TS 17. The microphone shall be omni-directional, with external filters to reject background noise.

PEI unit loudspeakers shall have output power sufficient to clearly hear instructions from the operator under the worst interior noise conditions. The PEI unit shall be marked with graphics on or near the unit to identify the unit as an "Emergency Intercom." The instructions shall read, "To Contact Driver Push Button Once". A removable car number plate shall be applied to each unit. Lettering size, style and color shall be submitted. Units shall be marked in raised lettering and in Braille in accordance with 36 CFR 1191 Appendix D, Section 703, Signs. Means shall be provided to prevent unintended nuisance activations.

#### **13.4.2 Cab-To-Cab Intercom**

When an operating cab is activated in a consist, it shall be possible to initiate a cab-to-cab intercom (IC) call from any cab by pressing the intercom control pushbutton. The IC call shall be annunciated and acknowledged in the receiving cab as specified above in this Section. The call can be cancelled in either cab by pressing the steadily lighted control pushbutton.

## **13.5 Automatic Passenger Information System**

### **13.5.1 General**

The Contractor shall provide an Automatic Passenger Information System (APIS) for each car, which shall consist of the following:

- A cab console mounted APIS control panel
- Four interior message digital display signs as described below
- Four destination signs (two end signs and two side signs), the two side signs should be viewable from the inside and outside of the vehicle
- A solid state automated announcement system which utilizes the PA system for audio announcements as described in the Public Address System section, above.

The Contractor shall provide in each car all the equipment described in this Section. The automatic announcement and display system shall operate in conjunction with the exterior facing destination signs. The Contractor shall submit a design report (CDRL 13-3)

### **13.5.2 APIS Control Panel**

The APIS control panel shall be provided in each cab on the lower cab console and within easy reach of a seated operator, this to allow the operator to control display and announcement of messages. The control panel shall include an alphanumeric display that duplicates the message shown on the interior display signs. The panel shall contain push buttons that allow the operator to skip a station or stations in the announcement sequence or to reverse the sequence for running the route in the opposite direction. The APIS control panel may be integrated into the ACH.

### **13.5.3 System Operation**

Selection of a route from the APIS control panel shall cause the automatic station announcement and display system to select a table of stations for that route. The database from which the automatic station announcement and display system makes route selections shall be adequately populated and structured in such a way that any route can be configured to use any combination of station(s) and message(s) in the database. The system shall be capable of managing 1000 different routes. The system shall function automatically, after the operator has entered the starting location, as the train proceeds from station to station. As the train leaves each station, the system shall be automatically set for the next station. Station location data shall be made available in real time to the APC equipment.

The precise interior digital displays and audio announcements to the passengers about the train and stations shall be determined during design review and shall include typical messages as follows:

- “This is a ‘*name of route*’ train....”

- “Next station is...”: To be announced as the train approaches a station, internal audio and visual
- An announcement that designates which train doors will be opening shall also be made
- Between stations, the internal display is to announce the next station. This is to be a visual announcement only
- Assorted special operational and emergency messages as selected by the operator from the destination sign control switch. The messages shall be audio and visual, both internal and external. Special messages selected by the control shall be:
  - Special
  - Test Train
  - Express
  - Training
  - Out of Service
  - Emergency
  - 100 additional announcement spaces shall be available for Sound Transit's use.

The system shall provide for multi-lingual announcements. Multi-lingual announcements shall be automatically produced by the pre-programmed selection of multiple, separate announcements.

The operator shall have the ability to interrupt and override the announcement system through actuation of the APIS control panel switches, PTT switch, IC and PA selector switch.

Exterior announcements, except for special operational and emergency messages, shall be audio only. Interior announcements shall be both audio and visual; however, visual announcements shall be limited to the preset announcements.

Station location information shall be transmitted to the APC equipment.

The system shall contain logic to detect system faults and to receive fault data from the destination and message signs. A fault log shall be maintained in the control unit. Fault data shall be accessible locally by PTU and through the MDS described in Section 9. The system shall comply with the requirements of Section 9.

#### **13.5.4 Audio Announcements**

Audio announcements shall have a bandwidth from 150 Hz to 8,000 Hz  $\pm$ 1 dB with a signal-to-noise ratio of 48 dB or better. From record to playback, the harmonic distortion shall be less than 1%. The output volume and audio quality shall be the same from each speaker. Speech peaks shall be limited to approximately 5 dB above the average input level.

Announcements shall be enabled by a control signal in the car with an active cab from the automatic passenger information system to the audio system, which shall cause the audio system to enter the PA mode and accept an audio signal from the APIS.

Audio messages generated by Sound Transit will be provided to the Contractor. The Contractor shall implement the audio messages using said recordings. Sample audio messages shall be provided to Sound Transit. (Include in CDRL 13-3)

### **13.5.5 Message Storage**

Each audio and text message shall be stored digitally along with information identifying the conditions under which the message is to be broadcast. The digital storage shall be a non-volatile form of memory. The memory shall have the capacity for at least 1,000 visual and audible messages with a total time of not less than 120 min. The digital, non-volatile memory shall be contained on a plug-in module to facilitate batch reprogramming, or shall be re-programmable locally on the car through the PTU. Memory shall be non-volatile that retains all programming in the event of power loss or activities such as the unplugging of circuit boards or connectors. Battery-backed memory is not permitted. The equipment shall be re-programmable through an Ethernet connector.

The Contractor shall provide one complete set of equipment for the modification of the visual and audible messages using the most current version of Microsoft Windows. This equipment shall include everything required to reprogram the on-board systems with new messages. The set shall be delivered 2 years after NTP, or 6 months before the delivery of the first vehicle, whichever is earlier. (Include in CDRL 13-3)

### **13.5.6 Passenger Information Interface Connections**

The control logic for the exterior destination signs, interior digital display signs, and audio announcement system shall be interfaced to an Ethernet network. (Include in CDRL 13-1)

Two wires shall be run to each exterior destination sign and interior digital display sign location, from the low-voltage dc circuit breaker panel to provide power for the sign controls. A dedicated circuit breaker shall be provided for each sign. Appropriate control, messages, and audio interface connections shall be provided between the control units and audio and digital display sign equipment to permit the equipment to provide the functions specified elsewhere in this Section.

### **13.5.7 Automatic Announcement Triggering**

The audio announcement system shall track the progress of the train along the selected route and make station and other informational announcements based on the train's location and destination.

The automatic announcements shall be triggered by the GPS system, and when GPS data is not available (in tunnels for example), by "dead reckoning". Refer to Section 14 for GPS and dead reckoning.

Use of marker transponders shall not be permitted.

### **13.5.8 Control Unit**

The APIS for each vehicle shall be provided with an electronic control unit to house the microprocessor-based control logic for the system. It shall be located in an electric locker and shall be easily accessible. It shall have a PTU connector for system access and software updating. The PTU connector shall be an Ethernet type connector.

A test switch shall be provided on each control unit that shall activate interior and exterior test announcements and sign displays which shall repeat every five seconds until the test switch is deactivated.

Refer to Section 17 for electrical and software design requirements. Refer to Section 18 for PTU requirements.

### **13.5.9 Information Signs**

#### **13.5.9.1 General**

The Contractor shall furnish and install a sign system of approved design and manufacture. The sign system for each car shall consist of four destination signs and four interior message displays. Destination signs shall be controlled from the cab console in the active cab on a trainline basis for all signs on a train. The Contractor shall provide a design report on the sign system, a description of the system and how it operates; electrical, electronic and mechanical drawings; and a description of the software and software documentation. (Include in CDRL 13-3)

#### **13.5.9.2 Sign Operation**

The signs shall be controlled by the APIS described above. The signs may be arranged to store their own messages corresponding to the Announcement System inputs.

The sign logic shall detect faults in individual signs and communicate the fault information to the automatic announcement system control unit.

The system shall be designed to be resistant to electrical noise common on electrified rail vehicles and shall not be confused or enter a fault condition if the destination selection is changed while the signs are in the process of displaying a previously selected destination. The signs shall display the last selected destination when power to the signs is cycled off and on. The sign display units and controls shall operate from the vehicle low-voltage dc system.

#### **13.5.9.3 Destination Signs**

Four automatic, remotely controlled destination signs shall be provided per vehicle: one on each end, located behind the upper portion of the windshield, and one on each side of the vehicle. Side signs shall be readable from inside and outside the car and shall be located in the top portion of the side window in the center car body section; or, if this is not possible, in a window near the center of the car. The installation shall prevent any fog or ice from forming on the glass and from impacting the destination sign's readability. Electrical heaters shall be provided if necessary to prevent fog and ice buildup.

The signs shall be all electric, alphanumeric, amber color, high-resolution, high-output LED display types meeting all other requirements of this Section. In addition, a multi-colored LED panel shall be provided next to the end and side destination signs to designate individual lines on the Sound Transit system. The size and layout of the LED panel shall be submitted to Sound Transit. Different colors shall be available, selected remotely from the automatic announcement and display and TOD system to coincide with the selected route. A total of eight colors shall be provided and chosen by Sound Transit. (Include in CDRL 13-6)

Graphics and lettering on the signs must be legible from a distance of not less than 150 ft (46 m) when illuminated by bright sunlight. The sign display shall be readable in direct sunlight or complete darkness. The horizontal readable viewing angle shall be a minimum of 120 degrees to half brightness. The display shall have a minimum contrast ratio of 35:1 and shall be suitable for both daytime and nighttime viewing. Exterior signs shall be equipped with automatic brightness adjustment, based on ambient lighting.

The display shall not require any external mask between pixels and shall not have any framing or support structure between characters which would give the sign a discontinuous appearance. The signs shall be installed in dust-proof enclosures of an approved type and design. The end sign enclosures shall be provided with an access door with a continuous hinge. The access door shall be equipped with latching devices to hold the door firmly in the open and closed positions and with locks operated by the crew key. The door shall be reinforced structurally to prevent drumming and shall not rattle. The end and side sign units shall be readily moveable to permit cleaning of the glass behind them. (Include in CDRL 13-6)

The end signs shall display 6 in (150 mm) high characters (upper case). The side destination signs shall display 4 in (100 mm) high characters (uppercase) on the exterior facing display and 2.3 in (58 mm) high characters (uppercase) on the interior facing display. The installed systems shall be in full compliance with the latest revision of the Americans with Disabilities Act of 1990 (36 CFR 1192, 49 CFR 38). Each legend of the end destination signs shall have a corresponding legend on the side signs. The destination sign legends, and legend storage capacity if appropriate, shall correspond to the routes and special messages described in this Section. Sound Transit will notify the Contractor of the delivery time of legends and colors specifications.

### **13.5.10 Interior Message Signs**

The interior message signs shall be an all-electronic, alphanumeric LED display. The display shall be a 16 x 224 matrix of pixels capable of displaying multi-color red, yellow and green characters 2.3 in (58 mm) high. A print-like appearance shall be achieved by employing proportional lettering. The signs shall be mounted transversely in pairs, back to back, hung from the ceiling near the center of each main body section, situated to permit any passenger in the train to have a view of at least one of the signs.

The display shall accept messages of at least 48 characters in length and shall present them as a scrolling message and as alternating segments, as selected by Sound Transit.

### **13.6 Train Radio**

Within 90 days of NTP, Sound Transit shall designate the radio system that will be installed into the LRV. The Contractor shall procure the designated radio equipment and install the complete radio system into the vehicle. The radio system design shall contain:

- Radio control heads (one in each cab);
- Radio transceiver and antenna (one per vehicle);
- Radio handset and provisions including hanger and hook switch and headset jack (one per cab);
- Radio power converter (one per cab, or as required by the radio design);
- Cab speaker (one per cab);
- All interconnecting cables and connectors between the radio transceiver, radio control heads, and other radio and communications equipment.

The Contractor shall prepare a train radio design report. It shall include antenna mounting location and methods, radio dc-to-dc converter ratings and design, all relevant electrical schematic drawings, mechanical drawings, and the plans for procuring, installing and testing the radio set function. (CDRL 13-4)

The Contractor shall test the radio set wiring and verify that the radio power supply functions properly. Sound Transit will assist the Contractor in its implementation of a radio system test by the radio supplier after delivery of the LRVs to Sound Transit.

#### **13.6.1 Vehicle-Mounted Antennas**

A weatherproof, low-profile antenna (one per radio transceiver) shall be mounted on the roof of the car near each radio transceiver. The antenna, cable, and matching cable connectors shall be furnished by the Contractor. The antenna mounting location shall be submitted as part of the train radio report noted above. The antenna installation shall not exceed the vehicle dynamic envelope and the antenna shall not protrude in such a manner as to be a safety hazard. The location shall not interfere with or damage mechanical car washer brushes, and shall be designed to withstand forces generated by these brushes.

The Contractor shall be responsible for the design, placement, implementation, and integration of the following:

- GPS antennas
- Wi-Fi antennas for uploads and downloads at terminals and the yard
- Radio voice antennas
- Provisions for antennas for passenger Wi-Fi (dedicated space determined and reserved, interference simulations take into account Wi-Fi antennas, but no roof holes required)

All of these antennas will be sharing limited roof space, and most will be operating both as transmitters and as receivers; therefore, it is necessary to carefully design the spatial distribution and orientation of these antennas in order to optimize performance and to mitigate interference. The ground plane of each antenna is part of the antenna system. Further, the structure of the vehicle will cause scattering, reflections, diffractions, etc.

The Contractor shall be responsible for the conduct of detailed and thorough electromagnetic modeling and simulation efforts using FEKO or some other similar and approved 3D full-wave electromagnetic CAD software tool.

Each of the following required performance parameters shall be evaluated by electromagnetic modeling and simulation. Simulation results shall be provided. These results shall include:

- Radiation patterns for each antenna at the low end, high end, and middle of the bandwidth (as well as at other frequencies of interest as requested by Sound Transit)
- VSWR versus frequency
- Realized gain versus frequency
- S-parameter coupling coefficients between antennas versus frequency
- Axial ratio versus frequency

The Contractor shall provide simulation results of other relevant performance parameters as deemed necessary by Sound Transit. These may include graphs of impedance versus frequency (real or imaginary), Smith charts, etc.

For each antenna, the performance of each parameter shall comply with the requirements specified below across the specified bandwidth of that particular antenna.

- The coupling between each antenna shall be evaluated in terms of S-parameters. The coupling ( $S_{ij}$ ) between each antenna shall be lower than -60 dB from 0 to 6 GHz. Each receiver shall include a harmonic BPF with at least 40 dB rejection in the reject band to minimize coupling between antennas.
- In each case, the antennas (after being mounted and connected on the vehicle) shall maintain a VSWR of 2:1 or better over the frequency band of the system.
- Each antenna shall be connected to a low loss coaxial cable with 50 ohms characteristic impedance, and a nominal attenuation not to exceed 3.5 dB/100 feet (3.5 dB/30 m).
- The GPS antennas shall be RHCP ( $AR < 1.5$ ) patch antennas with small form factors. The realized gain (taking into account VSWR and conductive and dielectric losses) of the train-mounted antenna in the zenith shall be at least 2.5 dBi across the bandwidth. The HPBW in the XZ and YZ planes shall each be at least 90 degrees over the entire bandwidth.

- Cellular antennas and Wi-Fi antennas used at terminals and in the yard shall be omnidirectional (within 3 dB) and vertically polarized ( $AR > 10$ ). Each shall have a realized gain not lower than 0 dBi across their respective bandwidths.
- The radio voice antenna shall be either directional or omnidirectional. Omnidirectional antennas shall have a realized gain of at least 0 dBi across their respective frequency bands. Directional antennas shall have a realized gain of at least 2.5 dBi across their respective frequency bands. Radio voice antennas shall be vertically polarized ( $AR > 10$ ).

Innovative filtering techniques to enhance isolation between antennas may be proposed. Other performance enhancing design techniques may also be proposed.

The Contractor may use MIMO, diversity techniques, beamforming, and other design techniques to optimize the performance of all RF systems.

All antennas shall be compliant with 47 CFR 15.247.

A waterproof method of mounting the antennas to the car body surface shall be provided.

The antenna cabling shall be installed in conduit, sized in accordance with Section manufacturer's recommendations.

### **13.6.2 Radio Power Converter and Protection**

A dc-to-dc power converter, one per transceiver, shall be provided to power the radio equipment. The dc-to-dc power converter shall be submitted as part of the train radio design report noted above. The power converter shall be a proven design, with at least five years successful operating history in revenue service on rail transit or railroad vehicles. The output voltage of the converter shall be adjustable from 12 Vdc to 14 Vdc with a 13.7 Vdc nominal setting. The unit shall be rated for a continuous output current of 20% greater than the maximum load current drawn by the transceiver. The converter shall be powered from the vehicles' low-voltage dc power supply, with a dedicated circuit breaker for each converter, and shall be in accordance with the requirements of Section 2.

Line and load regulation of the converter shall be 1% or less over the full range of the low voltage power supply, and from 0 to 100% rated load. Output noise and ripple shall be 75 mV rms or less at full rated output.

The converter shall include as a minimum the following protective features: Input voltage transient protection with energy levels up to 140 J and peak currents of 2000 A; input-to-output isolation of 1500 Vdc and the output shall be short-circuit-proof.

The converter shall include output over-voltage protection and current limiting, with backup protection provided by a circuit breaker. The converter input shall be protected by a circuit breaker as specified in Sections 9 and 17.

The power converter shall be installed proximate to the radio. All wiring between the two units shall be sized to allow no more than a 1.0 Vdc drop in the wiring at maximum rated load.

### **13.6.3 Radio Control Head and Handset**

The Contractor shall design the console to accommodate the radio control head, radio handset, handset hanger, and hookswitch, which will be furnished by the Contractor. The Contractor shall install this equipment and associated interconnecting wiring.

### **13.6.4 Radio Inter-Unit Wiring**

The Contractor shall furnish and install wiring between the antenna and radio transceiver, radio control head, radio handset, radio loudspeaker, and power converter, and between the radio and the communications system ACH (one in each cab).

## **13.7 Installation Considerations**

### **13.7.1 Location**

All communications and passenger information equipment not installed in the cab console or cab upper control panel shall be installed in an electric locker or in the cab ceiling space. The equipment and installation shall conform to the maintainability requirements of Section 2.

The communications and passenger information cabinet(s) shall be provided with sufficient ventilation to prevent equipment from exceeding its rated temperature. Ventilation openings shall be covered by appropriate grilles.

All modules (radio sets, logic units, PA amplifiers, power supplies, etc.) shall be single function plug-in units and removable for servicing without affecting other functions or devices. Replacement units shall not require calibration or adjustment. Devices shall be mounted on slides in racks with front accessible electrical connectors and securing hardware using self-locking fasteners or latches that can be operated by hand with no tools required.

Radio sets shall be locked into the mounting racks by a front accessible lock.

Housings, circuits, components, and interconnections shall be resistant to shock, vibration, and moisture as appropriate for their environment according to IEC 61373 and IEC 60529.

### **13.7.2 Wiring**

All cabling and interconnections shall be in accordance with the requirements of Section 17. There shall be no splices between terminals.

- All audio or data pairs shall be shielded twisted pairs. Shields shall be terminated to the local communications or data signal common or ground, as appropriate for the particular circuit. Shields and communications circuits shall be arranged to prevent ground loops and to prevent the shield from becoming a return conductor for vehicle power circuits.
- All inter-unit communications and passenger information wires shall be run in conduit(s) containing only communications or passenger information circuits.

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- The radio coaxial cable and connectors shall be as specified and provided by the radio equipment supplier. The antenna coaxial cable run shall be kept as short as possible.
- At interconnection points where disconnection is not normally required for maintenance, barrier type terminal strips may be used unless specified otherwise. Refer to Section 17. Components shall not be mounted on terminal strips. All other interconnection points shall use multi-pin connectors as described in Section 17, unless otherwise reviewed and approved by Sound Transit.

### **13.7.3 Inter-Car and Inter-Body Connections**

Communications and passenger information circuit connections between cars shall be made through the electrical coupler.

Communications and passenger information circuit connections between body sections of a car shall be through separately shielded cables with individually shielded audio pairs or data pairs. Connectors shall be of a heavy-duty waterproof type with gold plated contacts. Shield ground connections shall pass through connector contacts rather than the connector shell. Refer to Section 17 for additional connector requirements.

### **13.7.4 Loudspeaker Phasing**

Speakers shall be connected in phase.

### **13.8 Activation of Equipment**

The ACH, AACP, and all communications and passenger information equipment in all cabs shall be active whenever the auxiliaries are energized, except that system controls which relate to the active cab shall not be active in non-active cabs.

PA power amplifiers shall be normally keyed-off until an announcement is to be made. Keying-on of the amplifiers shall not result in transient noises, such as pops, clicks, and bumps.

### **13.9 Environmental Conditions**

All communications and passenger information equipment shall perform reliably, within the specified requirements, under the environmental conditions specified in Section 2. Equipment located on the car exterior shall perform reliably under the environmental conditions specified in Section 2.

Equipment shall be subject to a storage temperature range of -40°F to 140°F (-40°C to 60°C). Equipment operated within the storage temperature range shall not be damaged but may operate in a degraded mode outside the limits specified above.

### **13.10 Closed Circuit Television (CCTV)**

The design of the CCTV system shall provide a video and audio surveillance system and other specified functions in this Section. The CCTV network and equipment shall be designed and

configured such that a single network failure between components shall not cause the entire system to fail. The CCTV systems shall be comprised at, a minimum, of the following:

- IP color cameras
- A network video recorder (NVR)
- IP network switch
- Interfaces to the vehicle's local and trainline networks
- Monitors
- Interfaces to specified monitors
- All necessary accessories, devices, wires, and cables shall be furnished for proper interconnection of the CCTV equipment to provide a completely integrated and operational CCTV system.

A report on the design of the closed circuit television equipment design shall be provided (CDRL 13-5).

### **13.10.1 Camera Types**

Each car shall be equipped with cameras as follows:

- At least four interior surveillance cameras, located and configured to provide full coverage of the passenger areas, including views of doorways
- Two rear-facing cameras in each cab, located above the cab side windows, to provide the function of rear view mirrors
- A forward-facing camera in each cab behind the windshield, located within the sweep of the windshield wiper for a clean view of the area in front of the vehicle.

Mounting locations and field of view for all cameras shall be included in the design report (CDRL 13-5).

#### **13.10.1.1 End-of-Train Camera**

The front view camera in the trailing cab of a train shall act as a reverse view (or back-up) camera system for the train whenever the train is keyed up. The trailing camera video shall be accessible on the Ethernet communication trainline to drive a separately dedicated monitor in the leading cab of the train. The TOD shall not be used for this purpose. The monitor shall be configured the same as those provided for rear view mirror functions. See Section 5.

#### **13.10.1.2 Camera**

Cameras used in the CCTV system shall be of the same type, except as necessary to meet required performance. All cameras shall include adjustable mounts for aiming, and enclosures

for environmental and vandalism protection. Lens focal lengths and f-stops of each camera shall be optimized for the application.

Cameras shall be modern IP digital cameras capable of recording video:

- Video resolution capability shall be at least 1280 x 1024 and lower resolutions available
- Cameras shall be Power over Ethernet (PoE) cameras
- Imaging: Automatic WDR
- Illumination rating: 0.2 lux, or better.; shall be coordinated with imaging
- 16 bit color depth, minimum
- H.265 video compression
- Frame rate no less than 30 frames per second (fps), with lower frame rates available

The camera shall automatically compensate for low light conditions, no light (dark car) conditions, glare, and rapid ambient lighting changes within the vehicle. Camera sensitivity shall be sufficient for any possible combination of ambient and vehicle interior or exterior lighting levels, including vehicle emergency lighting. Camera frame rate, resolution, and bandwidth shall be remotely controllable via the CCTV PTU.

Camera failures, shall be detected by the NVR and reported to the MDS.

### **13.10.2 Camera Enclosures**

Interior camera enclosures shall:

- Be vandal-resistant
- Coordinated with interior finishing
- Include a tempered glass view port

Exterior camera enclosures shall:

- Be waterproof
- Include heating elements for defrosting and de-fogging, with control such that clear view for exterior cameras is available within 10 minutes of activation of any cab, and is maintained while any cab is active
- Prevent snagging of car wash brushes or debris
- Include a tempered glass view port
- Be removable without affecting camera adjustments

### **13.10.3 Network Video Recorder (NVR)**

An NVR shall be provided in each car with sufficient capability to perform, at a minimum, the following functions:

- Manage, monitor and record video from all cameras.
- Provide network interfaces between all cameras and vehicle networks.
- Provide diagnostics and fault detection for all cameras, the NVR, and other connected equipment. Communicate same to the MDS.
- Provide an interface to CCTV workstations and PTU.
- Include provisions for monitoring and recording additional compatible cameras, for monitoring and recording of video data and sound, as desired by Sound Transit.

The recording method shall include an approved authentication process to detect any alteration of the data after recording.

The NVR shall automatically include the vehicle car number, camera number, and a date/time stamp on all images. Date and time shall be maintained by an internal clock, synchronized by the vehicle's network clock at agreed intervals. Lack of a vehicle network clock shall not disrupt or alter the internal clock.

The storage medium shall be commercially available Solid State Drive (SSD). Reliability and service life of the storage medium shall be included in the design report (CDRL 13-5).

The storage device shall be removable and shall be secured via a keyed lock, or other approved mechanically secure methods.

### **13.10.4 Video and Audio Recording**

Video and audio from all cameras in the vehicle shall be continuously recorded in the local NVR whenever there is an active cab in the consist. The NVR shall continue recording for a period of time up to one hour after a deactivation of a cab, and this time shall be PTU adjustable.

The NVR shall be able to store a minimum of 14 days of surveillance video and audio from all cameras. Capacity shall be computed using a minimum 20 hours per day, maximum camera resolution, 24 frames per second, using the indicated camera compression. The NVR shall not utilize compression techniques that permanently lower the quality of the images

Recorded video and audio data shall be overwritten in a first in, first out manner to allow continuous recording.

Audio recording shall be capable of being turned OFF and ON for each camera location via the PTU.

Recorded data shall be retrievable from the NVR via the PTU and the CCTV Workstation.

### **13.10.5 CCTV IP Switches**

CCTV IP Switches shall be provided to connect all cameras, NVR and other devices as applicable. These switches shall be the pathway by which the cameras connect to the Ethernet backbones to transmit video images to the NVR, cab displays, and other devices as applicable.

The IP Switch shall be a ruggedized IP Switch, with sufficient Ethernet ports to support the camera arrangement specified in this Section, connection to the NVR plus at least four (4) PoE spares. The IP Switch shall support Power over Ethernet technology.

### **13.10.6 Cab Displays**

Monitors for display of CCTV cameras shall be industrial grade, ruggedized, color LCD monitors with resolutions and aspect ratios matching the connected cameras, or as approved. Except for sizes, monitor type and manufacturer shall be the same as for the TOD, or as approved.

Display screens shall be a minimum of 10 in (250 mm), diagonally, with pushbutton controls for contrast and brightness.

Rearview monitors shall be installed with the long dimension vertical, and with video image oriented the same. The end-of-train monitor location and orientation shall be determined during cab design reviews.

Displays shall be shrouded as necessary to prevent wash-out during bright light conditions.

### **13.10.7 CCTV Workstation**

The Contractor shall provide software and hardware necessary to store and manage video and audio data for both Sound Transit maintenance facilities.

Adapters shall be provided to mount, and power, a NVR and retrieved storage device such that video files may be viewed directly from the devices on the workstation. The data connection shall be either USB or Ethernet. Connection speed shall be sufficient to view stored video at full frame rates without downloading files to the PC.

The CCTV Workstation shall be capable of providing verification of authenticity of recorded data and downloading of system diagnostics and fault logs.

## **13.11 Automatic Passenger Counting System**

### **13.11.1 General**

The Contractor shall install and test automatic passenger counting hardware for the system on every vehicle. It shall count the passengers that enter and exit the vehicle at each station and the passenger count, location, time, and car number shall be recorded in an on board database for downloading via PTU and remote processing of the data at a later time. The system shall automatically transfer the data to the wayside via the same wireless LAN transceiver that is used

to transmit MDS information to the wayside when the vehicle is in the maintenance shop and yard.

The system shall count passengers with an accuracy of 96% or better for each round trip on the East Link and Central Link light rail systems. The system shall be capable of discriminating between persons and large objects, such as, for example, bicycles and baby strollers. Sufficient memory shall be provided to hold 8 days of data, assuming 20 round trips a day.

The Contractor shall provide the necessary operating software for the vehicle. Software needed for PTUs to maintain the system and download data and software necessary to analyze the data in the Sound Transit offices shall be provided. The Contractor shall provide Sound Transit with any necessary licenses to use the software for the design life of the vehicles.

The system shall consist of the equipment described below. The equipment shall conform to the material and design requirements of this Specification.

The Contractor shall prepare a design report on the APC system. (CDRL 13-6) The report shall include:

- Functional specification for the system
- Mechanical specifications of the system hardware
- Electrical specifications of the system
- Software design description
- Mechanical assembly drawings with weights, dimensions, and parts lists
- Electrical wiring schematic drawings for system interconnections
- Electrical schematic drawings for each device and assembly
- Installation drawings

### **13.11.2 APC Doorway Equipment**

Each doorway of the vehicle shall be equipped with multiple sensors and associated logic unit to sense passengers entering and exiting the vehicle. The combination of sensors and logic shall properly detect and indicate the correct passenger count regardless of whether single or multiple persons are simultaneously entering or exiting at a doorway, or any simultaneous or overlapping combination of entrances and exiting persons.

Large objects such as bicycles and baby strollers shall not be counted as persons.

The APC doorway equipment shall function accurately regardless of the size of the passenger, from small child to large adult.

The APC doorway equipment shall not interfere with operation of the doors.

The APC doorway equipment shall receive an indication from the door system when the doors are open.

Direct connections shall be used to communicate between APC sensors and the APC doorway logic unit. Communication between the door units and the central logic unit shall be by a network that conforms to the requirements of Section 9.

### **13.11.3 APC Logic Unit**

An APC Logic Unit shall be provided to collect, process, and store the data from the APC doorway equipment described in this Section. It shall determine the position of the vehicle by a combination of the following:

- Starting location information from the automatic announcement system as specified in this Section
- It shall receive distance traveled information from the GPS system as specified in Section 14
- No-motion as indicated by the vehicle no-motion logic specified in Section 2
- Door open status signals from the door control system

Logic shall process the door and location data and store it in non-volatile memory with sufficient capacity to comply with the requirements of this Section.

The APC Logic Unit shall contain logic to detect system faults and receive fault data from the APC doorway equipment. A fault log shall be maintained in the APC Logic Unit. In addition to functioning with the PTU to permit manipulation and display of this data, the system shall communicate with the MDS to transmit the fault log and permit manipulation and display of the passenger count data via the MDS specified in Section 9. It shall comply with the requirements of Section 9.

### **13.11.4 Remote Access**

The equipment shall be provided with the appropriate interfaces and software to use the vehicle MDS wireless communications equipment to automatically transfer APC data to the wayside. Refer to Section 9.

### **13.11.5 Integration with MDS**

The Contractor shall combine and integrate the APC, Communications, and MDS hardware, wiring, and functions to the maximum extent possible.

## **13.12 Standards**

All audio equipment shall conform to applicable standards of the AREMA (AAR) Communications Manual, Section 12.

## *Vehicle Communication Systems*

All audio equipment also shall conform to the following applicable standards of the Electronics Industries Association:

- SE-101 Amplifiers For Sound Equipment
- SE-103 Speakers and Sound Equipment
- SE-105 Microphones For Sound Equipment

### **13.13 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 13-1 Communication systems design report (Section 13.1.2)
- 13-2 Passenger intercom design report (Section 13.4.1)
- 13-3 Automatic passenger information system design report (Section 13.5.1)
  - 1. Sample audio messages (Section 13.5.4)
  - 2. Equipment for recording and modification of visual and audible messages (Section 13.5.5)
  - 3. Information signs (Section 13.5.9.1)
- 13-4 Radio design report (Section 13.6)
- 13-5 Closed circuit television equipment design report (Section 13.10)
- 13-6 APC design report (Section 13.11.1)

### **13.14 Cited References**

The following standards or references were cited in this Section at the referenced location:

AREMA	Communications Manual, Section 12-10 (Section 13.9)
EIA SE-101	Amplifiers For Sound Equipment (Section 13.12)
EIA SE-103	Speakers and Sound Equipment (Section 13.12)
EIA SE-105	Microphones For Sound Equipment (Section 13.12)
IEC 60268-16	Sound System Equipment – Part 16: Objective rating of speech intelligibility by speech transmission index (Section 13. 3.1)
IEC 61373	Railway Applications – Rolling Stock equipment – Shock and Vibration Tests (section 13.7.1)

*Vehicle Communication Systems*

IEC 60529	Degrees Of Protection Provided By Enclosures (IP Code) (Section 13.7.1)
36 CFR 1191	Americans with Disabilities Act (ADA), Accessibility Guidelines for Buildings and Facilities; Architectural Barriers ActT (ABA) Accessibility Guidelines (Section 13.4.1)
36 CFR 1192	Americans with Disabilities Act (ADA), Accessibility Guidelines for Transportation Vehicles (Sections 13.5.9.3)
47 CFR 15.247	Telecommunication – Radio Frequency Devices (section 13.6.1)
49 CFR 38	American with Disabilities Act (ADA), FTA Regulations (Section 13.5.9.3)

**END OF SECTION 13**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 14  
AUTOMATIC TRAIN PROTECTION, TRAIN-TO-WAYSIDE COMMUNICATIONS  
SYSTEM, EVENT RECORDER AND GPS RECEIVER/ANTENNA**

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## **SECTION 14: ATP, TWC, EVENT RECORDER AND GPS**

### **14.1 General**

This Section establishes the requirements for the carborne components of an Automatic Train Protection (ATP) cab signal system, Train-to-Wayside Communications (TWC) system, event recorder and GPS system.

The Contractor shall provide all carborne ATP equipment, TWC equipment event recorder and GPS equipment as described in the following sections. This includes all engineering and design, software documentation, hardware and equipment, installation, testing, interface management, safety analysis, reliability program, and warranty described elsewhere in the Specifications.

The ATP, TWC, event recorder and GPS systems shall be service proven as defined in Section 2.

### **14.2 Automatic Train Protection**

The Contractor shall provide the carborne portion of the Automatic Train Protection system. The Automatic Train Protection System shall be compatible with the existing Sound Transit ATP System, MicroCab, provided by Ansaldo. The wayside portion of the system will be furnished by Sound Transit. The equipment and operational interface shall be at the speed command signal decoded from the rails. The Contractor shall be responsible for coordination of the carborne system with wayside signal system contractor, including, but not limited to, EMI compatibility with the track circuit design, including those frequencies used for train detection and the car brake assurance feature. The Contractor shall prepare a cab signal interface report matrix. (CDRL 14-1)

The Contractor shall prepare an automatic train protection design and equipment selection report. (CDRL 14-2)

#### **14.2.1 System Description**

The train control system will use an audio frequency, dual-rail track circuit cab signal system with a speed command frequency of 2340 Hz, modulated as described in this Section to provide eight speed command signals, plus a zero speed, no-code command signal, to the vehicle. Single-rail 60 Hz track circuits may be used within interlockings, with speed command loops. The wayside logic will provide train detection, and define track block lengths and route conditions to select the correct speed commands.

The Contractor shall provide all functions necessary for system operation, including, but not limited to, speed command detection and decoding, dedicated speed sensing and overspeed protection, dedicated no-motion detection, brake assurance, speedometer and speed command display functions, operational mode controls and indications, ATP equipment self-diagnostics, and interfaces to the event recorder.

The ATP system will not require Automatic Train Operation functions, i.e., mainline service speed regulation, or automatic station stopping.

### **14.2.2 Carborne ATP Function**

The Contractor shall provide a carborne ATP subsystem and interfacing vehicle equipment for the following modes of operation:

- ATP Mode: Mainline operation with speed commands for all areas not designated as Street Running or Yard
- Street Running Mode: Street and yard operation governed by street traffic signal phases and rules, wherein track circuits do not provide detection for ATP speed commands. The Street Running Mode shall also operate as a stop and proceed mode in the event of track circuit failure that results in no speed commands in a signaled area.
- By-pass Mode: ATP by-pass operation available on any type of signaled track

#### **14.2.2.1 ATP Mode**

The Train Operator will regulate the speed within the allowable limits of the speed command. The ATP logic shall detect and annunciate an overspeed condition visually and audibly. Overspeed shall be detected within 0.5 s of a decoded speed command loss, or upon decoding a new speed command which is lower than the train velocity.

The ATP system shall reject the previously decoded command within 2 s if the train enters a zero speed command area (no code), or an area with a lower speed command.

Upon ATP detection of an overspeed condition, the ATP logic shall vitally request the train to apply a Safety Brake (SB). Refer to Section 2.

The overspeed condition shall be acknowledged by the Train Operator moving the Master Controller to the SB position, which shall silence the audible portion of the overspeed alarm. Refer to Section 5. Once the ATP overspeed condition is acknowledged, the operator may select any brake rate or even coast, but not propulsion, until the overspeed condition is no longer present.

Failure to acknowledge the overspeed condition within 2 s shall result in the ATP logic automatically applying irretrievable SB until zero speed.

The ATP logic shall have a brake assurance module that shall have the capability to detect a deceleration of 1.4 mph/s (0.63 m/s<sup>2</sup>). The brake assurance detection shall only be operational in a car with an active cab. The brake assurance feature shall use an inertial brake rate measurement, rather than a rate of change of velocity processed from a speed sensor(s).

When an overspeed condition is detected the brake assurance logic shall detect the required brake rate within 3 s or the ATP logic shall automatically request maximum brake without spin slide protection. Refer to Section 2.

#### **14.2.2.2 Street Running Mode**

Street Running mode shall be initiated by a 25 mph or 35 mph “Street Running”-specific speed command that shall be decoded by the ATP system as the train enters a non-exclusive street running area. Reference the “Speed Command Table” later in this Section. The ATP logic shall latch in Street Running mode until either the operator keys off the active cab controls or another valid, non-street running ATP speed command is decoded.

It shall also be possible to enter the Street Running mode manually via a momentary pushbutton/indicator on the panel. The pushbutton/indicator shall only be enabled when the train is stopped and there is no decoded speed command. The manual Street Running mode request shall be logged by the event recorder and MDS.

The audible and visual alarms, acknowledgement, penalty stop, and brake assurance provisions for Street Running mode shall be identical with the 35 mph ATP mode operation. If the vehicle speed exceeds the maximum allowable street running speed, as indicated by the speed command issued upon entering the street running segment, or by Train Operator action (reference this Section), the overspeed scenario in Street Running mode shall be the same as in the ATP mode.

When the Street Running command is decoded, the ATP mode indicator shall extinguish and the Street Running mode indicator shall illuminate. When exiting Street Running mode, the Street Running mode indicator shall be extinguished and the ATP mode indicator shall be illuminated.

Whenever the ATP logic enters into or exits from Street Running mode, it shall sound a momentary audible alarm. This audible alarm shall have different tone from an overspeed audible alarm.

After the ATP logic has been put into Street Running mode, it shall be possible to force it from the 35 mph speed limit into an alternate 25 mph speed limit. Except for the speed limit and speed limit display of 25 mph, Street Running shall perform identically for all features such as overspeed scenario, exit to ATP mode, and (ATP Indicator and Control Unit mode display. ATP package self-test shall verify and display both the 35 mph and 25 mph speed limits.

Selection of the 25 mph limit shall be by the following method:

- After the ATP logic has been put into Street Running mode by either a decoded cab signal or by manual selection, then after a 1 s delay a second operation of the Street Running momentary pushbutton shall force the speed limit to 25 mph.
- If the train is stopped and there is no ATP code, then an additional Street Running pushbutton activation shall toggle the ATP logic to Street Running mode with 35 mph speed limit.

##### **14.2.2.2.1 Existing Fleet Retrofit**

The Contractor shall retrofit the existing 62 ST1 vehicles and spares to also include the 25 mph Street Running mode speed limit. The existing ATP package is an Ansaldo MicroCab system complete with Aspect Display Unit (ADU) and ATP logic, which includes the Street Running

mode as described above, except that it has only the 35 mph speed limit. Contractor shall modify the ATP package, including ADU, as necessary to add the entrance into the 25 mph speed limit, the display of the 25 mph limit, the 25 mph overspeed detection and braking scenario, and the exit from 25 mph speed limit. The Contractor shall submit a design report explaining the plan for implementing this retrofit within 240 days from NTP.

Contractor shall perform qualification test on a first article retrofit ATP & ADU package to demonstrate the 25 mph Street Running speed limit performance, including an overspeed scenario, and sufficient tests to verify existing ATP package functions are not degraded. After the qualification test is accepted, the test on subsequent units can be reduced to configuration control on the software and passing an ATP self-test, which test shall include testing of these functions.

### **14.2.2.3 ATP Bypass Mode**

The ATP Bypass mode shall bypass any ATP system logic that would interfere with train operation, including overspeed protection, automatic brake applications, and alarms. The ATP Bypass mode shall permit the display of speedometer functions and decoded speed commands, if available, and it shall allow the train to proceed regardless of the nature of the ATP logic failure. Entry into Bypass mode shall allow the limitation of train speed as provided by the propulsion system overspeed protection (refer to Section 10).

The operator shall be able to select the ATP Bypass mode at no-motion speed through use of the ATP Bypass switch on the Upper Control Panel of the active cab. The ATP Bypass mode shall be accompanied with an intermittent audible alarm.

### **14.2.3 Carborne Equipment**

The Contractor shall provide a safe ATP subsystem with vital components and logic meeting the Specifications and the AAR/AREMA requirements for safe design and operation. The following ATP functions shall meet these requirements: speed command decoding, ATP logic, speed sensing, overspeed detection and SB application, maximum brake request, brake assurance, and motion sensing.

The Contractor shall provide a complete and working carborne ATP system and applicable vehicle interfaces consisting of, but not limited to, the items outlined in the following sections.

ATP equipment and its interfaces to the vehicle shall meet the requirements for equipment and design as contained elsewhere in the Specifications.

#### **14.2.3.1 Receiver Coils and Speed Command Decoding**

There shall be four receiver coils mounted on the vehicle. A coil shall be mounted to the truck above each rail in front of the truck leading axle. Receiver coil connections to the car body shall use lockable, weather-tight, connectors. The receiver coils, connecting cables, and all connections shall withstand all specified environmental conditions.

The receiver coil mounting arrangement shall be designed to withstand the shock and vibration loading inherent in a truck mounting. The mounting bracket shall include a serrated, lockable height adjustment for the full range of wheel wear. The mounting bracket and arrangement for adjustment shall be approved by Sound Transit.

Receiver coils shall be capable of detecting modulated 2340 Hz +/-11 Hz carrier wave speed command signals. If more than one speed command is present and detected, the lower speed command shall govern ATP logic output. Mounting and design of the receiver coils and the associated amplifier and decoders shall permit decoding speed commands from the rail even when traversing curves of 100 ft (30 m) radius or special trackwork with No. 5 turnouts, with a signal strength in each rail or speed command loops of 160 mA. Nominal signal strength of cab signal in rail will be 200 mA at the entering end of track circuits and may achieve up to 6 A at the leaving end of track circuits. The detection circuitry must be capable of operating over the entire current range. The carborne circuit design shall allow additional bandwidth as necessary to allow for cable and rail inductance, and for aging of coils, filters, and amplifier components. Design and mounting of the receiver coils and cable routing shall be such as to minimize EMI from carborne and wayside sources.

The carborne equipment shall decode the received speed commands. The wayside track circuit modules will generate the following cab signal amplitude modulated code rates with a duty cycle for each modulation rate nominally 50% ±1%. The detection of “No Code” in a track circuit shall cause SB to be maintained until other action occurs as specified.

<b>Speed Command Table</b>				
<b>Speed Command</b>	<b>Modulation ON</b>	<b>Modulation OFF</b>	<b>Period</b>	<b>Overspeed Detection Range</b>
25 mph Street Running mode	88 ± 1 ms	88 ± 1 ms	176 ± 1 ms	28 ±1 mph
35 mph Street Running mode	80 ±1 ms	80 ± 1 ms	160 ± 1 ms	38 ±1 mph
10 mph	72 ± 1 ms	72 ± 1 ms	144 ± 1 ms	13 ±1 mph
20 mph	64 ± 1 ms	64 ± 1 ms	128 ±1 ms	23 ±1 mph
30 mph	56 ± 1 ms	56 ± 1 ms	112 ± 1 ms	33 ±1 mph
35 mph	48 ± 1 ms	48 ± 1 ms	96 ± 1 ms	38 ±1 mph
40 mph	40 ± 1 ms	40 ± 1 ms	80 ± 1 ms	43 ±1 mph
45 mph	32 ± 1 ms	32 ± 1 ms	64 ± 1 ms	48 ±1 mph
55 mph	24 ± 1 ms	24± 1 ms	48 ± 1 ms	58 ±1 mph
0 mph	No code		--	--

### **14.2.3.2 Speed Sensing and Indication**

The dedicated ATP speed sensors, the ATP overspeed logic, the ATP no-motion logic, and the speedometer logic must be fully integrated. A speed sensor dedicated to ATP shall be provided on each motor truck, or alternatively on each axle of one motor truck. Refer to Section 10 for further speed sensor requirements.

The ATP enclosure shall contain means for field programmable wheel wear adjustment capable of matching the wheel measurements from full diameter to the condemned wheel size.

Speedometer and speed command display shall be integrated into the ATP Indicator and Control Unit in order to easily identify the speed, speed relative position to the speed command, and overspeed. Information shall be ergonomically arranged and displayed using analog indicators, and/or color, flashing light, or other methods best suited for safe and easy vehicle operation. The speedometer and speed command display shall be fully integrated mechanically as described below and installed in front of the operator. The ATP Indicator and Control Unit design shall be submitted to Sound Transit. (CDRL 14-3)

The speedometer shall be calibrated in mph and shall be accurate to a tolerance of +/-1.0 mph above 3 mph when the reference wheel diameters are properly set in accordance with this Section. The speedometer display scale shall sweep a 270 degree angle, reading from 0 to 65 mph, with 55 mph clearly marked. Speed command indicators shall be arranged around the circumference of the speedometer, with their locations related to the speedometer location of their indicated speed commands. The speed indicators shall be back lit with the relevant speed command printed on the front face, and shall use red LED's operating from the low-voltage dc system. The LED's shall be rated for not less than 100,000 hours, shall be configured with standard lamp bases, and shall be front replaceable. There shall also be two seven-segment displays situated inside the speed ring that also indicate the actual speed.

ATP dedicated vital no motion sensing shall detect train stopped at as low a velocity as practical but shall be no greater than 2 mph (3.2 km/h). This no motion sensor and logic shall be only for ATP purposes and not door control or other vehicle functions. As an alternative, the Contractor may interface the vital propulsion no motion detection for use in the ATP circuitry. Refer to Section 2 for requirements for safety design.

### **14.2.3.3 ATP Indicators/Controls**

The ATP indicators and controls shall only be energized at the active cab, except for the seven-segment digital speed indicators, which shall work in all cabs. The specified control/indicators shall be heavy-duty back-illuminated pushbuttons or switches suitable for mode selection functions, and shall be integrated into the ATP Indicator and Control Unit. The indicators shall be similar to the speed command indicators described in this Section, but shall have colors as described below.

The ATP mode pushbutton/indicator shall be white, and back illuminate the word ATP. The ATP mode indication shall be the default indication whenever not in Yard, Street Running, or ATP Bypass modes. The operator shall be able to initiate the ATP self-test by momentarily pressing the ATP mode push-button. The indicator shall flash when the ATP logic is performing self-test

and shall return to the ATP mode when the test is complete. Refer to the ATP Self-Test section, below, for further requirements for self-test.

The Street Running mode pushbutton/indicator shall be white, and back illuminate the word STREET. The indicator shall only illuminate when the ATP system has decoded and latched a Street Running code, or when the pushbutton is pressed and ATP acknowledges Street Running mode operation regardless of whether the 35 mph or 25 mph speed limit was selected by the operator. The pushbutton/indicator shall only be enabled when the train is stopped and there is no decoded speed command. The STREET indicator shall immediately extinguish whenever a valid, non-Street Running ATP speed command is decoded, and the vehicle shall revert to ATP mode.

The Bypass mode indicator shall be red, and back illuminate the words ATP BYPASS. The indicator shall only illuminate when the ATP system has been bypassed. This indicator shall not be controlled or powered from the ATP logic. The bypass mode shall inhibit the ATP mode, Street Running mode, overspeed function, and visual and audible indications. The ATP Bypass mode shall not inhibit the speedometer or decoded speed command indications as long as they are available from ATP.

#### **14.2.3.4 Audible Indication**

Three dedicated audible indicators shall provide the following ATP alarms (same as ST1 vehicles):

- The ATP overspeed audible alarm shall be a unique frequency and a continuous pulsed signal until acknowledged by the operator selecting SB on the Master Controller
- The Street Running mode alarm shall sound momentarily when train is entering or exiting Street Running mode. The sound can originate from the ATP overspeed alarm audible source if the alarms are clearly distinguishable; i.e., if the alarms have different frequencies and/or tones.
- The ATP Bypass mode shall have an intermittent audible signal with a unique tone for the duration of the bypass operation. This audible signal shall not be powered or controlled from the ATP logic.

#### **14.2.3.5 ATP Logic Module**

ATP logic shall be microprocessor based with vital software design and supplemented with solid state analog or relay circuitry as necessary to ensure reliable and safe performance. The logic enclosure shall have connectors for vehicle interfaces. The logic shall operate over full car-battery range, and be protected against power surges, conductive EMI, and reverse polarity battery connections, as required elsewhere in the Specifications.

The ATP logic equipment may either be one package per car with selection logic for receiver coils, controls and indications, or the Contractor may select to use one logic package per cab (two per car).

#### **14.2.3.6 ATP Self-Test**

The ATP logic shall have self-test capability, initiated by the master controller key switch being moved to the “ON” position. This self-test shall check ATP function necessary for safe vehicle operation. At a minimum, this shall include the functions outlined below. To the extent possible, the actual function being tested shall be activated. Alarms and indications associated with the functions shall be a consequence of the function being implemented properly or not, as appropriate for the condition of the equipment.

At a minimum, the self-test shall:

- Verify circuit continuity and function of the receiver coils and amplifier.
- Generate each speed command sequentially and decode it. The ATP logic shall verify each code is correctly received.
- Allow the operator to visually verify each speed command indication on the speedometer assembly during the test. This includes Street Running mode with both the 35 mph speed limit and the 25 mph speed limit.
- Generate a simulated speed sensor signal less than 55 mph for 3 s, then increase the simulated velocity to above the overspeed detection limit once a 55 mph command has been generated, decoded, and verified. Verify the overspeed alarms, ATP automatic safety brake request, and maximum brake request functions
- Allow the operator to visually verify each of the mode indicators except Bypass
- Verify the no motion logic circuit integrity and functionality
- Verify decelerometer signal is as would be expected under any given set of test conditions

Successful completion of the test shall result in a return to ATP mode. Failure of the logic to verify one of the functions shall leave the ATP indicator flashing with the self-test not proceeding. A push by the operator on the flashing ATP indicator/pushbutton shall terminate the test even if not complete. The test outcome, pass or fail, shall be reported to the event recorder and to the MDS. A complete self-test sequence shall require no more than 2 min.

#### **14.2.3.7 ATP Event Recording Interface**

The ATP logic shall provide interfaces to the vehicle event recorder for recording the following:

- Overspeed detection
- Overspeed acknowledgement
- ATP logic penalty stop request
- ATP logic maximum brake request
- Manual Street Running mode request

- Self-test successful completion
- Self-test failure
- ATP Bypass event

#### **14.2.4 ATP System Support**

The Contractor shall provide system support for the carborne ATP equipment. Support shall include test equipment, special tools if applicable (such as tools to mechanically adjust and calibrate the inertial accelerometer), operating and maintenance manuals, and training. See Section 18 for further details.

In addition to any other test equipment necessary to maintain and troubleshoot the ATP equipment, test equipment shall include two Portable Test Units (PTUs) capable of generating speed commands and inputting them into the ATP equipment. These shall be capable of simulating the speed command inputs during static test of the vehicles. The test set shall operate from vehicle battery, and the test connector input location shall be in an area of the vehicle from which the technician can observe both the ATP logic module status indicators and the cab ATP Indicator and Control Unit responses.

Manuals for ATP equipment shall be integrated with the operator, maintainer, parts catalog, test equipment, and training manuals for the complete vehicle, as required by Section 18.

#### **14.3 TWC System**

Signal and Communications equipment suppliers will be installing Train-to-Wayside Communications (TWC) loop antennae and interrogators at various locations along the LRT line. The wayside portion of the TWC system will be Vetag® compatible equipment, as originally developed by Philips, NV. Two firms (VECOM, Hanning and Kahl) make equipment compatible with the Vetag product line. The TWC system will be compatible with the existing Sound Transit TWC system. The Contractor shall provide the carborne TWC equipment and shall be responsible for coordination of the carborne system with the wayside TWC equipment and controls. The carborne portion of the TWC system shall be completely compatible with the message structure, the wayside loops and interrogators of the existing equipment.

The Contractor shall prepare a TWC System design report within 120 days after NTP. (CDRL 14-4)

##### **14.3.1 TWC System Description**

The system shall transmit a 19-bit digital data message from the vehicle to the wayside antennae at certain points along the route. The fixed wayside antennae shall transmit a signal, which shall activate any carborne transponder within range of that antenna and receive a digital message from the transponder. This signal shall be repeated at a rate as necessary to meet the functional requirements of the equipment. The digital message will be received and decoded by a wayside interrogator with the logic outputs interfacing to traffic control and train control logic. The

wayside signal contractor shall be responsible for providing loops, interrogators, and logic interfaces.

When a car passes over the antenna, the wayside interrogation signal shall activate the carborne TWC transponder. When the transponder receives the interrogation signal, it shall transmit a message to the wayside in the form of high-speed digital data. The data transmission scheme shall provide for receipt by the wayside equipment of four separate and complete, 19 bit messages from each carborne transponder with the train traveling at 59 mph (95 km/h). The TWC system shall permit location of the wayside interrogator up to 1,200 ft (365 m) from an associated wayside loop antenna.

Only selected transponders in a train shall be activated to respond to the TWC interrogation. The transponder under the trailing direction cab in each vehicle shall always be active. The energized lead cab transponder shall also be active but shall contain different information from the messages of the trailing cab transponders. The TWC system data message from the leading cab shall consist of, as a minimum, active cab indication, train number (0-99), route destination code (0-999), cancel, switch call left, switch call right, and pre-empt call. TWC system data message from trailing cab transponders shall consist of, as a minimum, inactive cab indication, end of train identification (as appropriate), and vehicle number (0-999). Refer to document 'TWC Codes and Data Requirements', RTA/AE 0027-12, included in reference documents, for the code and bit patterns.

### **14.3.2 TWC Transponder**

Two transponders per car shall be provided, one at each end, as well as all required mounting brackets and interconnecting cables and connectors.

The transponders shall be arranged for mounting under the car, shall be weather-sealed, and shall be capable of providing the reliability required elsewhere in this document, in the intended undercar environment. The undercar transponder location, height above top of rail, and height adjustment capability shall be compatible with existing wayside TWC equipment. The mounting transponder brackets shall be suitable for the operating environment and shall include any vibration damping features necessary to provide long-term integrity of the equipment. The mounting location shall not cause the transponder to be adversely affected by external EMI.

A multiple-conductor cable suitable for exposed use in an undercar environment shall be provided to connect the transponder to the car wiring via a car body mounted waterproof bulkhead connector. The connector shall be a quarter-turn or third-turn waterproof bayonet-type device. (Refer to Section 17 for connector requirements.) At the transponder end, the cable shall enter the transponder through a water-tight strain-relief bushing.

The transponder shall:

- Receive an interrogation signal from the wayside interrogator so as to cause the transponder to transmit the data message
- Activate the lights in the console panel switches when an interrogation signal is received to indicate that the transponder is in communication with a wayside interrogator

- Transmit the data message provided by the TWC cab control panel to the wayside interrogator

### **14.3.3 TWC Cab Control Panel**

The TWC cab control panel shall be mounted just to the right of the cab display panel and in front of the Audio Control Head.

The cab control panel shall include a unit of four pushbutton switches with the following functions:

- Preempt Call (which also serves as “train ready” at yard and dispatch locations)
- Switch Call - Left
- Switch Call - Right
- Cancel Call

The pushbutton switches shall be backlit when the carborne transponder for the active cab is over a wayside antenna and is being interrogated.

The panel shall also include a unit of four 10-position thumbwheel switches. Two of these switches shall be used to set the route destination code, and two shall be used to set the train number. Entry of route number and train number may be by other, functionally equivalent devices, which must be submitted to and approved by Sound Transit. The panel shall include a jumper arrangement such that the car number shall be pre-established when the cab panel and the jumper are installed in the vehicle.

The cab control panel shall accept the following inputs from the car systems:

- Low-voltage dc power positive
- Negative power return
- Cab active signal - positive low-voltage dc
- Trailing direction cab - positive low-voltage dc
- End-of-train signal - positive low-voltage dc

Inputs from the car to the cab control panel, and inputs and outputs to and from the panel to the carborne transponder, shall be connected by two quarter-turn or third-turn bayonet-type connectors, one for car inputs and one for transponder inputs and outputs. Mating connectors shall be provided for all cab control panel connectors. Connectors shall conform to the requirements of Section 17.

The cab control panel shall be designed and manufactured by the manufacturer of the carborne transponder. The control panel configuration and mounting arrangement shall be provided. (CDRL 14-5)

### **14.3.4 TWC Support Equipment**

A portable test interrogator shall be provided, consisting of a data display, interrogator card, and battery power supply housed in a portable service case, and a portable loop antenna. It shall be capable of verifying that a vehicle transponder is operating correctly and transmitting the desired encoded signals to the wayside. It shall provide the interrogation signal, plus reception, decoding, and display of the transponder response.

## **14.4 Event Recorder**

### **14.4.1 General**

Independent of the monitoring and diagnostic system described in Section 9, each car shall be provided with a fully electronic data recorder system that shall store times, speeds, distances traveled, and both analog and digital events as described below. The event recorder shall be a self-contained unit with data storage and retrieval capabilities as described in this Section. Unless explicitly stated otherwise, the event recorder shall comply with the requirements of IEEE 1482.1.

All signals provided to the event recorder shall be from their point of origin, not conditioned or processed by other systems. All signals provided to the event recorder shall be as independent from the on-board systems that use them to the greatest possible extent. If any signals are analog in nature, then digitized for transmission on the data communications bus, the original analog signal shall be provided to the event recorder.

The primary purpose of this recorder is to provide documentation in support of accident investigations. It must be a tamper-proof, fire-proof and self-contained design capable of withstanding high shock. Detailed environmental and mechanical requirements are described in Section 2.

The event recorder shall be based on a family of service proven designs, with at least five years successful operating history in revenue service on rail vehicles. Refer to Sections 2, 9, 15, and 17 for additional design requirements. The Contractor shall prepare a design report on the event recorder equipment, equipment interfaces, and installation within 180 days after NTP. (CDRL 14-6)

### **14.4.2 Functional Requirements**

The event recorder shall be capable of recording no less than:

- 128 digital signals
- 32 analog signals
- 4 frequency signals

In addition to the signals applicable in accordance with IEEE 1482.1, the event recorder shall record:

- Master clock, the source of which shall be the network clock via the train bus.
- Application of sand
- Vehicle number
- ATP overspeed detection
- ATP overspeed acknowledgement
- ATP logic penalty stop request
- ATP logic Maximum Brake request
- ATP self-test successful completion
- ATP self-test failure
- ATP Bypass event
- ATP manual street running mode request

The Contractor shall prepare a list of signals for Sound Transit review. If the specified signal-type allocation is inconsistent with the Contractor's design, Contractor shall propose a different allocation for Sound Transit's consideration. When the signal allocation is ultimately approved by Sound Transit, the assigned signals shall use only 90% of available recording channels, leaving the remaining as spares for potential future use.

Signal sampling and recording rates shall comply with IEEE 1482.1.

The recorder shall be able to store a minimum of 14 days of data, including signals from the spare channels, in non-volatile memory. This memory shall not require battery backup for data retention and shall remain intact for a period at least one year after removal from the car.

Event recorder data shall be retrievable via USB Flash drive or Ethernet connection to a PTU. In addition, it shall be possible to retrieve event data by removal of the event data memory module and reading the memory contents directly by means of a memory reader device.

Downloaded data shall be capable of being evaluated on an office computer. The viewing software shall automatically convert the time to Pacific Standard Time and also account for the shift to and from Pacific Daylight Savings Time. It shall not be possible to erase the data via the serial port on the recorder. The Contractor shall supply all necessary cabling and software to transfer, evaluate, display, and print the data in either tabular or graphic form.

#### **14.4.3 Location and Hardware Considerations**

The event recorder shall be located in the car interior in an electric locker, which shall require a crew key (refer to Section 15) for access. The installation shall be such that the event recorder is

tamper-resistant and waterproof; however, installation shall be such that the USB or Ethernet connections are readily accessible once the recorder is installed.

A terminal board shall be provided, with locations for all event recorder signals, including spares. Connections to the event recorder inputs shall be made at this terminal board.

#### **14.4.4 Construction Requirements**

The event recorder shall be constructed in accordance with the requirements of IEEE 1482.1. These requirements may be met by the design of the data storage devices themselves, by placing the device in an enclosure meeting the requirements, by judicious placement of the device within the car body envelope, or by a combination of these methods.

### **14.5 GPS Receiver and Vehicle Location Information**

#### **14.5.1 General**

Vehicle location information shall be provided by GPS, and in the event of loss of the GPS signal, by dead reckoning.

The GPS system, or dead reckoning when necessary, shall perform the following functions:

- Provide time reference information to the MDS system, vehicle network system and event recorder system as described in Sections 9 and 13.
- Provide location information to the communications system to trigger station announcements as described in Section 13
- Provide location and time information to the CCTV system
- Provide location information to the Passenger Counting system as described in Section 13
- Provide location information to the Radio system.

Architectures combining or cascading the GPS information to the various systems may be proposed, however the time reference provided to the event recorder system shall not be dependent on the MDS.

#### **14.5.2 GPS**

The Contractor shall provide a GPS receiver on each vehicle. The GPS shall be powered from the low-voltage power supply and shall be operational whenever the pantograph is up and the LVPS is operational. The GPS shall be augmented with Wide Area Augmentation System (WAAS) to improve the overall accuracy of the system. Irrespective of the availability of WAAS, the navigational information provided by the GPS instrumentation shall be used in a mathematical algorithm with the navigational information provided by the wheel tachometer to precisely update the location of the train relative to the Sound Transit track database.

### **14.5.3 Dead Reckoning**

In the event of the loss of GPS signal for any reason, the vehicle shall automatically revert to dead reckoning to calculate train location, by calculating distance travelled from the last station. The distance counter for dead reckoning shall reset to zero at each station after the train has stopped at the station, cycled the door, and the master controller is moved to a power position.

The distance signal used for dead reckoning may be from the propulsion system or the event recorder. It shall not be taken from the brake system.

### **14.5.4 Vehicle Location Accuracy**

The identified track location shall be within 25 ft (7.6 m) of the track centerline 95% of the time, based on time-stamped GPS coordinates, or dead reckoning based on distance and track geographical information in areas where GPS coordinates are not available.

The Contractor shall prepare a design report on the GPS system, including its approach to dead reckoning. (CDRL 14-7)

## **14.6 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 14-1 Cab signal interface parameters (Section 14.2)
- 14-2 Cab signal design and equipment selection report (Section 14.2)
- 14-3 ATP Indicator and Control Unit design (Section 14.2.3.2)
- 14-4 TWC System design report (Section 14.3)
- 14-5 Control Panel configuration and mounting arrangement (Section 14.3.3)
- 14-6 Event recorder equipment. Equipment interfaces and installation design report. (Section 14.4.1)
- 14-7 GPS design report (Section 14.5.4)

## **14.7 Cited References**

The following standards or references were cited in this Section at the referenced location.

- |             |  |
|-------------|--|
| IEEE 1482.1 | IEEE Standard for Rail Transit Vehicle Event Recorders (Sections 14.4.1, 14.4.2, 14.4.4) |
| AAR/AREMA   | Signal Manual of Recommended Practice (Section 14.2.3)                                   |

**END OF SECTION 14**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 15  
INTERIOR AND EXTERIOR APPOINTMENTS**

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## **SECTION 15: INTERIOR AND EXTERIOR APPOINTMENTS**

### **15.1 General**

This Section describes interior and exterior finishing, including insulation, floor covering, seats, windows, liners, mirrors, and other such equipment.

Within 60 days after NTP the interior and exterior color scheme, finishing and general appearance of the vehicle shall be subject to review and approval by Sound Transit. (CDRL 15-1) The initial submittals may be in the form of accurately colored renderings and models. Samples of all finishing materials and the material specifications shall be submitted with the initial submittal. Final approval shall not be granted until the first completed vehicle is inspected.

All materials shall meet applicable flammability, smoke emission, and other requirements specified in Section 17.

### **15.2 Interior Finishing and Accessories**

The vehicle interior shall be finished with high durability, low maintenance materials. All surfaces shall be free from tooling marks, gaps, distortions, and other visible defects. All surfaces shall be rigid and supported to prevent sagging, drumming, and vibration. Refer to Section 2 for vibration requirements.

Color and finish of all materials used in the vehicle interior shall not fade, change appearance, or run when exposed to LED light, sun-light, or chemicals typically used to clean LRVs.

Color shall extend all the way through all materials, except FRP and melamine where specified.

Painted interior surfaces where approved by Sound Transit shall use low gloss paint. The paint and paint process shall comply with Section 17 and shall be subject to Sound Transit review and approval (CDRL 15-2).

Powder coating shall only be used where paint is impractical and with the prior approval by Sound Transit. If powder coating is used, it shall comply with the requirements of TS 17.16.3.4.

Interior linings shall be mechanically fastened to their supporting surfaces. The mounting shall be designed to accommodate the dynamics of vehicle movement without transmitting stress to the liners. Interior linings shall be designed to have a minimum 1.0 in (25 mm) radius cove at intersecting adjacent surfaces.

To the extent possible, interior finishes shall be free from exposed fasteners. In cases where the contractor is unable to meet this requirement due to design constraints

"Anti-squeak" tape shall be used between all linings or panels and any structure to which they are attached or with which they come in contact. Linings which cover apparatus or areas requiring even infrequent maintenance access shall be fastened with approved quarter-turn crew key cam lock in a manner allowing ready removal or replacement.

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All exposed stainless steel shall be given an approved brushed finish. Grain direction shall be arranged to suit the decorative scheme.

All interior surfaces shall have a low-glare finish with a glossometer reading between 4 and 14, per ASTM D523, machine direction, using a 60 degree glossometer.

Walls and ceilings shall be graffiti resistant to ASTM D6578/D6578M, using cleaning agents agreed by Sound Transit, and per Sections 9 and 10, with a pass rating of 5, minimum.

The vehicle interior shall be free from sharp corners or edges due to design or as a result of poor workmanship. Gaps between apparatus that are not absolutely rigid shall be wide enough to prevent injury when the apparatus moves, or rigid spacers shall be provided to prevent the gap from closing.

Flat surfaces exposed to passengers shall not deviate from flatness by more than 0.125 in (3.2 mm) within any 36 in (915 mm) distance. The slope of any such deviation shall not exceed 1:128.

The articulation section flooring, walls, and other moving components shall move without audible noise under all conditions. All gaps between articulation section wall and ceiling panels shall be designed and sized to prevent injury. Under all conditions, gaps shall not increase or decrease in width so as to be hazardous to persons.

Interior articulation liners including ceiling, walls and floors shall be designed to aid in the inspection of all articulation appointments concealed by the interior enclosure, including access for lubrication points where required.

### **15.2.1 Insulation**

#### **15.2.1.1 Acoustical Insulation**

A vibration and sound damping material shall be applied to inner surfaces of all areas of the structural shell, including sub-floor pans, ends, roof, and side frames, and one side of air duct splitters (if used). It shall be resistant to dilute acids, alkalis, greases, gasolines, aliphatic oils, and vermin. The material shall conform to the flammability, smoke emission, and toxicity requirements of Section 17, and shall be applied to properly cleaned and primed surfaces as recommended by the supplier and as specified in Section 17.

The thickness of the installed damping material shall provide a vibration decay rate of not less than 35 dB/s, at a temperature of 70°F (21°C), as measured by the Geiger thick-plate, SAE J671, or other equivalent approved test method.

Application methods and thicknesses shall be according to the supplier's recommendations, and as follows:

- The inner surfaces of the car structural shell, except for the end underframe weldments, shall be coated with sound deadening compound. The inside surfaces of structural members shall be sprayed to the extent possible;

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- The mating surface between the structural members and the plymetal or composite floor of the vehicle shall not be coated;
- The outside surfaces of the main air duct and all ventilation cross ducts shall be coated with sound deadening compound;
- Duct splitters (if used) shall be coated on one side only;
- The ceiling below the main air duct shall not be coated; and
- A primer shall be applied prior to application of the damping material in accordance with Section 17 and the recommendations of the manufacturer of the damping material.

Acoustic insulation shall be applied to the articulation close off panels and bellows as necessary to meet the interior noise requirements of Section 2.

The Contractor shall submit an acoustic insulation design report to Sound Transit for review and approval. It shall include materials specifications; flammability, smoke emission, and toxicity test reports required by Section 17; application instructions; and drawings showing the application locations. (CDRL 15-3)

### **15.2.1.2 Thermal Insulation**

An approved insulation material shall be used throughout the roof, floor, side walls, and ends of the car bodies for thermal insulation. The vehicle shall be insulated to conform to the thermal transmission requirements of Section 7.

If fiberglass insulation is used, it shall be manufactured from long, textile-type glass fibers drawn from a calcium borosilicate mixture to an average diameter of 9 microns. It shall be bonded together with a thermosetting phenolic resin which shall not exceed 6% by weight. The fiberglass shall not mold, rot, or sustain vermin. It shall not corrode any metals or settle under car vibration. It shall not have an odor or be capable of absorbing odors. It shall be capable of performing to a high temperature limit of 450°F (230°C).

Thermal breaks shall be provided between the main conditioned air supply duct and roof structural members, between interior finish panels and any metal primary or secondary structural members which are thermally grounded to the outside surface of the car body skin, and any other location where it is necessary to interrupt an all-metal path between the interior of the car body and the outside car body skin.

The roof, sides, ends of the cars, including cabs, including the inside faces of posts and structural members, shall be insulated with insulation which shall fill the entire volume of the available cavity. The density of the insulation shall be selected by the Contractor to meet the car body transmission heat gain requirements of Section 7. The roof insulation shall be retained by stainless steel wires or strips. Side and end wall insulation shall be retained by spears or other approved method provided steps are taken to ensure that sharp pointed ends will not be a hazard to personnel or maintenance equipment.

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The floor shall be insulated with two layers of equal thickness of fiberglass separated by a vapor barrier. The insulation shall be placed in the structural floor between the transverse floor beams and shall fill the entire volume of the available cavity. Floor insulation shall be compatible with the material used at the affected locations in the car structure. The density of the insulation shall be selected by the Contractor to meet the car body transmission heat gain requirements of Section 7.

The Contractor shall submit a thermal insulation design report to Sound Transit for review and approval. It shall include materials specifications, application instructions, and drawings showing the application locations. (CDRL 15-4)

### **15.2.1.3 Urethane Foam Prohibited**

The use of urethane foam insulation is prohibited anywhere in the construction of the car. See Section 17 for other prohibited materials.

### **15.2.2 Floor Covering**

The floor covering, and its accessories, shall provide a durable and watertight covering for the floor panels and other car structures. The floor covering shall comply with the floor material requirements of Section 17.

The floor covering shall be smooth rubber sheets in the seat area. Floor covering in the wheelchair accommodation areas shall be smooth rubber sheets with an integral non-slip grit surface. Longitudinally ribbed rubber sheets shall be used in the aisle, including in articulation sections. Similar ribbed rubber sheet shall be used in the entrance, with ribs running transversely across the car. The interior steps shall be covered with ribbed rubber stair tread material with the ribs running parallel to the step tread depth. Steps and door thresholds shall be provided with integrally colored safety nosing as specified below in the Installation section. Any metal trim or edging with applied color shall be powder coated. The application of paint and primers for these areas will not be permitted.

The floor covering shall have a static coefficient of friction of not less than 0.6 when measured in accordance with ASTM D2047, using leather and rubber shoe materials. Leather shoe material shall be in accordance with Federal Specification KK-L-165C. Rubber shoe material shall be in accordance with ASTM Method D 1630.

The Contractor shall submit a floor covering design report to Sound Transit for review and approval. It shall include materials specifications, application instructions, and drawings showing the application locations. (CDRL 15-5)

#### **15.2.2.1 Sealing and Leveling**

Prior to applying the floor covering, all voids, indentations, fastener heads, and separations between floor panels shall be filled with an approved flame-retardant leveling compound. The floor shall be made smooth and flat within 0.063 in (1.6 mm) measured within any 36-in (915 mm) distance in any direction.

### **15.2.2.2 Floor Covering Installation**

The floor shall be covered with a transit grade rubber floor covering of approved material and color scheme. Floor covering widths shall be selected such that no more than three longitudinal strips shall be required to cover the floor from wall to wall in the end car body sections. A single strip shall be used to cover the floor in the center car body section.

The back of the floor covering sheet shall be sanded before laying, then securely bonded to the floor panels with an adhesive recommended by the floor covering manufacturer.

Floor covering under the seats shall be 0.125 in (3.2 mm) minimum thickness smooth rubber sheet. Underseat floor covering shall be laid in continuous strips with transverse joints permitted only at the doorways.

Wheelchair area floor covering shall be 0.125 in (3.2 mm) thickness rubber sheet.

Ribbed rubber sheet shall be 0.187 in (4.7 mm) minimum thickness. The center aisle floor covering shall run between entranceways without transverse joints. The center aisle floor covering width and installation shall be such that it can be replaced without removal of the seats.

The floor covering in each entranceway area shall run from threshold to threshold. The floor covering at all doorways shall mate with, and be sealed at, the threshold and shall be water tight.

Each step and door threshold shall be provided with a yellow safety nosing running the full width of the step or door threshold and which contrasts visually from the stair tread and riser covering by 70%, as determined by the following formula:

$$\text{Contrast (\%)} = [(B1-B2)/B1]*100$$

where:

B1 = Light reflectance value of brighter area

B2 = Light reflectance value of darker area

The safety nosing shall be resistant to chipping, peeling, fading and other forms of premature failure.

Floor covering at exposed removable floor access panels and at the edge of the articulation section shall be peripherally trimmed with a stainless steel molding. Additional reinforcement is required by the hardware interface to the stainless steel molding to ensure minimal wear. The use of quarter turn or similar fasteners is required.

### **15.2.2.3 Cove Moldings**

A cove molding shall be applied between the floor covering and all side walls, end walls, equipment boxes, floor heaters, and all other vertical surfaces at which, or behind which, the floor covering terminates, including those in the operator's cab. The cove molding shall be an approved brushed finish stainless steel or anodized aluminum.

## *Interior and Exterior Appointments*

The cove molding shall form a watertight seal with the floor covering and the vertical surface. Cove radius shall be the minimum size consistent with maintenance access to dirt in the corners.

Cove corners, splices, or terminations shall be made by means of formed pieces that rigidly connect to the cove pieces.

In place of cove molding where floor covering meets walls, the floor covering may be curved upward onto the walls. The floor covering shall be adequately supported in the curve and curve radius shall be not less than that recommended by the floor covering manufacturer. The floor covering shall be terminated with an edge sealant or other method approved by Sound Transit.

### **15.2.3 Walls and Ceiling**

The Contractor shall submit a walls and ceiling design report to Sound Transit for review and approval. It shall include materials specifications, application instructions, and drawings showing the application locations. (CDRL 15-6)

#### **15.2.3.1 Side and End Walls**

Side and end wall lining shall be covered with 0.125 in (3.2 mm) thick minimum, balanced melamine, FR Grade, or other material, service proven on similar transit applications and approved by Sound Transit. Only one joint shall be allowed per wainscot section between side entrance doors and in each passenger compartment level. The joint in the wainscot panel shall be hidden from view by the seats where appropriate.

Window masks shall be provided at all car body windows, including windshields. The masks shall be sloped to eliminate dirt collecting areas. All joints shall be supported and covered with moldings.

The colors of moldings on all exposed surfaces shall blend in with the colors of the adjacent panels, except where approved by Sound Transit.

#### **15.2.3.2 Ceiling**

The portion of the ceiling between air diffuser-light fixture assemblies shall be constructed of 3/8 in (10 mm) thick minimum, melamine-faced panels with an aluminum honeycomb core. Alternative materials and material thickness may be used with Sound Transit approval during design review. Transverse joints shall be spaced no closer than 4 ft (1220 mm). Longitudinal joints will not be permitted. Ceiling panels shall be individually removable. The Contractor shall install trim caps between the ceiling panels.

The sharply curved portion of the ceiling outboard of the light fixtures shall be constructed of melamine-faced 0.08 in (2.0 mm) minimum thickness aluminum, molded fiberglass reinforced composite, or approved equal. Alternatively, these panels may be formed by extensions of the window masks, or may be flat diagonal sections, using the above materials.

Alternative techniques may be proposed for use in place of those described in the prior paragraph to permit the cornice areas to be used as equipment lockers. The areas shall be covered with flat

panels that will provide the transition from the ceiling to side walls. The design shall be coordinated with the need to have card holders above the windows as required by this Section. The panels shall be hinged at the top and secured at the bottom by key operated latches operated with the Sound Transit crew key, and shall have “hold open” devices. Construction shall be rugged and secure, using the materials described in this Section or may be constructed from formed sheet metal that is coated with an approved thermosetting powder coating, as specified in Section 17.

The ceiling under the overhead air conditioning units shall be composed of a minimum number of pieces similar to the ceiling panels between the air diffuser-light fixtures, consistent with the need for access to equipment. Longitudinal joints in this area will be permissible only at light fixtures. Exposed, but inconspicuous, approved quick-acting quarter-turn fasteners shall be used for access. Access panels and/or grilles under the overhead air conditioning units for access to, and removal of, the apparatus shall be hinged and equipped with safety catches as described for return air grilles in Section 7.

### **15.2.3.3 Moldings**

All ceiling and wall joints shall be covered with a snap-on, H-Type, plastic insert, or other type of molding having no exposed fasteners, unless otherwise approved. Moldings shall be hard-surfaced plastic, plastic-coated aluminum or steel, or aluminum or steel coated with an approved thermosetting powder coating, in a color and gloss matching the adjacent lining, or may be anodized aluminum. Moldings shall be mechanically attached to the car structure.

All non-metallic moldings and inserts shall meet the flammability, smoke emission, and toxicity requirements of Section 17.

All molding pieces close to the floor shall be made from materials that will not corrode during cleaning activities and cleaning agents used by maintenance.

### **15.2.3.4 Equipment Supports**

Ceiling panels and wall linings shall not be used to support any equipment. All equipment shall be supported directly by the car structure or by hangers welded to the car structure.

Ceiling panels may be supported by the air distributor-light fixture assemblies and by hinges welded to the roof structure. These hinges shall be no greater than 40 in (1015 mm) apart.

## **15.2.4 Windows**

### **15.2.4.1 General**

All windows shall be of the single-glazed, fixed type laminated safety glass supported directly by the car structure with neoprene glazing strips, except where frames are used, in which case the frame shall be supported directly by the car structure with neoprene glazing strips.

The glazing strips shall be laced from the outside of the vehicle. The ends of the glazing strip shall be joined together by the hot vulcanization process to form an endless glazing strip.

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All sash frames, where used, and glazing strips shall be so arranged that they are easily removable from the outside of the vehicle for repair or replacement. In all cases they shall have internally rounded corners, both inside and outside the vehicle, to facilitate cleaning. The glazing sections shall be designed to make a watertight seal without the need for sealing compounds between the glazing strip, the glass, and the car body structure.

All windshields, their glazing strips, and supporting car body structure shall meet the impact test requirements of 49 CFR 223 Type I. Cab side windows shall meet the requirements of 49 CFR 223 Type II. Side facing glazing shall meet the requirements of ANSI Z26.1.

The Contractor shall submit a windows design report to Sound Transit for review and approval. It shall include materials specifications for the glass, frames, glazing strips, and Vandal Shield (refer to this Section); application instructions; and drawings showing the application locations. (CDRL 15-7)

### **15.2.4.2 Side and Door Windows**

The side and door windows in the passenger section shall be 1/4 in (6.4 mm) laminated safety glass, tinted neutral gray, and shall meet the requirements for glazing materials in Section 17. They shall have 44%  $\pm$ 4% light transmission. The minimum area of each side window shall be 12 ft<sup>2</sup> (1.1 m<sup>2</sup>). The top horizontal edge of the side window shall be located not less than 72 in (1830 mm) above the finished floor.

Passenger side windows and mountings shall be designed to resist a static force (load) of 300 lbf (1330 N) with the load distributed over an area of 16 in<sup>2</sup> (10,300 mm<sup>2</sup>). The window must remain fully attached to the vehicle during and after the load is applied.

All passenger compartment windows shall be supplied with an optically clear, distortion-free layer of polyester film on the interior facing surface. The polyester film shall be multi-layer Vandal Shield or approved equal. The Vandal Shield shall be installed such that it can be removed and replaced without removing the glass from the window frame or glazing rubber. Air bubbles or foreign material inclusions shall not be permitted in the finished product.

One or two windows shall be placed in each side wall of the center car body section. Individual side windows shall be interchangeable with windows of the same size. Not more than three different window sizes shall be used for the side windows.

### **15.2.4.3 Windshields**

A one-piece, heated, flat or curved, tinted windshield shall be provided and shall be subject to Sound Transit review and approval during design review. Curved windshield glass shall be curved along a single axis.

The windshield shall be electrically heated for defrosting and defogging. Refer to the requirements for heated glass in Section 7.

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The windshield shall be gasketed in place. The windshield installation shall be watertight. The windshield shall be laminated safety glass and shall meet the glazing materials requirements of Section 17.

The windshield shall be designed and installed to minimize external glare as well as reflections from inside the vehicle when the vehicle is operated at night with the passenger interior lighting in use. The windshield shall be provided with a graduated tinting that becomes progressively less transparent toward the top of the windshield. The destination sign legend area shall not be tinted. The tinting scheme shall be submitted to Sound Transit during design review.

The windshield shall permit a maximum field of view for a seated Operator in the range of the fifth female percentile to the ninety-fifth male percentile of the general population, as defined in Humanscale 1/2/3 (M.I.T. Press) or Human Factors Design Handbook (Woodson, Tillman, and Tillman). The vertically upward view shall be a minimum of 15 degrees measured above the horizontal. The vertically downward view shall permit detection of an object 42 in (1060 mm) high (measured from top of rail) placed 24 in (610 mm) in front of the vehicle anticlimber. A standing operator shall be able to see and confirm the position the vehicle coupler on his or her train in order to confirm safe alignment for coupling. The horizontal view shall be a minimum of 90 degrees about the forward line of sight. Unrestricted view requirements apply for all possible Operator seat adjustments. The upper portion of the windshield may cover the end destination sign.

The windshield shall be easily replaceable from outside the vehicle. The contractor shall provide the special tools required for windshield replacement..

### **15.2.4.4 Cab Side Window**

The cab side windows must open. A latch, operable from inside the cab only, shall be provided to hold the window closed. The window shall be effectively weather stripped, reinforced for hard usage, and designed to eliminate rattling. In the fully open position, the opening will be large enough to provide access to pole mounted switches. The configuration will be subject to approval by Sound Transit. The cab side window shall be designed in a manner to not trap water within the window frame.

The window frame shall be satin finished anodized aluminum. The cab side window glazing shall be laminated safety glass of a thickness to meet the impact requirements of this Section and the glazing material requirements of Section 17. The windows shall be provided with a tinting to match the side windows.

The cab side window shall be electrically heated for defrosting and defogging.

### **15.2.5 Passenger Seats**

#### **15.2.5.1 General**

Each vehicle shall be provided with passenger seats to meet the seating arrangement requirements of Section 2. Mobility impaired accommodations as described in this Section shall be provided. The seating arrangement shall be predominantly transverse, knee to back, and 4

abreast (2 plus 2) separated by an aisle of 25 in (635 mm) minimum width, except where required to be wider to accommodate free circulation of wheelchairs. Seats and cushion inserts shall be interchangeable with like seats and cushions in all vehicles.

Passenger seats shall be contoured stainless steel with stainless steel frames and replaceable cushioned inserts. Internal non-visible framing members may be of mild steel. The seats shall be a design previously employed on rail transit vehicles, unless approved otherwise by Sound Transit.

The minimum total seat depth, measured from the seat's forward edge to the forward surface of the seat back, shall be 16 in (405 mm); minimum seat spacing shall be 29 in (735 mm); minimum seat back cushion to back of seat ahead shall be 25.2 in (640 mm). The individual seat width shall be 18 in to 19 in (460 mm to 480 mm). Overall multiple-passenger seat widths shall be multiples of 18 in to 19 in (460 to 480 mm) which may be achieved through the use of stainless steel spacers placed between individual seats.

The Contractor shall submit a passenger seat design report to Sound Transit for review and approval. It shall include materials specifications, application instructions, and drawings showing the seat locations. It shall include responses to all requests for Sound Transit approval that are listed in all of this Section's subsections. (CDRL 15-8)

#### **15.2.5.2 Construction**

The seat construction and its attachments to the car body shall withstand, without permanent deformation, the loads to be expected in transit operation, but in no case less than the following:

The seat design and installation shall withstand a longitudinal force applied for a minimum of 5 s (acting in either direction from front of seat to back, and back of seat to front, and equally distributed along the top edge of the seat back) of 300 lbf (1330 N) per sitting position (total 600 lbf (2670 N)) for two-passenger seat) with deflections everywhere less than 0.75 in (20 mm) with no failure. A permanent maximum set of 0.125 in (3.2 mm) will be permitted under these conditions.

The seat design and installation shall withstand a longitudinal force applied for a minimum of 5 s (acting in either direction from front of seat to back, and back of seat to front and equally distributed along the grab handle) of 300 lbf (1330 N) per grab handle with deflections less than 0.75 in (20 mm) anywhere with no failure. A permanent maximum set of 0.125 in (3.2 mm) will be permitted under these conditions.

The seat design and installation shall withstand a downward vertical load of 400 lbf (1780 N) applied uniformly along the front edge of each sitting position. A permanent maximum set of 0.125 in (3.2 mm) will be permitted under these conditions.

The transverse seat attachment to the side structure, and seat boxes as appropriate for the design shall be constructed to resist the force of two 95th percentile adult males being thrown against the seat with a longitudinal acceleration of 5g (49 m/s<sup>2</sup>). The loads shall be applied both from the back and front of the seat. Seat distortion shall be allowed; however, the seat shall not tear loose from its fastenings.

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Seats shall be cantilevered from the wall. The wall structure shall be adequately reinforced to withstand the seating loads experienced in service without deflection. A stainless steel, energy absorbent grab handle shall extend across the top of the entire seat back and shall be firmly attached to the seat frame, except where the seat back is adjacent to a windscreen or wall. Each passenger seat frame and its support shall be constructed as an integrated unit. Seat attachment shall permit easy replacement of the seat. The seat mounting method shall be subject to Sound Transit review and approval.

Seats shall be mounted on seat boxes only if reviewed and approved by Sound Transit. Seats which provide access to equipment shall be designed to allow easy and frequent removal without wear or damage to any part, if seat removal is required for enclosure access. Removable seats shall be equipped with a lock operated by the crew key described in this Section.

Gaps between seats and walls or windows shall be controlled or held rigid to prevent injury when the seat moves.

The stainless steel seat and back pans, visible framing, and pedestals shall have a 180 grit, horizontal finish. The seat back pans shall be sculptured to provide knee room. No manufacturer's logos or markings shall be visible to passengers.

### **15.2.5.3 Cushion Inserts**

Cushion inserts shall be provided for all passenger seats. The cushions shall be removable, shall be provided for both bottom and back installation, shall not be less than 0.5 in (13 mm) thick, shall be low smoke flexible foam and shall be contoured for maximum comfort. Cushion upholstery material shall be a flat woven transportation quality 90% wool, 10% nylon blend back coated fabric. The fabric pattern and colors shall be Lantal Textiles Article Number 7298, Color 44 which is used on existing Sound Transit vehicles as developed jointly by Sound Transit and the fabric supplier Lantal Textiles, Inc., 1300 Langenthal Drive, Rural Hall, NC 27045. Cushion inserts shall be constructed of inherently fire retardant materials meeting the seat material requirements of Section 17. Details of the current seat fabric design criteria is as follows:

- Part Number – F072980044DS2 “L” Design
- Content – 100% CS Trevira Polyester
- Width – 54”
- Weight – 15.70 oz/sy (+/- 10%)
- Pattern Repeat – Vertical 6.94”
- Pattern Repeat – Horizontal 6.75”
- Ends Per Inch – 142.2
- Picks Per Inch – 64

Seat and back inserts shall be detachable by means of a simple release mechanism employing a special tool so that the inserts are easily removable by the maintenance staff, but not by the passenger. Sound Transit review and approval will be required for both construction and installation methods. All seat inserts of a given type shall be completely interchangeable.

#### **15.2.5.4 Sample Seat**

Prior to placing a quantity order for seats, the Contractor shall furnish to Sound Transit one complete two-passenger seat, one flip-up seat, and one complete one-passenger seat, including trim finish, constructed in accordance with the design provisions specified above for review and approval. (CDRL 15-9)

#### **15.2.6 Mobility Impaired Accommodations**

##### **15.2.6.1 General**

Accessibility to the cars for mobility impaired persons confined to wheelchairs shall be available through all four doors per side. Two wheelchair spaces shall be provided in each half of the car (four spaces per car). The spaces shall be designed to locate the wheelchair longitudinally (end facing) in the car. Each wheelchair accommodation space shall provide for a minimum clear floor space of 48 in by 30 in (760 mm by 1220 mm). Horizontal handrails, with a vertical section at one end, shall be provided on the wall, or under the flip-up seat, adjacent to the complete length of each wheelchair space. The horizontal section of the handrails shall be located 27 in (685 mm) above the car floor.

One wheelchair space shall be provided adjacent to the front doorway on the right side of each car half. The second wheelchair space shall be provided on the diagonally opposite side of the car half, adjacent to the articulation area doorway. In each doorway area wheelchair space a longitudinal seat that flips up to allow space for wheelchair parking shall be provided. The first transverse double seat facing both wheelchair parking areas shall also be configured as a flip-up seat.

Mobility impaired accommodations shall comply with the latest FTA interpretation of the Americans with Disabilities Act (36 CFR 1192 and 49 CFR 27, 37 and 38).

##### **15.2.6.2 Flip-up Seat Construction**

The back of the flip-up seats shall be designed to be similar in shape and contour to the standard seat back, complete with cushions. The flip-up seats shall be supported by the wall, and the interior liner exposed beneath the seat shall be left unobstructed for easy cleaning.

The seat bottom assembly shall be a design which folds up to provide space for the wheelchair. When not in use the seat bottom shall automatically go to the “raised” position. Regardless of the seat bottom position it shall be firmly in place under normal conditions. A horizontal stanchion shall be mounted to the seat bottom of the longitudinal seat for use by wheelchair riders.

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The seat design and installation shall withstand a downward vertical load of 400 lbf (1780 N) applied uniformly along the front edge of each sitting position. A permanent maximum set of 0.125 in (3.2 mm) will be permitted under these conditions.

The flip up seat shall be designed to eliminate pinch points, sharp edges and gaps throughout the range of motion and in all positions.

The design and location of the flip-up seating shall be subject to Sound Transit review and approval during design review.

### **15.2.7 Stanchions, Handrails and Windscreens**

#### **15.2.7.1 Stanchions and Handrails**

Vertical stanchions shall be located on the inboard edge of each windscreen. These stanchions shall not interfere with access by wheelchairs.

Vertical stanchions shall also be provided for alternate transverse seats and on each side of the longitudinal seats in the center car body section. The stanchions shall extend from the seat grab rail or floor to the car ceiling. The stanchions shall be inset from the seat edge to provide a 30 in (760 mm) aisle width.

Vertical stanchions shall be rigidly mounted to the floor, wall support structure, or seat grab rails. The upper stanchion mounting shall be to car structure, arranged so that stanchions do not transmit any car body structural forces. Stanchion mounting shall not produce rattling and noise.

Curved diagonal grab rails shall be provided on each side of the interior stepwells. They shall be rigidly attached to the floor at the bottom and top of the steps and function as a handhold for passengers. A clear stepway of 25 in (635 mm) minimum between grab rails shall be provided.

Vertical grab rails, approximately 24 in (610 mm) long, located with the bottom of the rail between 33 and 35 in (840 and 890 mm) from the floor, shall be provided inside the car on each side of each doorway and on the non-cab-door corner of the passenger side of each cab partition. These grab rails shall not intrude on the clear opening width of the doorway.

Longitudinal grab rails, mounted to the vertical stanchions, the ceiling, and the cab partition, as appropriate, shall be provided along each edge of the center aisle adjacent to longitudinal seats and facing cross seats except directly behind the cab door. These grab rails shall be positioned 74 in (1880 mm) above the finished floor to assist passengers standing in the aisles.

Eight nylon web hand straps shall be provided in each car half, attached to the longitudinal grab rails, for passengers who cannot reach the longitudinal grab rails.

The stanchions, grab rails, and fittings shall be made of stainless steel with an approved circumferential finish. The grab rails shall be designed without the need for any lateral supports. All surfaces shall be smooth and free of sharp edges which might injure passengers. Knuckle clearance shall be 1.50 in (38 mm) minimum. All fasteners shall be tamper-resistant, stainless steel.

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All stanchions and grab rails shall have a diameter of 1.25 in to 1.5 in (32 mm to 38 mm) and comply with the latest FTA interpretation of the Americans with Disabilities Act (36 CFR 1192 and 49 CFR 27, 37 and 38).

Stanchions, handrails, and grab rails shall be mounted directly to the car structure only, unless specified otherwise. They shall not be mounted directly to an interior liner.

Each vertical stanchion and grab rail and its mountings and supports shall withstand, without permanent deformation, a horizontal load of 300 lbf (1330 N) applied in any direction at the midpoint of the stanchion or grab rail. Each horizontal and diagonal grab rail shall withstand, without permanent deformation, a vertical or lateral load of 300 lbf (1330 N) at the midpoint of the span.

### **15.2.7.2 Windscreens**

A windscreen shall be provided adjacent to each side of all side doorways. Windscreens shall be located so that the clear door opening is not reduced by the vertical grab rails adjacent to the doorways.

The windscreens shall be solid 0.5 in (13 mm) minimum thickness double sided, melamine faced plymetal panels in the wainscot area and 0.250 in (6.4 mm) thick, minimum, clear, laminated or tempered, safety glass above the solid panels. The laminated glass panel shall be retained in an aluminum frame attached flush to the top of the lower windscreen panel and sidewall. Tempered glass panels without exposed sharp edges may be used without an aluminum frame. The upper edge of the frame or tempered glass panel shall be attached to the windscreen stanchion and shall be at least 72 in (1830 mm) from the floor. A minimum of 2.5 in (64 mm) shall be provided between the glass panel frame or tempered glass panel and the windscreen stanchion for hand clearance. The windscreens on the forward side of the forward doorways shall be solid panels from the low floor level up to the top of the high floor section wainscot area, then glass panels as described above. The Contractor may propose aluminum with a melamine finish windscreens as an approved equal for the plymetal panels in the waistcoat area.

Multi-layer Vandal Shield, or approved equal, shall be applied to both surfaces of the windscreen glass panel. The Vandal Shield shall be installed such that it can be removed and replaced without removing the glass from the frame. Air bubbles or foreign material inclusions shall not be permitted in the finished product.

The windscreens adjacent to the wheelchair spaces shall be of reduced width to provide wheelchair maneuvering room.

Windscreen design, materials, and installation shall be subject to Sound Transit approval during design review.

## **15.2.8 Equipment Enclosures**

### **15.2.8.1 General**

All exterior and interior equipment enclosures shall be constructed to NEMA Type 4 and NEMA Type 12 standards, per NEMA 250 Enclosure standards, respectively and as described below. Where conflicts exist, this document shall prevail.

All welding shall be done in accordance with the welding requirements in Section 17.

Equipment enclosure walls and covers of large boxes shall be stiffened with the stiffeners welded in place. Stiffening criteria shall conform to high quality commercial practice and shall be submitted for approval.

The interior of all equipment enclosures and covers shall be powder coated gloss white. Exteriors shall be finished according to the approved car color scheme. Refer to Section 17 for finish requirements. Seals and cover hardware shall not be painted.

Equipment enclosure cover openings shall have a NEMA-type formed lip which provides a bearing surface for the cover seal. The portion of the lip bearing on the seal shall be flat and no less than 0.125 in (3.2 mm) wide.

The cover shall have folded edges that overlap the box opening lip by at least 0.375 in (9.5 mm) with the cover fully secured. The folded edges shall be completely welded at the corners. The cover edge may also serve as the clamp bearing surface.

Seals shall be attached and retained in a channel near the periphery of the cover. Seals shall be closed cell neoprene foam at least 0.375 in (9.5 mm) thick and shall remain resilient and watertight for at least 10 years. The seal shall be compressed no more than 50% with the cover securely fastened, with cover making hard contact with the frame or a stop, to prevent over compression of the gasket. Cover gaskets located at the mitered corners shall be sealed to form a single continuous gasket. The sealing system shall pass the water test in Section 16.

RFI gasketing with continuously conductive contact strip shall be installed on all equipment boxes and covers for all equipment that could produce RF, including auxiliary power supplies and traction inverters.

Equipment enclosure design, materials and installation shall be subject to Sound Transit approval during design review.

### **15.2.8.2 Exterior Equipment Enclosures**

Exterior equipment enclosures shall be constructed of stainless steel or, where approved, fiberglass reinforced plastic (FRP), or aluminum with corrosion protection as approved by Sound Transit. Enclosures constructed of stainless steel or aluminum shall have continuous welds along all seams. The battery box shall comply with the requirements of this Section and with the battery installation requirements in Section 9.

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All roof equipment enclosures where maintenance personal may step or walk shall be designed to support the loads specified for roof load in Section 3.

Materials used in underfloor- or roof-mounted equipment box assemblies and the workmanship involved in the assembly and finish of underfloor or roof mounted equipment boxes shall conform to the applicable requirements of Section 17. If FRP or other potentially combustible materials are proposed and approved, they shall conform to requirements for FRP and flammability, smoke emission and toxicity in Section 17. Mechanical properties of the laminate shall conform to FRP strength requirements in Section 17.

Underfloor equipment with a direct line of sight to a wheel for any possible truck orientation shall be protected from water splash, flying rock ballast, or other objects thrown by the wheel. If separately-mounted, solid-metal shields are used to provide such protection, they shall not hinder the flow of heated air from the underfloor to a degree which might allow overheating of wiring or apparatus.

Underfloor- and roof-mounted equipment enclosures shall be watertight when subjected to hose cleaning, car wash, driving rain, and tested in accordance with the requirements in Section 16. The enclosures shall contain drain holes fitted with cotter keys or other approved, simple drain clearing mechanisms for discharge of condensation and leakage due to damaged or deteriorated seals.

Equipment shall be arranged for the maximum ventilation of parts and the minimum restriction of cooling air. The high temperature air exhausted from one piece of equipment shall not be directed to the air intake of another piece of equipment. Equipment enclosures that are provided with air from the forced air ventilation system shall be equipped with a manometer test fitting in an accessible location on the box to allow easy measurement of box pressurization.

All underfloor equipment shall be arranged to allow ready access from the side of the vehicle, from the maintenance pits, and when the vehicle is on lifts. Access to roof mounted equipment shall be from the top of the enclosure. Labels and warning indicators shall be applied as required by this Section.

Equipment installed in underfloor- or roof-mounted boxes shall not be attached directly to the box by bolts or other fasteners through the enclosure walls, top or bottom sheets. They shall be attached to standoffs or subplates which are in turn welded to the box. In addition, sufficient clearance (1/2 in (13 mm)) minimum shall be provided between the exposed sides and covers of the equipment enclosure and the internal equipment to protect the internal equipment from damage due to minor impacts.

Boxes required to be accessible from the side of the vehicle shall be as flush as possible with the side of the vehicle, consistent with the skirt arrangement and with the vehicle clearance diagram.

All underfloor and roof mounted enclosures shall be grounded to the car body, as specified for safety grounding in Section 9.

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All hardware, including hinges, used to secure access covers or access plates on equipment enclosures shall be made of stainless steel. All mounting hardware for access covers shall have captive nuts or bolts.

Equipment box access covers shall be constructed of steel or FRP. FRP covers shall meet FRP and flammability and smoke requirements in Section 17.

All access covers shall be provided with quick-release, spring-loaded latches which operate with a toggling-type action. The latches and latch catches shall be arranged so that they do not protrude beyond the bottom or edge of the box or cover in the latched position. The latches shall not violate the vehicle dynamic clearance outline if not engaged. The latches shall compensate for seal relaxation considering the worst case condition of hard contact between the cover and box. In this extreme case, the latch shall hold the cover firmly to the box without rattling. The latch and all its components shall be fabricated from stainless steel. Prior to delivery, cover latches shall compress the cover seals no more than 50% of the compressible height of the seal and shall be watertightness tested. The latches shall not have separable or non-retained parts.

A spring-loaded safety catch shall be provided at the center of each underfloor box cover. The safety catch shall be designed to retain the cover within the vehicle dynamic clearance envelope at all operating speeds without the cover latches engaged.

Underfloor equipment enclosures shall be provided with top-hinged or bottom-hinged access covers on the outboard side and, if required, top-hinged access covers on the inboard side. Outboard covers shall swing open a minimum of 90 degrees for quick examination of the interior without removing the covers. Inboard covers, if used, shall swing open to the maximum extent possible, but in no case less than 60 degrees. Roof-mounted equipment enclosures shall be provided with hinged, top access covers, hinged on the inboard or top side of the enclosure where appropriate. The covers shall open at least 90 degrees. Equipment covers shall be removable without having to disassemble other parts, brackets or components of the vehicle.

All hinged covers shall be readily removable without the use of tools. Openings provided upon removal of covers shall be of sufficient size to permit removal and replacement of any component in the box and easy access to equipment in the box for inspection and maintenance. A minimum of 15 in (380 mm) of clearance shall be provided perpendicular to the opening face plane.

All top-hinged outboard covers and all roof mounted enclosure covers shall have an internal "hold open" feature. The "hold open" feature shall in no way interfere with or impede the easy removal or replacement of the cover, nor shall the "hold open" mechanism present the possibility of shorting or grounding internal electrical parts when the cover is opened or closed. The "hold open" mechanism shall be designed such that it will stay with the cover when the cover is removed; however, it shall also be easily removable from the cover for replacement.

All covers more than 36 in (915 mm) wide shall have two or more handholds arranged about the center of gravity of the cover and, for underfloor enclosures, recessed flush into the cover surface. The handholds shall not accumulate debris or moisture. The covers shall be arranged so that only one person is required to easily open, remove, re-apply, close, and latch any cover,

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regardless of size. Adequate clearances for all handholds, latches, and other appurtenances shall be provided so that a person wearing gloves is not hindered.

Doors, covers, and access panels on underfloor- and roof-mounted boxes shall be interchangeable between boxes of the same size and type within a vehicle and between vehicles.

Underfloor- and roof-mounted equipment boxes shall be waterproof except where equipment must be ventilated. Equipment vents shall be arranged to minimize water entry and deflect direct water spray. Stainless steel screens welded to the inside of the enclosure shall cover all vents. Vents may be provided in the top of underfloor enclosures where necessary and shall be provided with internal baffles to prevent water from falling onto equipment. Vented areas shall not permit entry to the equipment by foreign objects.

Sensitive underfloor- and roof-mounted equipment for which the drainage holes or vents are not acceptable shall be placed in a completely sealed enclosure within the equipment enclosure. Other schemes may be submitted for Sound Transit review approval during design review.

The arrangement for conduit, cable, wire routing, connections to equipment enclosures, and equipment contained in enclosures shall be configured so that structural, electrical and environmental integrity is maintained, and so that the removal and replacement of the equipment enclosure are facilitated. Each arrangement employed shall be subject to Sound Transit review and approval during design review.

All control and power cable terminations shall be made internal to the enclosures or in waterproof, gasketed junction boxes. Cable entry shall be by means of watertight sealing glands. Glands and cable terminations shall provide for cable replacement without removal of lugs, terminals, or connectors from the wires.

Conduit shall be connected to underfloor and roof equipment enclosures using watertight connectors. The entrance of conduit or cables in the top and bottom of equipment boxes will not be permitted.

### **15.2.8.3 Interior Equipment Enclosures**

The use of interior equipment enclosures shall require review and approval by Sound Transit during the design review process. All electric or electronic equipment located inside the vehicle shall be mounted in approved, dust-proof, water tight, underseat equipment enclosures or in electric lockers in the cab, adjacent to the articulation or in the ceiling cove area. All equipment so mounted shall be readily accessible and shall be removable through the access cover. The access cover shall be secured with quarter-turn crew key. The access covers shall be designed to be rattle-free during the operation of the vehicles.

Interior enclosures may use access panels for covers if a full dead front is provided. All interior enclosures shall include a metal top, sides, and bottom.

Equipment enclosures located under seats shall be constructed of a stainless steel structural frame, and faced with sheets of rigidized stainless steel. Access to underseat enclosures shall be by removal of the seat (see this Section) or through access panels in windscreens. Seat boxes

shall have a removable access cover. A stainless steel cove molding shall be provided where the seat box meets the floor covering as described in this Section.

### **15.2.9 Run Number Sign**

A three-digit, LED type number sign shall be provided and installed to the left of the Operator's position in each cab. The digits shall have the capacity to display any number from 0 to 9. Size and location shall be such that the sign can be easily read through the windshield from street level. Provision shall be made to view the number while setting the sign. The sign shall be illuminated whenever the adjacent cab is energized except during loss of LVPS output.

### **15.2.10 Advertisement Card Holders and Display Racks**

Continuous card holder channels shall be located inside the car on the panels above the windows. The transom cover above each doorway shall also include card holder channels in line with those above the windows. The holder shall accommodate an advertising card 10.75 in (275 mm) high. The back of the holders shall be open so that the car interior finish will show in the event the holders have no cards. The color of the card holder channels shall match that of the surrounding panels. The design of the channels shall be such that the ad cards cannot sag or slip out of the holders during train operation.

Display racks to accommodate brochures, fliers, or other informational material shall be provided at the articulation bulkheads, facing the ends of the car and on the backs of the cabs, facing toward the articulations. Display racks shall be designed to securely retain their contents and shall be mounted approximately 40 in (1015 mm) above the vehicle floor. Front facing sections shall be constructed of a clear material to enable reading of the material through the front of the pocket.

A total of eight display racks shall be provided, four in each body section. Two racks in each body section shall provide one pocket for an 8.5 by 11 in (16 by 280 mm) insert and one pocket for a 4 by 8.5 in (102 by 216 mm) insert. The other racks in each body section shall provide eight pockets for 3 by 7 in (76 by 178 mm) inserts. All pockets shall be approximately 2 in (50 mm) deep.

### **15.2.11 Keys and Locks**

Two different types of keys shall be provided for access to various car equipment or control; the keys shall be identical to what is being used on the ST1 LRVs. The key types are:

- Master Controller Key – Barrel type key shall operate the master controller key switch, as described in the Master Controller Group section in Section 5.
- Crew Key – Cross type key shall allow maintenance and operations personnel access to restricted compartments as determined by Sound Transit.

500 keys of each type shall be delivered to Sound Transit two years after NTP or 60 days before the arrival of the first vehicle, whichever comes first.

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The Contractor shall submit a report on the key design and planned usage for Sound Transit review and approval. Samples of each type of key shall be submitted with the report. (CDRL 15-10)

### **15.2.12 Passenger Intercom**

Provision shall be made for installation of passenger intercoms as detailed in Section 13.

### **15.2.13 Bicycle Space**

Space with racks to support bicycles shall be provided as specified in the General Vehicle Configuration section of Section 2.

The bicycle racks shall be the bracket (hook) type and shall be suitable for holding two (2) adult size bicycles within each A and B car body section. The complete vehicle shall be suitable for storing a total of 4 bicycles. All visible components shall be constructed from stainless steel. The racks shall be mounted as close to the interior sidewall to minimize how far the bicycle protrudes into the passenger isle.

Each single bicycle bracket and its mountings and supports shall withstand, without permanent deformation, a horizontal load of 300 lbf (1330 N) applied in any direction on the bracket. Each single bicycle bracket shall withstand, without permanent deformation, a vertical load of 300 lbf (1330 N) at the bracket. An analysis to validate the design shall be submitted to Sound Transit for review and approval. (CDRL 15-11)

### **15.2.14 Passenger Compartment Fire Extinguisher**

A 10 lb (4.5 kg) capacity fire extinguisher with a minimum rating of 4-A:30-B:C, marine type shall be located in a passenger accessible enclosure within the passenger compartment. The fire extinguisher shall be located behind a frangible cover to prevent passenger misuse.

## **15.3 Exterior Finishing and Accessories**

### **15.3.1 Roof Surface**

A non-skid surface shall be applied to the entire roof, including covers of the roof mounted equipment enclosures.

### **15.3.2 Equipment Well and Roof Shroud**

The roof-mounted equipment shall be shrouded and may be installed in a recessed well. The shrouds and wells shall permit water run-off and drainage (see this Section) and provide sufficient air-flow for proper equipment cooling. Shroud sections shall be installed to allow water to flow between the shrouds and the car body.

Shrouds shall be constructed of stainless steel, fiberglass or aluminum meeting the requirements of Section 17. The shrouds shall be finished to match the surface finish and color scheme of the car body. All shroud attaching bolts shall be stainless steel with minimum diameter of 3/8 in (9.5

mm) and shall mate with captive nuts. The shroud mounting bolts shall be hidden from view. Threaded studs will not be permitted for shroud attachment. The shrouds shall be designed so that they do not restrict service access to the roof equipment and shall not protrude past the vehicle's dynamic clearance envelope. Roof shrouds shall be interchangeable within their respective positions throughout the vehicle fleet.

### **15.3.3 Exterior Rear View Television**

Closed circuit television (CCTV) shall enable the Operator to supervise the loading and unloading of passengers at all doorways of the car when the doors are open, and to verify that the last doors on the longest train are clear of passengers. Refer to Section 13 for CCTV technical requirements.

### **15.3.4 Painting and Striping**

The car shall be painted white and striped according to the Sound Transit wave/color scheme. The bottom wave is dark blue painted on the car. The middle wave is green on 3 M vinyl film. The top wave is light blue on 3M vinyl film. The specific colors and patterns will be provided by Sound Transit. A dark blue area aligned with the windshield vertical edges shall be applied from the top edge of the windshield and extend to the roof of each cab. The roof and roof-mounted equipment enclosures shall be painted dark gray, as approved by Sound Transit. Primers, fillers, paint, and striping materials shall be applied as specified in Section 17. (Refer to this Section, CDRL 15-1.)

### **15.3.5 Rain Gutters and Water Drainage**

Rain gutters or other devices shall be installed to prevent water drainage over the sides of the main body sections and cab ends. Gutters shall be integral with the roof structure via roof sheet corrugations or similar configurations.

The gutters shall empty into concealed drainage conduits having screens at the water entry points, which shall empty below the floor line of the vehicle. Drainage conduits shall have no sharp bends and shall be designated for easy clean-out. Drainage conduits that run inside the car body structure shall be fully insulated to prevent condensation. Drainage conduits shall not run through equipment lockers except as reviewed and approved by Sound Transit during the design review process.

The gutter system and drainage conduits shall be sized to prevent accumulated water from overloading the system during car acceleration and braking or on grades and to accommodate the maximum rainfall rate for the Seattle metropolitan area. Refer to Section 2.

### **15.3.6 Skirts**

If car structure does not otherwise cover these areas, removable side skirts shall be provided between and outboard of the trucks in high floor areas and under the center car body section. Skirts shall not be load bearing members and shall be removable with common hand tools. The skirts shall form a uniform lower edge with the bottom of the car body in the low floor areas. Skirt fasteners for attachment of the car body shall be captive to the skirt.

## *Interior and Exterior Appointments*

Removable skirts shall be provided on the tapered portion of the car ends. In this area structural members shall provide a smooth transition from the level of the bottom of the low floor side sill to the anticlimber. The visible areas of this structure shall be finished and painted to the same standards as the rest of the exterior.

Skirts shall be constructed of aluminum, HSLA steel, stainless steel, or FRP, and shall be finished and painted to the same standards as the rest of the exterior. Skirting shall be subject to approval as part of the exterior finishing scheme.

Skirts shall be of a rigid design and should not release when pulled in the center.

Skirts shall not serve as access covers for undercar equipment boxes unless explicitly approved by Sound Transit during design review.

### **15.3.7 Hinged Front Hood**

Hinged front hoods shall be provided to cover the coupler area at each end of the vehicle when the coupler is not being used. Refer to Section 4.

### **15.3.8 Front End Sheathing**

The front end sheathing shall be formed from HSLA steel sheet as specified in Sections 3 and 17 or from one piece of easily replaceable fiberglass reinforced plastic meeting the FRP requirements of Section 17.

## **15.4 Graphics**

Graphics shall be provided throughout the vehicle to provide passengers and Sound Transit personnel information regarding vehicle operation and safety.

All controls and devices intended for Sound Transit personnel use shall be clearly labeled with text. All equipment intended for passenger use, however infrequent, shall be labeled both with text and graphical figures or icons. Sound Transit and Link logos and car numbers shall be on 3M "Dark Blue" reflective vinyl film.

At a minimum, the following text and graphics shall be provided:

- Car Numbers - Car numbers shall be applied to both the exterior and interior of the car as described in the Identification section in Section 2. Car number locations, sizes, and numbering sequence shall be submitted to Sound Transit for review and approval during design review.
- Contractor's name plate - Two builder's plates may be applied to the interior of each car. One each may be applied on top of the passenger side wall of the cab. Plate size and wording shall be submitted to Sound Transit for review and approval during design review.

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All console switches or wall exposed switches and operating devices shall be labeled by engraving into the panel, or other approved means. (Painted or silk screened labels are not permitted.)

All test points, fault indicators, modules, wire junctions, pipes, tubes, and wires shall be identified as required by Section 2 for maintainability.

All components, including hidden devices shall be labeled with embossed aluminum anodized plates, or other approved means. Refer to the component identification requirements in Section 19.

Other designations - Additional approved graphics shall be provided for passenger and safety information including, but not limited to: door emergency releases, intercom locations and instructions, and handicapped information.

All equipment boxes shall be labeled with safety warnings for High Voltage if appropriate. The labels shall be embossed anodized aluminum plates, mechanically fastened to the access cover.

All text and graphic layouts, nameplates and locations, shall be provided by the Contractor for review and approval by Sound Transit. (CDRL 15-12)

### **15.5 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 15-1 Interior and exterior color scheme (Section 15.1)
- 15-2 Paint and paint process (Section 15.2)
- 15-3 Acoustic insulation design report (Section 15.2.1)
- 15-4 Thermal insulation design report (Section 15.2.2)
- 15-5 Floor covering design report (Section 15.2.4)
- 15-6 Walls and ceiling design report (Section 15.2.5)
- 15-7 Windows design report (Section 15.2.6.1)
- 15-8 Passenger seat design report (Section 15.2.7.1)
- 15-9 Sample seat (Section 15.2.7.4)
- 15-10 Key report and samples (Section 15.2.13)
- 15-11 Bicycle rack analysis (Section 15.2.15)

15-12 All text and graphics layouts (Section 15.4)

## **15.6 Cited References**

The following standards or references were cited in this Section at the referenced location:

ANSI Z26.1	Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways - Safety Code (Section 15.2.6.1)
ASTM D523	Standard Test Method for Specular Gloss (Section 15.2)
ASTM D1630	Standard Test Method for Rubber Property– Abrasion Resistance (Footwear Abrader) (Section 15.2.4)
ASTM D2047	Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine (Section 15.2.4)
ASTM D6578/D6578M	Standard Practice for Determination of Graffiti Resistance (Section 15.2)
Fed. Spec. KK-L-165C	Leather, Cattlehide, Vegetable Tanned and Chrome Retanned, Impregnated, and Soles (Section 15.2.4)
NEMA 250	Standard for Enclosures for Electrical Equipment (1000 Volts Maximum) (Section 15.2.10.1)
SAE J671	Vibration Damping Materials and Underbody Coatings (Section 15.2.1)
36 CFR 1192	Americans with Disabilities Act (ADA), Accessibility Guidelines for Transportation Vehicles (Sections 15.2.8.1, 15.2.9.1)
49 CFR Part 27	Nondiscrimination on the Basis of Disability in Programs and Activities Receiving or Benefiting from Federal Assistance (Sections 15.2.8.1, 15.2.9.1)
49 CFR Part 37	Transportation Services for Individuals with Disabilities (ADA) (Sections 15.2.8.1, 15.2.9.1)
49 CFR Part 38	Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles (Sections 15.2.8.1, 15.2.9.2)
49 CFR 223	Safety Glazing Standards-Locomotives, Passenger Cars and Caboose (Sections 15.2.6.1)
MIT Press	Diffrient, Tilley, and Bardagly, “Humanscale 1/2/3”, The MIT Press, 1974 (Section 15.2.6.3)

*Interior and Exterior Appointments*

Ref. Book                      Woodson, Tillman, and Tillman, “Human Factors Design Handbook”, (Section 15.2.6.3)

**END OF SECTION 15**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 16  
TESTING**

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## **SECTION 16: TESTING**

### **16.1 General**

The complete vehicle and all of its components shall be subject to a comprehensive test program to verify compliance with all specified design, performance, reliability, maintainability, and safety requirements. The Contractor's test plans, procedures, and reports shall meet the requirements of this Section and are subject to review and approval by Sound Transit. Test plans and procedures shall be approved by Sound Transit prior to the start of any test.

All tests described in this Section shall be performed as indicated unless specifically waived by Sound Transit. All tests shall be performed on production components without modification or special preparation.

Sound Transit will, at its option, witness all tests. At least 15 days prior to each test, the Contractor shall notify Sound Transit in writing of the date, time and location the test will be performed.

Material test requirements appear in Section 17. Other test requirements may appear in other sections.

#### **16.1.1 Test Classifications**

##### **16.1.1.1 Qualification Tests**

Testing shall demonstrate compliance with design requirements at all operating and environmental extremes. These tests shall be performed on production components, assemblies, subsystems, and cars, and shall be performed on the highest level of assembly that will allow demonstration of design compliance. Qualification tests are limited to the number of units needed to demonstrate design compliance, typically one or two. Generally, these will be the first units produced; however, Sound Transit reserves the right to select equipment at random. These test requirements are described in this Section and include performance and operational tests.

The Contractor shall perform all Qualification tests specified herein, unless the Contractor can furnish data and test reports acceptable to Sound Transit, which indicate that equipment furnished under this Contract is substantially identical to equipment which has been Qualification-tested for the same application, and that those tests demonstrated compliance with the requirements of the Specifications. Sound Transit shall be the sole judge of acceptability of the data. Should submitted data not be acceptable to Sound Transit, the Contractor shall complete the tests as specified with no increase in contract cost or extension of the delivery schedule.

Sound Transit may also relieve the Contractor of the testing requirements if the Contractor successfully tested similar system and/or system hardware and software in the last two years prior to receiving NTP, and meets Service Proven Design requirements outlined in Section 2.

The Contractor will present to Sound Transit the proposed list of tests it would like Sound Transit to waive, the similarities and differences between the original and proposed system

## *Testing*

and/or system hardware and software, including the manufacturing process and estimated cost impact to Sound Transit if Sound Transit approves a waiver.

Thirty days after receiving from Sound Transit an approval to the list, the Contractor will present the test procedures and reports for each of the waived test for Sound Transit review and approval process. The Contractor is required to perform at no cost to Sound Transit any test not waived by Sound Transit.

### **16.1.1.2 Conformance Tests**

Conformance tests demonstrate that all delivered equipment operates within specified limits and is in compliance with design requirements. Conformance test requirements may vary from an inspection and functional demonstration for a simple component to a full system demonstration of a vehicle. These tests are routinely performed at ambient conditions unless a specific environmental or operating limit is necessary to demonstrate acceptable operation. These tests are described in this Section.

### **16.1.1.3 On-Site Tests**

On-site testing demonstrates that each vehicle is ready for revenue service. These tests shall be performed on Sound Transit property unless directed otherwise by Sound Transit. These tests are described in this Section.

### **16.1.2 Requirements**

The specified tests are considered to be an absolute minimum by Sound Transit. The Contractor shall be responsible for assuring that each design and performance requirement of the Specifications is assigned to a specific test effort. The Contractor and its subcontractors may perform additional testing, as they deem necessary.

All facilities, labor, materials and equipment necessary to conduct the specified tests , such as weights, instrumentation, and data processing equipment, shall be provided by the Contractor.

### **16.1.3 Test Plans, Procedures and Reports**

The Contractor shall submit to Sound Transit, for approval, a Master Test Plan covering all tests and adjustments listed in this Section and otherwise required in the Specifications and include an identification of any waivers of FRA or other Federal, State or local safety regulations required for the testing of the equipment for revenue service operation. The Test Plan shall identify all tests by reference to the appropriate number of this Section and the applicable design section. The Test Plan shall show the time, date and place of each test to be performed as well as the objective of each test. The time, date and place should be submitted in the Master Test Plan near each test, in the Master Test Schedule and in the Master Program Schedule format. The Test Plan shall cover all suppliers' and subcontractors' tests to be completed at the suppliers' or subcontractors' plants, all Contractor's tests to be completed at its plant prior to shipment, and all testing to be conducted by the Contractor on Sound Transit's property prior to delivery and acceptance. The Master Test Plan shall be submitted to Sound Transit for review and approval no later than 150 days after NTP and resubmitted bi-monthly with updates. (CDRL 16-1)

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The Contractor shall prepare a Detailed Test Procedure for each test described in this Section, and for any other tests conducted by the Contractor in connection with its own Quality Assurance program. Each test procedure shall be submitted to Sound Transit for review and approval. The Contractor shall submit, as part of each test procedure, forms to be used to record data accumulated in that test. Such forms shall also contain a step-by-step format for data reduction, formulae used in deriving the format, criteria for acceptability, and justification for the criteria set forth.

Each test procedure shall be submitted to Sound Transit in advance of the initial conduct of a planned test to provide at least 30 working days to review and approve the procedure, unless requirements that are more restrictive are specified for a particular test. No testing shall occur and no results shall be considered valid until approval of the test procedures by Sound Transit.

Each procedure shall include as a minimum the following items as applicable:

- System description and system drawings, schematics, and diagrams showing the main system functions and parameters, and location and connections of the measuring points. There should be a clear correlation between the text and the drawings.
- Test objective, including requirement to demonstrate that the equipment meets the safety requirements specified in this part when operated in the environment in which it is to be used, test set-up description, drawings, schematics, diagrams, loading of the system or test specimen and the loading increments. There should be a clear understating of the test set-up with system or specimen under the tests and a clear correlation between the text and the drawings.
- Typical logging sheets, print-outs, plotting forms, and examples of any other data sheets which will be used during the test or in the final report.
- Table(s) showing the measuring points, their expected nominal, minimum and maximum values and conditions that cause the readings.
- Table(s) of predicted values at selected sensor or gauge locations. This table shall list the sensor number, predicted value, a space to enter the actual value (check marks are not allowed) and a space to enter the pass or fail
- Detailed list of the test instrumentation, sensors and gauges including data acquisition system, the instrumentation accuracy, the manufacturer description of the instrumentation, and current calibration certificates.

The Contractor shall submit a report of each test, including copies of all test data, to Sound Transit for review and approval. In case of tests that are performed on all cars, or all components, the reports of those tests shall be included in the appropriate Car History Book. In every case, the report shall include a description of the test, all raw data collected in the test, all data reduction forms, and a summary of the results in a manner that can be directly compared to the Specifications without further calculations.

Each report shall include as a minimum the following as applicable:

## *Testing*

- Test narrative with the dates, timing (start, finish, interrupts), location of the test set-up elements, and list of attending test personnel;
- Record of each instrument used during the tests and record of applicable calibration certificate;
- Tester initials that each step identified in the test procedure was completed;
- Filled tables as required in the procedure;
- Graphs, chart and other records required in the test procedure;
- Photographs taken during the testing with relevant notations. The record photographs shall be mounted on pages the same size as the report pages;
- Description and explanation of every discrepancy between the procedure and actual testing; and
- Description and explanation of every value that does not comply with the test criteria, and a recommended disposition of the same.

Test reports for tests classified as commercial (quality assurance) tests shall not be submitted for approval but shall be made available to Sound Transit upon request.

In case of difference between this Section and other sections contained in the Specifications, the stricter requirements shall apply.

### **16.1.4 Insulation Testing**

The integrity of the electrical insulation shall be confirmed where specified below by performing insulation resistance tests and high potential tests on individual devices, systems and apparatus, and then on the completed car.

#### **16.1.4.1 Insulation Resistance Tests**

Insulation resistance shall be conducted on all circuits within a device, system or vehicle. Insulation resistance tests shall be conducted before high potential tests are conducted. Tests shall be conducted to verify the state of the insulation to the case or car body, between wiring of different voltage classes, and between the input and output circuit of high voltage line switches and circuit breakers. Semiconductor devices may be protected against the test voltage by means of shorting jumpers if they are not inherently protected by the circuit in which they are used.

On items with double insulation, such as grid resistors mounted on an insulated frame, each set of insulation shall be individually tested, (i.e., resistors to frame and frame to car body.)

The following insulation resistance limits shall apply when all circuits on the vehicle of a given voltage class are connected in parallel under all environmental conditions including high humidity:

## Testing

<b>Nominal Circuit Voltage [Vdc or Vac]</b>	<b>Test Voltage [Vdc]</b>	<b>Minimum Insulation Resistance [Megohm]</b>
Below 90	500	2
90 to 300	1000	4
Above 300	1000	5

The test limits for individual devices or apparatus shall be higher than the above listed limits, as is appropriate for that hardware, so that the limits for the completed vehicle can be met.

### 16.1.4.2 High Potential Tests

A high potential test shall be conducted after the insulation resistance tests are completed and passed. The high potential test shall be conducted on all circuits within a device, system or completed vehicle. Tests shall be conducted to verify the state of the insulation to the case or car body, between wiring of different voltage classes, and between the input and output circuit of high voltage line switches and circuit breakers. Semiconductor devices may be protected against the test voltage by means of shorting jumpers if they are not inherently protected by the circuit in which they are used.

All components and systems shall be in place when the high potential tests are being performed, unless prior approval from Sound Transit has been given to allow certain components to be disconnected during the test. The Contractor shall jumper together the various wires in a system to ensure that all parts of a system are tested, and to prevent capacitive currents or fault currents from passing through and damaging low voltage devices.

On items with double insulation, such as grid resistors mounted on an insulated frame, each set of insulation shall be individually tested, (i.e., resistors to frame and frame to car body.)

The test shall be conducted by applying test voltages according to IEEE-16, for a period of 1 min, across the insulation being tested, the test is passed if there is no insulation breakdown or excessive leakage current. The test voltage shall be at a frequency of 50 or 60 Hz with a sinusoidal waveform. Alternatively, the test voltage can be dc with a value equal to 1.75 times the ac rms voltage.

The test voltage for subsequent tests on a vehicle after delivery to Sound Transit shall be 0.85 times the value defined above for the circuit to be tested.

Standard apparatus may be production tested for 1 s at a test voltage 20% higher than the defined 1-min test voltage.

### 16.2 Component Qualification Tests

As a minimum the following qualification tests shall be performed as indicated. Tests shall be completed before a component is installed on the first vehicle, but in any case all shall be

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completed and submitted to Sound Transit for review and approval before any vehicles are shipped from the assembly plant.

### **16.2.1 Flammability and Smoke Emission**

All materials supplied for this car shall be tested to the Flammability and Smoke Emission requirements of Section 17. The FST report shall be submitted no later than 12 months from NTP. The test results that are included in the Flammability and Smoke Emission Test Report shall not be more than 3 years old from the time of NTP.

### **16.2.2 Door Panel**

One door panel of each type, selected at random by Sound Transit, shall be tested to confirm compliance with the strength requirements of Section 6. (Procedure: CDRL 16-2) (Report: CDRL 16-3)

### **16.2.3 Windows**

End-facing windows shall be tested in accordance with 49 CFR 223, Type I tests. Cab side windows shall be tested in accordance with 49 CFR 23 Type II tests. Other side-facing windows, including side door windows, shall be tested in accordance with ANSI Z26.1 tests. Windows to be tested: one of each type. (Procedure: CDRL 16-4) (Report: CDRL 16-5)

### **16.2.4 Seat**

One seat frame, seat installation/attachment, cushion, back, and seat set of upholstery material of each type shall be tested to confirm compliance with the requirements of Section 15. (Procedure: CDRL 16-6) (Report: CDRL 16-7)

One complete flip-up seat shall be tested to ensure reliable operation of the spring and latch mechanisms and compliance with the passenger seat and mobility impaired requirements of Section 15.

One operator's seat shall be fully tested to ensure the seat's reliable operation and compliance with the requirements of Section 5.

### **16.2.5 Motors**

#### **16.2.5.1 AC Traction Motors**

The ac traction motor, selected at random by Sound Transit, shall be given a type test by the manufacturer in accordance with IEC 60349-2 or IEEE Std. 11, as appropriate. The first motor produced in each production lot, and one additional for every one hundred motors shall be tested. (Procedure: CDRL 16-8) (Report: CDRL 16-9)

The traction motor testing shall demonstrate compliance with the requirements of Section 10.

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### **16.2.5.2 AC Auxiliary Motors**

The first and one additional motor of each type, selected at random by Sound Transit, shall be given an IEC Publication 60349-1 or-2 type test, including a heat run, by the manufacturer, to demonstrate its capabilities and power rating. Both motors of each model tested shall be tested at their continuous rating. (Procedure: CDRL 16-10) (Report: CDRL 16-11)

Alternatively, for motors that have prior vehicle service history when operating from an inverter power supply, the manufacturer may submit type test data for one motor of each model ac motor being used on the LRV.

### **16.2.5.3 Dc Auxiliary Motors**

The first motor of each type and an additional one of each type, selected at random by Sound Transit, shall be given an IEEE Standard 11 or IEC Publication 60349-1 type-test, including a heat run, by the manufacturer, to demonstrate its capabilities and continuous rating. (Procedure: CDRL 16-12) (Report: CDRL 16-13)

### **16.2.6 Propulsion Gear Unit**

Two propulsion gear units, selected at random by Sound Transit, shall be subjected to a 100-hour test, and shall be mounted with torque load simulation. The test shall subject the units to conditions that are, in general, 20% more severe than would occur under the most extreme operating conditions (i.e., power increased by 20%). Torque load shall include the effects of dynamic braking. (Procedure: CDRL 16-14) (Report: CDRL 16-15)

The test shall be started with the unit at a temperature from 60°F to 90°F (16°C to 32°C). A fan or other device may be provided so that in-service air flow conditions are simulated. The temperature rise measured in the oil sump shall not exceed the gear oil supplier's recommendations for maximum temperature consistent with the life between oil changes, as stated in the Contractor's maintenance manuals. The direction of rotation shall be reversed every successive 8 h until the 100-hour test is completed. Noise and vibration tests shall also be performed to verify the requirements of Section 2.

The power and return wiring shall simulate installation on a vehicle. The Contractor shall show by testing stray current bypass motor or gear unit bearings.

After completion of the test, the gear units shall be disassembled and all parts examined. Gear tooth mesh and tooth pattern shall be checked and recorded before and after the test. Any sign of deterioration of any part shall be investigated jointly with Sound Transit. The test report shall include test records of running time, oil temperatures, oil sample analysis and vibration and sound level readings taken at such intervals as required to verify compliance with the Specifications.

### **16.2.7 Auxiliary Power Supply**

Auxiliary power supply (APS) tests shall be performed on the first production unit of each type and one additional unit of each type selected at random by Sound Transit. These tests shall

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include all aspects of the following for the design requirements, environmental ranges, and supply voltages given in Sections 2, 9, 17, and as herewith listed (Procedure: CDRL 16-16) (Report: CDRL 16-17):

- All output and control requirements;
- Performance and capacity requirements;
- Transient load and short term over-load response;
- Fault detection and annunciation requirements;
- Insulation, isolation, and transient rejection requirements;
- Heat run, designed to test the system for the worst case heat loadings for:
  - Maximum rated output current at the lowest operational input voltage; and
  - Lightest possible load, at the highest operational input voltage;
- Noise measurements shall be made sufficient to demonstrate compliance with Section 2; and
- Repetitive restarts to simulate ice on OCS.

### 16.2.8 Low Voltage Power Supply and Battery Charger

Low voltage power supply (LVPS) and battery charger (BC) tests shall be run on the first production unit of each and one additional unit selected at random by Sound Transit. If the APS, LVPS and BC are provided as an integral unit the test requirements of this Section can be combined and conducted concurrently. The design qualification tests of the LVPS and BC shall include the following: (Procedure: CDRL 16-18) (Report: CDRL 16-19)

- A continuous heat run of the unit at rated input voltage and rated output voltage and current. The heat run shall be of sufficient duration to allow all critical elements to stabilize in temperature. Temperature rises over ambient shall be within Contractor's limits as set forth in the test plan.
- The unit under test shall be run for 1 h at an input voltage just below the upper limit of the specified operating range and at rated output current and voltage.
- The unit shall be run for 1 h at an input voltage just above the lower limit of the specified input range for which rated output voltage and current is to be delivered, at rated output voltage and current.
- The unit, when connected to its rated load, shall be cycled OFF and ON by interruption of the source voltage supply external to the unit under test. Rate of cycling shall be approximately 1 s on, 0.5 s off, and shall continue for 2 min.
- The unit shall be started into an open circuit five times in succession.
- The unit shall be started into a short circuit five times in succession.

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- The unit shall be started while connected into an overload of 120% of rating. The overload shall then be removed and the unit shall automatically provide rated output voltage.
- Noise measurements shall be made sufficient to demonstrate compliance with Section 2.
- At operating points representing the full range of conditions for delivery of rated output voltage and for routine current limit operation, output voltage and output voltage wave forms shall be monitored by an oscilloscope to determine compliance with the specified regulation and levels of ripple.

### **16.2.9 Battery**

One battery shall be tested to establish that the batteries will meet the requirements of Section 9. Testing shall include a discharge cycle and charge retention on open circuit. (Procedure: CDRL 16-20) (Report: CDRL 16-21)

### **16.2.10 Truck**

One of the first three truck frames of each design, complete with bolster and selected at random by Sound Transit, shall be subjected to static and fatigue tests described in this Section. This truck frame and bolster shall be radiographically inspected as required by this Section prior to commencing the test.

The primary suspension test described in this Section shall be done during the same time period as the static and fatigue test.

One of the first three cars assembled shall be used in the performance of the equalization test described in this Section.

The Contractor is responsible for selecting test loads and conditions that will develop a high level of confidence in the adequacy of the truck design. Test loads and conditions specified herein are a minimum. Greater loads and more severe conditions may be imposed by the Contractor.

A test procedure shall be prepared for each test. The procedure shall include a description of the test, the purpose, how and with what equipment the specimen is to be loaded and in what load increments, the type and location of strain gauges, the location of deflection gauges, complete description of all instruments, and details of the data acquisition system. Drawing and sketches shall be included to clarify the text. Also included shall be the drawings showing the test fixture, the specimen installed in the fixture, and location of load application points. The procedure shall include a list of the steps to be performed. Test procedures for all truck tests shall be combined and shall be submitted not less than 90 days in advance of the test date, and approvals of the test procedure and stress analysis are necessary prerequisites for testing. (CDRL 16-22)

The test report shall include a copy of the current calibration for every instrument and gauge to be used during the test. The calculation of the accuracy of the test system shall be included. Typical logging sheets, print-outs, plotting forms, and examples of any other data sheets that will

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be used during the test or in the final report shall be submitted as part of the test procedure. Tables shall be included which show the maximum allowable gauge reading for each gauge and loading condition. There shall be a table listing for each strain gauge, the strains calculated by the FEA at the gauge location, so that the output of the strain gauge reading is readily comparable to the information in the table. Other tables, showing the allowables for all other test criteria, shall be included in the test procedure.

The Contractor shall conduct a stress coat test by either the brittle lacquer or photo-elastic methods of at least one quadrant of the truck frame and one-half of the bolster to confirm areas of high stresses and orientation of principal stresses. A test procedure shall be prepared for stress coat testing.

Adequate number of rosette strain gauges shall be applied to the truck frame and bolster for the tests described in this Section at locations of expected high stress and other areas of interest. Location and number of strain gauges shall be based on the stress analysis, the Contractor's experience, the stress coat test results, and the direction of Sound Transit. Drawings and sketches showing the location of every strain gauge shall be prepared by the Contractor and submitted as part of the test procedure. Sound Transit will review and approve strain gauge locations. The strain gauges shall be SR-4 type, or other approved gauges specifically suitable for the application. The gauges shall be calibrated in accordance with the manufacturer's instructions for the material being measured. The gauges shall be compensated for temperature. A load cell shall be installed at each point of load application. All load cells shall be recorded simultaneously with all strain gauges.

All gauges and instruments shall be in current calibration. The method of calibration and time period for recalibration shall be in accordance with the laboratory's national standard or ISO. The laboratory shall have on file a current certification of calibration traceable to the laboratory's national standard.

The Contractor shall prepare a color photographic record of the tests. This record shall include photographs of the trucks in the various test fixtures, installation of critical strain gauges, repairs or modifications, deviations from the drawings, and any areas that were found non-compliant. The Contractor shall prepare and submit a final test report within 30 days after successful completion of the structural tests. (CDRL 16-23) It is the approval of this test report that constitutes the acceptance of the truck structural tests.

The test report shall include:

- A table of contents;
- The test procedure (with all its appendices, including calibration certificates);
- A narrative describing the conduct of the test, with dates and locations of test elements;
- Tables showing stresses and deflections which were 85% or more of the allowable;
- Description and explanation of any value that exceeded the test criteria;

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- Appendices containing all data; i.e., output from each gauge for each load step. These data shall be identified with the date that they were recorded;
- The record photographs shall be mounted on pages the same size as the report pages;
- Stress (or strain) vs. load curves for the 10 greatest tension stresses and the 10 greatest compressive stresses for each test series; and
- A table listing, for each strain gauge, the calculated stress from the strain gauge reading and the calculated stress from the stress analysis. The values shall be readily comparable.

### 16.2.10.1 Static Load Test

The purpose of this test is to verify that the maximum allowable static stresses selected by the Contractor and approved by Sound Transit are not exceeded under maximum expected static loads. The truck and bolster shall be loaded twice, with complete release of the load between applications. Strain gauges shall be re-zeroed after the first load application and the offset from zero recorded and reported. All required data shall be taken during both load applications. The methods and points of test load application and reaction shall simulate as closely as possible the actual loading conditions to which the truck will be subjected in service.

The vertical test load shall be as specified in Section 11.

The truck will be compliant with the Specifications if all of the following are met:

- Maximum stresses calculated from strain readings in any gauge during the second load application do not exceed 50% of the material's yield stress;
- Indicated residual strains following removal of the second loading do not exceed the maximum error resulting from the accuracy of the instrumentation; and
- There are no permanent deformation, fractures, cracks, or separations in the truck.

If any of the above criteria are not met, the truck design shall be corrected and the truck retested at the Contractor's expense, and this process shall continue until these criteria are met.

### 16.2.10.2 Fatigue Test

To demonstrate that the truck has adequate fatigue strength under dynamic loading, the static test truck frame and bolster shall be subjected to not less than two million cycles of dynamic loading as specified below. Upon successful completion of two million cycles the truck shall be tested in additional increments of one million cycles with the load increased for each increment by an approved schedule. This testing shall continue until truck failure or six million cycles, whichever occurs first. The additional cycles above the initial two million are solely to determine fatigue life margin. The truck and bolster may be tested as a unit or separately and may contain its internal elastomeric cushioning and springs or an approved substitute therefore, but not shock absorbers. The truck and bolster, which undergoes this test, shall not subsequently be used on a production vehicle, and shall be permanently marked or destroyed.

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Prior to the test, the test truck shall be given a wet, fluorescent magnetic-particle or fluorescent dye-penetrant inspection for cracks and other defects that might impair the performance of the truck during the test. Magnetic particle and dye penetrant inspections shall be in accordance with the requirements of Section 17. Any such defects found shall be recorded, and if required, repaired using an approved procedure in accordance with, as a minimum, the requirements of Section 17 for structural castings and welding and brazing. The type, size, location and repair of each defect shall be documented by photographs and drawings, and all such documentation shall be included in the truck fatigue test report.

The mean vertical load shall be the truck's share of completed vehicle plus an AW2 passenger load minus the weight of the truck, and the applied vertical load shall vary about the mean vertical load plus and minus 25%. The lateral load shall vary between 15% of the mean vertical load acting towards one side of the truck and 15% of the mean vertical load acting towards the other side. The longitudinal load shall vary between 15% of the mean vertical load acting towards one end of the truck and 15% of the mean vertical load acting towards the other end. The lateral and longitudinal loads shall act as if they were applied at the center of gravity of the car body at the AW2 load, with resulting vertical loading applied to the bolster. Accessory loads shall vary between plus and minus 100% of their maximum steady state values: motor under maximum braking torque and brake unit tractive effort under maximum service brake application and maximum track brake tractive effort reaction. The phasing of the loads shall be selected by the Contractor and approved by Sound Transit, and shall be such as to produce the worst case stresses at critical locations.

During the fatigue test, the truck shall be visually inspected periodically to detect possible crack initiation and progression. If evidence of crack progression or failure is found, the test shall be halted, the appropriate corrective action taken, and the test rerun from the beginning, (on another truck if desired). All load cells and strain gauges shall be recorded for both maximum and minimum loadings.

The truck will be compliant with the Specifications if all of the following are met after two million cycles:

- Stresses calculated from strains measured at critical locations do not exceed fatigue allowables. Critical locations and fatigue allowables shall be as selected by the Contractor and approved by Sound Transit. This stress range shall be within the allowable fatigue endurance limit for non-redundant structures obtained from AAR M-1001, Section 7, Material Properties – Fatigue Properties of Members and Details, or AWS D1.1/D1.1M, Section 9 or the Contractor's own tests if more appropriate and conservative.
- Indicated residual strains at strain gauges on principal structural elements following removal of all loads do not exceed the maximum error resulting from the accuracy of the instrumentation.
- There is no permanent deformation, fractures, cracks, or separations in the truck.
- At the conclusion of two million cycles, a magnetic particle or dye-penetrant inspection shall be made for cracks. The post-test inspection procedure shall duplicate the pre-test

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inspection procedure. If cracks are found which were not present before the test, or cracks have propagated from original recorded dimensions, the design shall be corrected, and the test rerun from the beginning with a new test specimen at the Contractor's expense. This process shall continue until these criteria are met.

### 16.2.10.3 Primary Suspension Tests

A load/deflection test and accelerated aging tests shall be performed to demonstrate that the spring rate of the primary suspension system and the creep rate for the materials used are within the design limits. The purpose of these tests shall be to prove that the primary suspension system performance meets design requirements and will not produce excessive deflections under any service load or allow the truck to infringe on the minimum clearance to the top of the rail as specified in Section 2.

Data from previous tests on the same primary suspension elements may be submitted within 90 days of NTP, and if acceptable to Sound Transit this test will be waived.

### 16.2.10.4 Equalization Test

To verify the equalization provided by the truck design, the test car, ready to run, shall have one wheel first raised 2 in (51 mm) and then lowered 2 in (51 mm) with respect to the plane formed by the three other wheels of the same truck as they rest on level, tangent track. Contact between all wheel treads and the rails on the entire car shall be verified for both conditions. In addition, one wheel shall be first raised 1.5 in (38 mm) and then lowered 1.5 in (38 mm) with respect to the plane formed by the other three wheels as they rest on level, tangent track without resulting in a change of more than 60% in the weight on any wheel with respect to its null-position weight in either condition. In the event that the required equalization is not attained as a result of these tests, the truck design shall be corrected, and the truck retested at the expense of the Contractor. This test shall be performed on one motor truck and the trailer truck of one of the first three completed cars.

### 16.2.10.5 Truck Radiographic Inspection Test

One of the first three production trucks of each type, including the frame, bolster, and any other primary structural members, shall be qualified by radiographic inspection of all critical welds for welded or cast-welded trucks and critical areas for castings. Critical welds shall be defined as:

- All full penetration welds;
- All welds subject to tensile stresses in excess of 50% of the weld's rated fatigue life;
- All non-redundant load path welds whose failure could cause truck failure or derailment; and
- All welds whose failure could impair brake performance.

Critical areas of castings shall be defined as:

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- All areas whose combined static loads and fatigue loads exceed 3,000 lbf/in<sup>2</sup> (20 MPa) tension;
- All areas subjected to fatigue range in excess of 15,000 lbf/in<sup>2</sup> ( $\pm 7,500$  lbf/in<sup>2</sup>) (100 MPa ( $\pm 50$  MPa)) regardless of static load; and
- All areas whose failure could result in derailment or impairment of braking performance.

Radiographs shall be made in accordance with AWS D1.1/D1.1M for welds or requirements of Section 17 for castings. Inspection quality level shall be selected by the truck manufacturer to be consistent with the truck design, but shall not be of lesser quality than that required by Section 9 of AWS D1.1/D1.1M for welds and Section 17 for castings. Any defects found shall be repaired and the truck re-inspected. This process shall continue until a truck passes the inspection. Production variables shall be corrected for welds or cast areas that continue to fail inspection. Critical areas may be sectioned and etched to demonstrate weld soundness. In this case, there shall not be less than three etched sections at each critical area, and the location of each shall be approved by Sound Transit.

### 16.2.11 Coupler and Draft Gear

Coupler and draft gear design qualification tests shall include tests which validate the performance and capacities of the following: (Procedure: CDRL 16-24) (Report: CDRL 16-25)

- Coupler draft and buff loading;
- Draft gear deflection and emergency release;
- Anchor casting static loading;
- Folding and stowage;
- Gathering range, and mechanical coupling and uncoupling;
- Electrical coupling and uncoupling;
- Centering; and
- Vertical strength capability.

These tests shall be done on a test stand as appropriate.

### 16.2.12 Equipment Noise Tests

Noise design Qualification tests conducted on equipment prior to its installation shall be performed early in the production phase. Test conditions shall be those applicable to pre-installed equipment as stated in Section 2. (Procedure: CDRL 16-26) (Report: CDRL 16-271)

### 16.2.13 Car Body Structural Tests

Structural testing, including all reports, shall be designed and developed to confirm that the analyses of each car body type structure specified in Section 3 are accurate, and that the car body

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structures meets the requirements of Section 3. The test reports shall be sufficient for long-term use as part of the permanent information to be used to maintain, repair and modify the car throughout its life.

### **16.2.13.1 General**

The first complete production vehicle, including the two main body sections and the center section, shall be tested by the Contractor to show that the critical portions of the car body structure comply with the Specifications. The tests shall be made at a Sound Transit-approved facility. The tests shall not begin until the car body stress and energy absorption analyses, and the test procedures have been approved.

The test specimens shall be completely inspected and all non-conformances corrected. All inspection, test, and corrective action reports shall be available for review prior to testing. Particular attention shall be paid to recording flatness and straightness.

The test shells shall be structurally complete, consisting of all car shell structure, and fiberglass front end mask (if part of the design), but excluding such items as exterior and interior trim, windows, doors (except those used in the vertical load test), seats, lights, interior lining, insulation, or other parts that would obscure any structural member from view or that would interfere with the performance of the test. Underfloor and roof mounted equipment shall be simulated by equivalent weights at their respective locations. All structural tests shall be conducted on the same specimen.

The car shells shall be weighed and the weight recorded prior to installation of any test equipment. The weight report shall be available prior to the start of the tests. For the tests, the car shall be supported on the trucks or equivalent supports to allow longitudinal movement.

All gauges and instruments shall be in current calibration. The method of calibration and time period for recalibration shall be in accordance with the test laboratory's national standard or ISO. The laboratory shall have on file a current certification of calibration traceable to the laboratory's national standard.

The Contractor may conduct preliminary tests, but all critical dimensions and flatness must be verified after the Contractor tests and before the official test begins. The official test (test of record) shall be witnessed by Sound Transit. A copy of all recorded data shall be given to the Sound Transit witness at the conclusion of each test. (CDRL 16-28)

Where practical, all gauges shall have an electric output suitable for recording on electronic (magnetic) media. A data acquisition system shall be provided to permanently record all gauge output at each load step. At the end of each load step, a printout of all strain gauge readings in proper engineering units (microstrains) and a plot of load vs. gauge reading for critical gauge locations shall be given to the Sound Transit representative for review. The Contractor shall obtain approval from the Sound Transit representative after every load step before proceeding with the next step. A paper and an electronic copy of all data shall be available to the Sound Transit representative at the end of each test. The Contractor shall not break down the test fixtures until the Sound Transit representative has reviewed all the data.

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The Contractor shall prepare a color photographic record of the test. This record shall include photographs of the car in the several test fixtures, installation of critical strain gauges, repairs or modifications, deviations from the drawings and any areas that were found to be non-compliant. (CDRL 16-29)

Sound Transit reserves the right to test a second car of each type during the construction period. Should such a test be ordered, it shall be at the expense of Sound Transit unless the tests prove the design is non-compliant in any structural area. If non-compliant, the Contractor shall then be responsible for the test expenses and for all Sound Transit-associated costs, and the cost of modifications necessary for the car and all other cars to comply with the Specifications. The Contractor (at its own expense) shall also perform a complete set of structural tests to qualify the modified car.

### 16.2.13.2 Car Body Structural Test Procedure

A test procedure shall be prepared for each test. The procedure shall include a description of the test, the purpose, how and with what equipment the specimen is to be loaded and in what load increments, the type and location of strain gauges, the location of deflection gauges, complete description of all instruments and gauges, and details of the data acquisition system. Annotated copies of catalogue cuts may be used to provide some of this description. An explanation of the accuracy of the instrumentation shall be provided. Drawings and sketches shall be included to clarify the text. The test procedure shall include a step-by-step instruction describing how load is applied, the load at each step, when to record data, and the place where authorization to proceed is to be obtained from the Sound Transit representative. Test procedures for all car body tests shall be combined and shall be submitted not less than 90 days in advance of the test date, and approvals of the test procedure and stress analysis are necessary prerequisites for testing. (CDRL 16-30)

The test procedure shall include a description of gauge(s) to be used during the test. It shall include a calculation of the accuracy of the test system for each test. Typical logging sheets, print-outs, plotting forms, and examples of any other data sheets which will be used during the test or in the final report shall be submitted as part of the test procedure.

Tables shall be included which show the maximum allowable gauge reading for each gauge and loading condition. Other tables shall be included which show the requirements for all other test criteria.

Each test procedure shall contain a table of predicted strain (or stress) at selected strain gauge locations. Refer to Section 3 for additional details. This table shall list the strain gauge number, predicted strain (or stress) from the stress analysis, the location of the strain, a space to enter the actual strain (or stress) and a space to enter the calculated percent difference, defined as:

$$\text{Percent Difference} = \frac{\text{Actual} - \text{Predicted}}{\text{Predicted}} \times 100$$

### 16.2.13.3 Strain Gauges

A minimum of 300 rosette strain gauges shall be applied to the car structure for the end-compression load tests. A minimum of 300 rosette strain gauges shall be applied to the car structure for the vertical load tests. A minimum of 300 rosette strain gauges shall be applied to the car structure for the diagonal jacking tests. Gauges may be used for more than one test if located on the structure appropriate to more than one test, but readings from at least 300 rosette strain gauges in locations as described below for each test. Linear gauges may be used instead of rosettes where it can be shown that the stress is in one direction only and what that direction is. The location of the strain gauges shall be based on the Contractor's experience, the stress analysis, and Sound Transit recommendations. Half of the gauges shall be placed in areas where the stress may be critical and the other half shall be placed in locations to validate the stress analysis.

Drawings and sketches showing the location of every strain gauge shall be prepared by the Contractor and submitted as part of the test procedure. These drawings shall dimension the location of every gauge showing the distance from edges, connections and bends. The location on the upper or lower, inner or outer surface shall be noted on these drawings.

The strain gauges shall be bonded resistance (SR-4) type or other approved gauges suitable for the application. Gauges used on FRP shall be appropriate for that material. The gauges shall be calibrated in accordance with the manufacturer's instructions for the material being measured. The gauges shall be compensated for temperature.

For each collision and corner post load test, there shall be a minimum of 100 rosette strain gauges applied to the post and car structure. Gauges may be used for more than one test if located on the structure appropriate to more than one test, but readings from at least 100 rosette strain gauges in locations as described below shall be obtained for each test. Linear gauges may be used instead of rosettes where it can be shown that the stress is in one direction only and what that direction is. Half of the gauges shall be placed in areas where the stress may be critical and the other half shall be placed in locations to validate the stress analysis.

### 16.2.13.4 Deflection Gauges

Vertical deflection of the car body shall be measured along both side sills during all tests. Sufficient gauges shall be used to define car body deflection from end to end with a smooth curve, and shall be located at least at the front and articulation end sills, at the bolsters, at appropriate points on the articulation section, and at intermediate points as necessary. Measurements shall be taken to the nearest 0.01 in (0.25 mm), and the deflections shall be considered as the average of the readings recorded on both sides of the car.

Additional deflection gauges shall be applied at the end sill, near the ram at the opposite end sill, near the reaction, and at the transition wall between high and low floors.

For the diagonal jacking test, an additional deflection gauge shall be applied at the jack which is lowered or raised to measure the vertical movement at this point.

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During the vertical load test, the change in car body width at the belt rail, and at the top of the door opening posts shall be measured and recorded. Additional deflection gauges shall be applied in door openings in order to measure the worst-case change in the diagonal dimensions of the opening during the tests.

The deflection gauges shall have electric output compatible with the data logging apparatus used with the strain gauges. All deflections shall be recorded simultaneously with the strain gauge recordings.

In addition to the above electronic recordings, five dial indicators of sufficient stroke shall be employed to measure the vertical deflection at the center of both side sills, the longitudinal deflection at the anti-climber next to the ram and next to the reaction at the opposite end of the car. The fifth indicator shall be located next to the lowering jack during the diagonal jacking test. These dial indicators shall be read and manually recorded at every load step.

Deflection gauges shall be applied to the post at a minimum of three places on each post being tested: top, bottom, and load application point. These gauges shall be mounted to measure the deflection of the post in the direction of the applied force. In addition, a dial indicator shall be mounted at the middle of the post in each test.

### **16.2.13.5 Load Cells**

Load cells shall be provided at the appropriate location for each test. Each load cell shall be calibrated to 1% accuracy and certified within two months before commencement of these tests over the full range of 1.5 times the maximum load to which the load cell will be subjected during these tests. The load cells shall have electric output compatible with the data logging apparatus used with the strain gauges. All loads shall be recorded simultaneously with the strain gauge recordings.

A single load cell shall be placed at the end of the ram for the compression test. A load cell shall be placed at each secondary spring location for the vertical test. A load cell shall be placed at each jack location for the diagonal jacking test. Load cell readings shall be taken and recorded at each step of the vertical, compression and diagonal jacking load application and removal process.

### **16.2.13.6 Vertical Load Test**

#### **16.2.13.6.1 Test Description**

The car body specimen supported on trucks or a simulation, shall be subjected to a vertical load test. A test load equal to the static vertical operating load specified in Section 3 AW4, shall be applied to the specimen. The load shall be applied in five approximately equal increments resulting in a total of six vertical load increments. One of these increments shall be equivalent to a ready-to-run car body weight plus a passenger load of AW2. Another of the increments shall be equivalent to a ready-to-run car body weight plus a passenger load of AW3. The test load may be applied by means of weights or jacks, but shall be distributed in proportion to the distribution of weight in the finished car. The specimen shall be unloaded in the increments that it was loaded, in reverse order. Strain gauge and deflection readings shall be taken at each load increment. The

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vertical load test procedure shall provide for the anti-climber combined load test as required by this Section.

At least one side door shall be installed in the doorway subject to the greatest shear deflection. The door shall be complete with operators, thresholds, and all sealing and weather-stripping. The required door equipment shall be production equipment installed in accordance with production drawings and procedures. At each increment of test load, the doors shall be operated at the intended speed and the force to open and close shall be measured. Open and close forces shall be within permissible limits specified by the car builder based on the characteristics of the door engine. If either the open or close force (or both) exceeds the permissible limits, the Contractor shall be required to take corrective action. The vertical load test must then be repeated in its entirety.

### 16.2.13.6.2 Test Criteria

The car will be compliant with the Specifications if all of the following are met:

- Stresses are in accordance with the requirements of Section 3.
- Vertical deflection readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at that point which represents the measured deflection for maximum vertical load.
- Strain readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.
- Recorded residual vertical deflection between bolsters following removal of the maximum vertical test loading does not exceed 0.04 in (1.0 mm).
- Recorded residual car transverse width and/or opening diagonal dimensions following removal of the maximum vertical test load do not exceed 0.04 in (1.0 mm).
- Indicated residual strains at strain gauges on principal structural elements following removal of the maximum vertical loading do not exceed the maximum error resulting from the accuracy of the instrumentation.
- Car body deflection, as measured during the vertical load tests under a load equal to the passenger load of AW4, is not more than the allowable specified in Section 3.
- Car body vertical deflections measured at the side sill during the test at AW2, AW3, and AW4 shall agree with the analysis calculated deflection within +/-10%.
- There are no permanent deformations, fractures, cracks, or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and Sound Transit to determine if the failure is the result of weld quality or stress.

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- The flatness and straightness of structural members meet the requirements of Section 3.
- The side doors open and close at speeds and operating force levels as required without binding at all test loads.

### 16.2.13.7 Compression Load Test at the End Sill

#### 16.2.13.7.1 Test Description

The ability of the car body structure to resist the end sill compression loads specified in Section 3 shall be tested.

During the compression test, the car shell shall be supported on trucks or a simulation thereof to allow free longitudinal movement. The car shell shall be tested at AW0 condition or loaded with sufficient dead weight to bring the total body weight (of test specimen) up to AW4 loaded car, whichever the stress analysis indicated was worst case. This loading shall be distributed in proportion to the distribution of weight in the finished car.

The test load shall be applied to the anti-climber. The load shall be distributed over an area not to exceed the height of the anti-climber by 12 in (305 mm) in width.

The compression test load shall be applied by means of a controlled hydraulic ram, and the force measured by a means independent of those producing the force. Cushioning means, such as lead sheets, shall be provided to ensure uniform bearing. The test load shall be applied horizontally on the car longitudinal centerline. The load shall be applied in increments of 25, 50, 75, 87.5, and 100% of full load. After each load increment is applied, the load shall be reduced to not more than 2% of full load. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. The ram shall be supported at the car end but shall remain free to move longitudinally with respect to the car end. If vertical forces will develop at the ram during testing, these forces must be measured.

#### 16.2.13.7.2 Test Criteria

The car will be compliant with the Specifications if all of the following are met:

- Stresses are in accordance with the requirements of Section 3.
- The vertical deflection of each side of the test structure shall be within  $\pm 10\%$  of the value determined by the analysis.
- Vertical deflection readings plotted against load do not vary by more than  $\pm 5\%$  from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- Strain readings plotted against load do not vary by more than  $\pm 5\%$  from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point, which represents the measured deflection, at maximum load.

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- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.
- Recorded residual vertical deflection between bolsters following removal of the maximum test load does not exceed 0.04 in (1.0 mm).
- The residual horizontal deflection between ends following removal of the maximum load does not exceed 0.04 in (1.0 mm).
- Indicated residual strains at strain gauges on principal structural elements following removal of the maximum loading do not exceed the maximum error resulting from the accuracy of the instrumentation.
- There are no permanent deformations, fractures, cracks, or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and Sound Transit to determine if the failure is the result of weld quality or stress.
- The flatness and straightness of structural members meet the requirements of Section 3.

### 16.2.13.8 Compression Load Test at the Coupler

#### 16.2.13.8.1 Test Description

The ability of the car body structure to resist the coupler compression loads specified in Section 3 shall be tested.

During the compression test, the car shell shall be supported on trucks or a simulation thereof to allow free longitudinal movement. The car shell shall be tested at AW0 condition or loaded with sufficient dead weight to bring the total body weight (of test specimen) up to AW4 loaded car, whichever the stress analysis indicated was worst case. This loading shall be distributed in proportion to the distribution of weight in the finished car.

The test load shall be applied to the coupler fixation base plate in the end underframe with a hydraulic ram and applied longitudinally at the vertical centerline of draft.

The compression test load shall be applied by means of a controlled hydraulic ram, and the force measured by a means independent of those producing the force. Cushioning means, such as lead sheets, shall be provided to ensure uniform bearing. The test load shall be applied horizontally on the car longitudinal centerline. The load shall be applied in increments of 25, 50, 75, 87.5, and 100% of full load. After each load increment is applied, the load shall be reduced to not more than 2% of full load. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. The ram shall be supported at the car end but shall remain free to move longitudinally with respect to the car end.

### 16.2.13.8.2 Test Criteria

The car will be compliant with the Specifications if all of the following are met:

- Stresses are in accordance with the requirements of Section 3.
- The vertical deflection of each side of the test structure shall be within +/-10% of the value determined by the analysis.
- Vertical deflection readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- Strain readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point, which represents the measured deflection, at maximum load.
- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.
- Recorded residual vertical deflection between bolsters following removal of the maximum test load does not exceed 0.04 in (1.0 mm).
- The residual horizontal deflection between ends following removal of the maximum load does not exceed 0.04 in (1.0 mm).
- Indicated residual strains at strain gauges on principal structural elements following removal of the maximum loading do not exceed the maximum error resulting from the accuracy of the instrumentation.
- There are no permanent deformations, fractures, cracks, or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and Sound Transit to determine if the failure is the result of weld quality or stress.
- The flatness and straightness of structural members meet the requirements of Section 3.

### 16.2.13.9 Collision and Corner Post Load Tests

The ability of the car to resist the collision and corner post loads shall be tested, see Section 3. These tests shall be conducted in two parts. The first part shall be tests that have a pass-fail criterion equal to or less than permanent deformation (elastic tests). These tests shall be performed on the same test specimen with the same instrumentation as used for the car body compression and vertical load tests. The second part shall be a test of the collision post loaded at 15 in (380 mm) above the floor, sufficient to cause permanent deformation (elastic-plastic test). The second part will require the construction of a model of the front end of the car up to the bolster. The model shall be a duplication of all structure that supports or influences the support of the post(s).

### **16.2.13.9.1 Collision Post Elastic Load Tests**

#### **16.2.13.9.1.1 Test Description**

The ability of the car body structure to resist the collision post longitudinal loads specified in Section 3 shall be tested.

During the collision post test, the car shell shall be supported on trucks or a simulation thereof to allow free longitudinal movement. The car shell shall be loaded with sufficient dead weight to bring the total body weight (of test specimen) up to that of an AW0 loaded car body. This loading shall be distributed in proportion to the distribution of weight in the finished car.

A longitudinal test load as specified in Section 3 shall be applied to the collision post at an elevation of 15 in (381 mm) above the top of the underframe. This load shall be distributed over an area not to exceed the width of the primary center collision post by 4 in (102 mm) in height.

The test load shall be applied by means of a controlled hydraulic ram, and the force measured by a means independent of that producing the force. A fixture and cushioning means, such as lead sheets, shall be provided to ensure uniform bearing and prevent crippling around the area of force application. This fixture and cushion shall not be attached to the post. The test load shall be applied horizontally parallel to the car longitudinal centerline. The load shall be applied in increments of 25, 50, 75, 87.5 and 100% of full load. The load shall be reduced to not more than 2% of full load after each step. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. The ram shall be supported at the car end but shall remain free to move longitudinally with respect to the car end.

#### **16.2.13.9.1.2 Test Criteria**

The car will be compliant with the Specifications if all of the following are met:

- Deflection readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- Strain readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- The deflection of each post shall be within +/-10% of the value determined by the analysis.
- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.
- Indicated residual strains at strain gauges on principal structural elements following removal of the maximum loading do not exceed the maximum error resulting from the accuracy of the instrumentation.

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- There is no permanent deformation, fractures, cracks, or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and Sound Transit to determine whether the failure is the result of weld quality or stress.
- The flatness and straightness of structural members meet the requirements of Section 3.

### 16.2.13.9.2 Corner Post Elastic Load Tests

#### 16.2.13.9.2.1 Test Description

The ability of the car body structure to resist the corner post longitudinal compressive loads specified in Section 3 shall be tested.

During the primary side collision post longitudinal test, the car shell shall be supported on trucks or a simulation thereof to allow free longitudinal movement. The car shell shall be loaded with sufficient dead weight to bring the total body weight (of test specimen) up to that of an AW0 loaded car body. This loading shall be distributed in proportion to the distribution of weight in the finished car.

A longitudinal test load as specified in Section 3 shall be applied to the corner post at an elevation of 15 in (381 mm) above the top of the underframe. This load shall be distributed over an area not to exceed the width of the primary side collision post by 4 in (102 mm) in height.

The test load shall be applied by means of a controlled hydraulic ram, and the force measured by a means independent of that producing the force. A fixture and cushioning means, such as lead sheets, shall be provided to ensure uniform bearing and prevent crippling around the area of force application. This fixture and cushion shall not be attached to the post. The test load shall be applied horizontally parallel to the car longitudinal centerline. The load shall be applied in increments of 25, 50, 75, 87.5 and 100% of full load. The load shall be reduced to not more than 2% of full load after each step. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. The ram shall be supported at the car end but shall remain free to move longitudinally with respect to the car end.

#### 16.2.13.9.2.2 Test Criteria

The car will be compliant with the Specifications if all of the following are met:

- Deflection readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- Strain readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- The deflection of each post shall be within a +/-10% of the value determined by the analysis.

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- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.
- Indicated residual strains at strain gauges on principal structural elements following removal of the maximum loading do not exceed the maximum error resulting from the accuracy of the instrumentation.
- There is no permanent deformation, fractures, cracks, or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and the Sound Transit to determine whether the failure is the result of weld quality or stress.
- The flatness and straightness of structural members meet the requirements of Section 3.

### 16.2.13.9.3 Corner Post Transverse Load Test

#### 16.2.13.9.3.1 Test Description

The ability of the car body structure to resist the corner post transverse loads specified in Section 3 shall be tested.

During the corner post test, the car shell shall be supported on trucks or a simulation thereof. Transverse restraining apparatus may be attached to the car body bolsters. The car shell shall be loaded with sufficient dead weight to bring the total body weight (of test specimen) up to that of an AW0 loaded car body. This loading shall be distributed in proportion to the distribution of weight in the finished car.

A transverse test load as specified in Section 3 shall be applied to the corner post at an elevation of 15 in (381 mm) above the top of the underframe. This load shall be distributed over an area not to exceed the width of the primary side collision post by 4 in (102 mm) in height.

The test load shall be applied by means of a controlled hydraulic ram, and the force measured by a means independent of that producing the force. A fixture and cushioning means, such as lead sheets, shall be provided to ensure uniform bearing and prevent crippling around the area of force application. This fixture and cushion shall not be attached to the post. The test load shall be applied horizontally perpendicular to the car longitudinal centerline. The load shall be applied in increments of 25, 50, 75, 87.5 and 100% of full load. The load shall be reduced to not more than 2% of full load after each step. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. The ram shall be supported at the car end but shall remain free to move longitudinally with respect to the car end.

#### 16.2.13.9.3.2 Test Criteria

The car will be compliant with the Specifications if all of the following are met:

- Deflection readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.

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- Strain readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- The deflection of each post shall be within a +/-10% of the value determined by the analysis.
- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.
- Indicated residual strains at strain gauges on principal structural elements following removal of the maximum loading do not exceed the maximum error resulting from the accuracy of the instrumentation.
- There is no permanent deformation, fractures, cracks, or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and Sound Transit to determine whether the failure is the result of weld quality or stress.
- The flatness and straightness of structural members meet the requirements of Section 3.

### 16.2.13.10 Diagonal Jacking Test

#### 16.2.13.10.1 Test Description

The car shell shall be loaded to its AW0 weight, with all trucks (or an equivalent weight) hanging from the body bolsters. The car shell shall be supported symmetrically at the minimum number and placement of jack pads necessary to support the car safely. The jack in the position that, when lowered, subjects the car body structure to worst-case diagonal loading, shall then be lowered in five equal increments until the load on the jack is 10% of its original value. All gauges shall be recorded at each increment of jack position. The procedure shall be reversed until the load on the jack is returned to its original level.

The test described in the prior paragraph shall be repeated using the car jack socket adapters.

#### 16.2.13.10.2 Test Criteria

The car will be compliant with the Specifications if all of the following are met:

- Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to the start of the test program as part of the stress analysis.
- Strain readings plotted against load do not vary by more than +/-5% from a straight line (linear) deflection curve, with one end point at the origin (no load) and the other at the point which represents the measured deflection at maximum load.
- The vertical deflection of each side of the test structure shall be within +/-10% of the value determined by the analysis.

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- Indicated residual strains at strain gauges following return to original level do not exceed the maximum error resulting from the accuracy of the instrumentation.
- There shall be no permanent deformation, fractures, cracks or separations in the car structure. Broken welds and bonds shall be jointly inspected by the Contractor and Sound Transit to determine whether the failure is the result of weld quality or stress.
- The flatness and straightness of structural members do not exceed the requirements of Section 3.

### 16.2.13.11 Structural Changes

Any structural changes or modifications made during any test or during construction and assembly shall be subjected to the entire test series. All cars constructed prior to and subsequent to the tests shall incorporate such structural changes or modifications. The additional tests and the modifications shall be at the expense of the Contractor.

### 16.2.13.12 Car Body Structural Test Report

The Contractor shall prepare and submit a final test report within 30 days after successful completion of the structural tests. (CDRL 16-31) Approval of the test report constitutes acceptance of the car structural tests. The test report shall include:

- A table of contents;
- The test procedure (with all its appendices);
- A narrative describing the conduct of the test;
- Tables showing stresses and deflections that were 80% or more of the allowable;
- Description and explanation of any value that exceeded the test criteria;
- Appendices containing all data, i.e., output from each gauge for each load step. These data shall be clearly identified and include the date that they were recorded;
- The record photographs shall be mounted on pages the same size as the report pages;
- Side sill deflection curves for each load step;
- Stress (or strain) vs. load curves for the 10 greatest tension stress locations and the 10 greatest compressive stress locations for each test series; and
- Tables comparing the strain/stresses computed in the analyses with strains measured/stresses computed from the strain gauge readings for each test. These tables shall be annotated to explain differences between the predicted and test values.
- Instrumentation and gauges calibration certificates.

### **16.2.13.13 Crush Energy Tests**

#### **16.2.13.13.1 Elemental Energy Tests**

A series of crush tests shall be performed. These tests shall measure the force required to compress (crush) a structural energy absorber element a measured distance in order to develop a force-displacement curve for every such element in accordance with Section 3. The performance of structural members that are specifically designed not to interfere with the operation of energy absorbing elements shall also be verified by test.

Test specimens shall be manufactured in the same manner as the part to be used on the car. Each shall have a grid pattern appropriate to the specimen size marked over its entire surface. The specimen and associated test fixture shall be mounted in a calibrated test machine.

The specimen shall be dynamically compressed (crushed). The force and deflection shall be continuously recorded (plotted) during the test. At the same time, the test shall be recorded on two color video cameras. The cameras shall be situated to best show the crushing of the specimen. One of the cameras shall be set up to show the force-deflection plot and the specimen in the same frame. All tests shall be witnessed by a representative of Sound Transit.

Prior to testing, a test procedure shall be submitted for approval. (Procedure: CDRL 16-32) The procedure shall include a description of the test, test specimens, and test apparatus; the purpose of the test; location of video cameras; and complete descriptions of all instruments, gauges and data acquisition system. Drawing(s) showing the specimen with grid pattern, the fixtures, the attachment of the specimen to the fixture, and test apparatus shall be included. The procedure shall be a step-by-step instruction describing how the load is applied, and how it is recorded. The procedure shall contain detailed steps, calculations and tables for the correlation of analysis results with test results. The test procedures shall be submitted not less than 90 days in advance of the scheduled test date. Procedure approval shall be required prior to commencement of the test.

A test report shall be submitted for approval. (Report: CDRL 16-33) It shall contain the raw data as well as reduced data. It shall include the force-deflection curves and photographs of the specimens before, during and after the tests and current calibration certificates for all test equipment used during the test.

A copy of all the videos in MPEG-4 format or as approved by Sound Transit and NTSC (North America) compatible shall be included with the original report. The report shall contain correlation of test and analysis data. Approval of the energy absorption analysis report will depend on the approval of the crush energy test report.

#### **16.2.13.13.2 Car Body Energy Test**

Full-scale crash testing of a car end shall be performed to validate the analysis model. The crash test is to be conducted at 20 mph (32 km/h). If the Contractor can establish the accuracy of its crashworthiness analysis from prior programs where a test was performed and the results were in substantial agreement with the analysis, waiver of this test will be considered. It must be shown

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that the analysis model used previously and the model to be used for the program are substantially the same.

The purpose of the test is to show that the car body meets the requirements of Section 3, and to verify the crashworthiness analyses also specified in Section 3.

The test procedure will follow the format as required by this Section. The procedure shall be developed by the Contractor and approved by Sound Transit. (CDRL 16-34)

The test report shall meet the requirements of this Section. (CDRL 16-35)

### **16.2.14 Collision Post Elastic-Plastic Test**

The ability of the connections between the collision post and the car body structure to withstand a longitudinal load equal to the ultimate load carrying capacity of the post as specified in Section 3 shall be tested, at the option of Sound Transit (see SP-10). (Procedure: CDRL 16-38) (Report: CDRL 16-39)

The test specimen shall be a full-scale structural model of a cab end of a car. The structural model shall contain all structural elements required to support the primary center collision posts including the end underframe and roof extending from the forward end of the end frame to the bolster. All connections shall be the same as on production cars. The bolster end of the model shall be attached to a rigid fixture so that the stresses in the post and its supporting structure will be the same as it would be in a car subjected to the same load.

The specimen shall be instrumented as required for the car and collision post in this Section. The strain gauges and deflection gauges shall be installed in the same locations so that the structural equivalence of the model to the car body can be resolved.

The longitudinal test load shall be applied to the collision post at an elevation of 15 in (381 mm) above the top of the underframe. This load shall be distributed over an area not to exceed the width of the primary center collision by 4 in (102 mm) in height.

The compression test load shall be applied by means of a controlled hydraulic ram, and the force measured by a means independent of that producing the force. The reaction force at the rigid fixture behind the bolster shall also be measured. A fixture and cushioning means, such as lead sheets, shall be provided to ensure uniform bearing and prevent crippling around the area of force application. This fixture and cushion shall not be attached to the post. The test load shall be applied horizontally parallel to the car longitudinal centerline. The fixture must be designed so that it continues to apply the load in the horizontal direction as the post deflects. The initial load shall be applied in increments of the same magnitude as those used during the primary center collision post elastic load test (refer to this Section). The load shall be reduced to not more than 2% of full load after each step. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load.

The strain gauge readings and deflections measured during this test shall be within 5% of the gauge readings for the same load and location measured during the primary center collision post

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elastic test, (refer to this Section). If difference exceeds 5%, the fixture and/or the model will be corrected until 5% agreement between the two tests is obtained.

After agreement between the two tests is demonstrated, the collision post shall continue to be loaded in increments of 25% of the full load specified in the primary center collision post longitudinal load test until the load carrying capacity of the collision post is obtained. Alternately, steps may be determined according to post deflection measurements. At each 25% load increment (deflection increment), all load cell(s), strain gauges, and deflection gauges shall be recorded. The load need not be relaxed at each step.

The ultimate load carrying capacity of the post is defined as the condition where the post cannot support an increased load and the center of the post has deflected more than its full depth. This deflection is measured at the middle of the post from a line connected between the top and bottom of the beam.

### **16.2.14.1 Test Criteria**

The collision post will be compliant with the Specifications if all of the following are met:

- All strain gauges and deflection gauges have the same readings for the same loads at the same locations as the primary center collision post elastic load test for 0 to 100% of the elastic loads specified in Section 3.
- The connections between the primary center collision post and all other structural members are not broken before the ultimate carrying capacity of the post, as defined above, is reached.

### **16.2.15 Floor and Roof Fire Endurance Tests**

The Contractor shall perform fire endurance tests of the floor and roof.

#### **16.2.15.1 Floor Assembly Testing Requirements**

Refer to Section 17.

#### **16.2.15.2 Roof Assembly Testing Requirements**

Refer to Section 17.

**16.2.16 FRP Side Skin Tests – This section has been removed from the Specifications.**

## **16.3 System Qualification Tests**

Systems to be supplied shall be given a qualification test unless the Contractor can meet the requirements of this Section for relief from such tests. The following system qualification tests shall be performed by the Contractor, or under its direction, to demonstrate conformance to the requirements of the Specifications.

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The tests shall be performed using actual equipment approved by Sound Transit for use on the LRVs procured under this Contract.

### **16.3.1 Communication, Passenger Information, CCTV, GPS and APC Systems**

All Contractor supplied components of the vehicle communications, passenger information, closed circuit television (CCTV), global positioning system (GPS) and automatic passenger counting (APC) system shall be tested to verify compliance with Section 13. (Procedure: CDRL 16-40) (Report: CDRL 16-41)

### **16.3.2 Propulsion System**

A laboratory test shall be conducted on one car set of propulsion equipment, including motors, drive gear, braking resistors, power conditioning, protection devices, logic, controls, and master controller, using a computer-controlled dynamometer which can simulate actual vehicle and passenger loads, train resistances, and the actual ST alignment and operating schedules. Testing shall mimic the conditions defined in Section 2, at worst case ambient temperatures. The test shall verify adequate thermal capacity while operating on ST's alignments, including towing, and system response times and linearity. Temperatures of motors, power electronics, brake resistors, gear drive oil, and other critical system components shall be recorded. The propulsion equipment shall be instrumented to verify that no leakage current is flowing along or through the drive train components (e.g. motor bearings, gear units) from the traction motor to ground. Testing shall use equipment procured under this Contract and shall be conducted in the specified voltage range specified in Section 2.

This set of propulsion equipment shall also be tested for electromagnetic emissions, conductive and inductive, according to the methods referenced in Section 2. (Procedure: CDRL 16-42) (Report: CDRL 16-43)

### **16.3.3 Friction Brake System**

The friction brake system qualification testing shall include the following tests on one of the first three production systems or system components as appropriate. (Procedure: CDRL 16-44) (Report: CDRL 16-45)

#### **16.3.3.1 Response**

The friction brake system shall be tested to determine conformance to the specified requirements for output force, time, and magnitude response to all control inputs. Stability of response shall also be demonstrated.

The friction brake response shall be recorded both in apply and release mode. Graphs showing the hysteresis of the friction brake system shall be generated.

#### **16.3.3.2 Linearity**

A set of dynamometer test runs shall be made with a friction brake system, to determine conformance to Specification requirements for accuracy and time response. Test runs shall be

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made corresponding to car loadings of AW0, AW2, and AW3, with entry speeds of 10, 20, 30, 40, 50, and 55 mph (16, 32, 48, 64, 80, and 89 km/h), for each load condition. For each entry speed, input signals calling for 25, 50, 75, and 100% of full service braking effort, and emergency braking effort shall be used. All tests shall be run with brake discs initially at ambient temperature and also with hot discs. "Hot" disc temperature is defined as being between the maximum and minimum cooled disc temperature between station stops of the specified duty cycle for the Brake System Capacity Test, as developed during that test.

Results shall be plotted to show both the instantaneous and average relationship between input signals and output braking effort over the speed and weight ranges for both motor and trailer trucks.

### **16.3.3.3 Brake System Capacity**

A brake disc of each type shall be tested on a dynamometer or flywheel to verify the brake system capacity with brake disc initially at ambient temperature and also hot (as defined in this Section). The test shall be run using the friction brake duty cycle specified in Section 12. The disc and pad surface temperatures shall be measured and recorded throughout the test and shall not exceed the design limit determined by the disc or brake pad manufacturer for normal duty cycle and for failed dynamic brake duty cycle. At the completion of this test the brake unit shall remain in an undamaged, fully operable condition. Production disc, actuator and pads shall be used for this test.

### **16.3.3.4 Pressure**

All hydraulic brake system components shall be tested at 200% of the maximum system pressure. No component damage or leakage shall occur.

An accumulator shall be demonstrated to withstand a minimum burst pressure of 10,000 lbf/in<sup>2</sup> (69 MPa) or four times the maximum hydraulic system pressure, whichever is less.

### **16.3.3.5 Brake System Endurance Test**

A complete friction brake system including the electronic control unit shall be subjected to an endurance test of 1.5 million cycles of normal apply and release applications. The test shall include a range of pressures, including 0%, 10%, and 90% of normal maximum pressures. Brake reaction forces shall be simulated on the actuators. Slack adjuster operation shall be simulated by shim removal or other approved method. Failures which occur shall be within the specified reliability values.

### **16.3.3.6 Brake System Environmental Test**

A complete car set of friction brake equipment including the electronic control units and hydraulic pressure supply system shall be subjected to an environmental test as described in this Section. If it is impractical to test a complete system at once, duplicate parts of the system may be simulated, with the requirement that at least one representative assembly of each type is subject to the test conditions.

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The environmental test shall be conducted over the temperature range specified in Section 2 and the humidity range found in the Seattle metropolitan region. The test shall consist of cycling the temperature and humidity that the equipment is exposed to between the minimum and maximum temperature and humidity conditions according to the following test schedule while recording performance parameters for the equipment at minimum, nominal, and maximum vehicle power supply voltages for the system.

The test schedule shall start with an overnight (8 h minimum) soak at the minimum temperature with the power off. The equipment shall then be turned on. While continuously being operated the equipment shall be subjected to 8 temperature and humidity cycles between minimum and maximum with each cycle to last 12 h, including holding at the minimum and maximum temperatures for at least 1 h each during each cycle.

No system or component failure or leakage shall occur.

### **16.3.4 Door System**

Door, door operator, control, and sensitive edge design qualification tests shall include an accelerated life test of 1.5 million cycles for one complete set of door hardware. These tests shall be completed before the first car is ready for final assembly. The test fixture used shall accurately represent the actual car body and installation. (Procedure: CDRL 16-46) (Report: CDRL 16-47)

Failures recorded during testing must correlate within reliability values specified in Section 2. Failures in this context shall mean any instance where repair or adjustment is required to maintain compliance with specified requirements. If any redesign is required to provide Specification compliance, the test shall be rerun from the beginning at the Contractor's expense.

Door tests verifying speed, noise, wind load, and loading requirements shall be performed at the beginning, mid-point, and end of the life test for comparative evaluation. Door testing shall include the effects of wind and ventilation system car body pressurization. Wind loads shall include a 50 mph (80 km/h) wind oriented at 90 degrees to the side of the vehicle. Effects of ambient temperature extremes shall be evaluated during the vehicle climate room tests.

### **16.3.5 Unitized HVAC System**

#### **16.3.5.1 General Requirements**

One air conditioning unit complete with all controls shall be given a dual chamber climate room test by the manufacturer to verify the capacity and functioning of heating, ventilation and air conditioning system according to the requirements of Section 7. This test shall be successfully completed prior to the vehicle climate room tests required by this Section. (Procedure: CDRL 16-48) (Report: CDRL 16-49)

Appropriate test log sheets and calculation forms shall be generated and included with the Qualification Test Procedure which shall become a part of the Qualification Test Report.

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Equipment qualification testing shall be conducted at nominal supply and control voltages except where otherwise specified.

### **16.3.5.2 Test Methods and Standards**

The air-conditioning equipment test setup shall be in accordance with ANSI/ASHRAE Standard 37. However, HVAC unit return and outside air flows shall be balanced as required by design, and fresh air inlets shall be open during the test, to simulate the realistic operating conditions and to verify adequate mixture of the outside and return air streams.

The HVAC unit shall meet the watertightness requirements of the Watertightness Tests section, below.

Sound and vibrations levels shall be tested to ensure conformance with the sound and vibration requirements of Section 2, and sound shall meet the recommendations of AMCA Standard 300.

In the event of conflict between the referenced standards and the Specifications, the Specifications shall govern.

### **16.3.5.3 Instrumentation**

The accuracy and tolerances of all instrumentation and tests shall comply with Sections 5 and 9 and Table 2 of ANSI/ASHRAE Standard 37. All temperature measurements and measurement techniques shall comply with ANSI/ASHRAE Standard 41.1.

Proof of the calibration of all instruments, traceable to a master at the national standards organization of the applicable country, shall be submitted to Sound Transit for approval prior to testing.

All data (temperature, pressure, voltage, current, speed, and event) shall be continuously recorded during all tests by a data acquisition system meeting the requirements listed below, and using appropriate transducers.

All test data shall be recorded by a computer based data acquisition system with sufficient input channels to record the required data. If multiple recorders are necessary to obtain the required number of channels then they shall be time synchronized. The data sampling rate shall be adjustable, with the minimum time being not more than one sample per second. Each sample shall be time and date stamped. Real time display of test data and trending shall be possible. Real time calculation and display of information such as the average of several channels, difference between selected channels, or minimum and maximum of a group shall be possible. All real time display data and recorded data shall be in engineering units, and if possible shall be selectable between I-P and SI units. Recorded data shall be capable of export to normally available spreadsheet programs such as MS Excel.

The data acquisition system shall be capable of recording both analog data streams and digital (on/off) events. It is preferred that digital events be recorded on an interrupt basis.

#### 16.3.5.4 Data Requirements

All data recordings shall be conducted according to ANSI/ASHRAE Standard 37. The data listed below shall be the minimum recorded by the Contractor during the testing.

- Temperatures:
  - Unit mixed air inlet - °F DB and °F WB
  - Unit air outlet - °F DB and °F WB
  - Condenser air inlet - °F DB (and °F WB if required)
  - Condenser air outlet - °F DB (and °F WB if required)
  - Air next to High Limit Switch -°F DB
  - Air next to backup protection device - °F DB
  - Discharge at compressor (12 in (300 mm) away from compressor) - °F DB
  - Suction at compressor (12 in (300 mm) away from compressor) - °F DB
  - Liquid leaving condenser - °F DB
  - Condenser liquid at TXV - each circuit -°F DB
  - Suction at evaporator - each circuit -°F DB
  - Compressor crankcase oil - °F DB
  - Condenser fan motor windings - two at each motor end
  - Evaporator blower motor windings - two at each motor end
  - Air adjacent to the High Limit Switch
  - Air adjacent to the Shunt Trip Circuit Breaker Activating Device

Note: All refrigeration system thermocouples shall be soldered to a metal surface and insulated.

- Pressures, lbf/in<sup>2</sup> (kPa):
  - Discharge at compressor
  - Suction at compressor
  - Liquid leaving condenser
  - Liquid entering evaporator coil – each circuit
  - Suction at evaporator - each circuit
- Air Flows, ft<sup>3</sup>/min (m<sup>3</sup>/h)
  - Discharge at compressor
  - Evaporator coil
  - Condenser coil(s)
- Pressures, inch of water (mm of water)
  - Evaporator fan total or evaporator fan static
  - Air supply plenum - static
  - Evaporator coil air pressure drop
  - Static pressure difference across nozzle inside air tunnel
  - Condenser coil pressure drop
- Barometric pressure, inch of mercury (kPa)

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- Electrical - Compressor, Condenser and Evaporator motors and heater section separately and the unit as a whole
  - Volts - each phase for ac loads
  - Amps - each phase for ac loads
  - Watts
  - RPM (all motors) (Indirect measurements must be approved by Sound Transit)
  - Power factor (ac loads)
- Event Recorder inputs shall be used for the operation of the following components:
  - Compressor
  - Condenser fans
  - Evaporator blower
  - Solenoid valve - main liquid line
  - Solenoid valve - modulation
  - Overhead heat
  - High limit switch
  - Back-up Protection Activating Device
  - High Pressure Switch
  - Low Pressure Switch
- Miscellaneous
  - Refrigerant oil flow rate or verification of the return of the oil to the compressor (if required) – ft<sup>3</sup>/min (l/s)
  - Ratio of refrigerant in refrigerant-oil mixture (if required) - ft<sup>3</sup>/ft<sup>3</sup> (m<sup>3</sup>/m<sup>3</sup>)

### 16.3.5.5 Test Requirements

#### 16.3.5.5.1 Scan Test

The temperature control components shall be exposed to the temperature environments they will experience on the car. All points of temperature control shall be verified on temperature rising and temperature falling. The temperature of applied load, as appropriate for the control system shall be varied as slow as necessary for the proper recording of the temperatures during equipment operating events.

The simulated vehicle interior and ambient temperatures shall be cycled up and down through the operating range of the temperature sensors. A data acquisition system independent of the HVAC unit PTU shall be used to verify the operation of the contactors and equipment, as well as the feedback on the PTU.

Any malfunction of the system or components at any temperature shall constitute a failure of the test. The use of test switches to control the unit independent of the temperature sensors is not permitted.

#### **16.3.5.5.2 Control Stability Test**

Under steady state operation at design conditions, the power and control voltages shall be varied between the limits allowed by Section 2 to show the effect of such change. The system shall be shut down and restarted while the power and control voltages are at their minimum values.

#### **16.3.5.5.3 Cooling Capacity**

Cooling capacity shall be verified at the design conditions listed in Section 7, following the procedure of ANSI/ASHRAE Standard 37. In addition to test "A", one of the secondary applicable test methods "B" shall be selected by the manufacturer from Table 1 of the Standard.

#### **16.3.5.5.4 Maximum Operating Conditions**

A system functional test shall be performed at ambient condition C of Section 7 and recirculated air to evaporator at 75°F DB (24°C DB) and 55% RH.

A successful test shall consist of continuous operation of the system at these conditions for 1 h without shutdown due to high pressure, modulation, circuit breaker trip, compressor motor overload, or any device failure. A shutdown for any reason while operating at these conditions shall constitute a failure of the test. All data shall be recorded every 5 min during the steady state of operation.

#### **16.3.5.5.5 Extreme Ambient Operating Conditions**

A system functional test shall be performed at ambient condition D of Section 7 and recirculated air to evaporator at 85°F DB (29.5°C DB) and 67°F DB (19.5°C DB).

A successful test shall consist of continuous operation of the system at these conditions for 1 h without shutdown due to high pressure, modulation, circuit breaker trip, compressor motor overload, or any device failure. A shutdown for any reason while operating at these conditions shall constitute a failure of the test. All data shall be recorded every 5 min during the steady state of operation.

At the end of 1 h of operation, the system shall be momentarily stopped and then restarted. The system shall continue to function properly with all components safe from malfunction. There is no capacity to be met. This test shall be conducted at nominal supply voltage.

Following this test, the condenser/fresh air ambient shall be slowly raised to the point when the high pressure cutoff transducer or switch activates and shuts off the system. Record pressures and temperatures of the pressure switch cutoff and reset conditions.

#### **16.3.5.5.6 Modulation Pressure Test**

A test with air entering the condenser higher than 104°F (40°C) DB, and at the evaporator air mixture based on the conditions of this Section shall be used to demonstrate pressure modulation capability. As the condenser outlet air dry bulb temperature rises, pressures and temperatures

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shall be recorded and the system shall be allowed to cycle by the high pressure transducer. All system pressures and temperatures shall be recorded.

A successful test shall consist of 1 h of continuous operation of the system without shutdown due to high pressure, cutoff, circuit breaker tripping, compressor motor overload, or any device malfunction.

### **16.3.5.5.7 Low Temperature Operation Test**

A low temperature operation test shall be conducted at a minimum recirculated air dry bulb temperature to ensure a partial cooling operation, with no reheat, 50 percent RH, and ambient conditions 2°F (1 K) higher than the condition E of Section 7. After attainment of the specified temperature conditions, the unit shall be operated continuously for a period of 4 h at partial cooling. During the test, the unitized air cooling system shall operate without damage to the equipment and without the formation of any ice or frost on the evaporator coil or piping. Proper oil return to the compressor shall be verified during the test. The compressor oil sight glass (if equipped) shall be monitored, either by direct observation, or by video camera if direct observation is not possible with the unit operating. The data shall be recorded every 10 min during steady state operation.

### **16.3.5.5.8 Insulation Efficiency and Condensate Carry-Over Test**

The unit insulation efficiency shall be tested with ambient and evaporator entering air temperature at 80°F DB (27°C DB) 75°F WB (24°C WB). The unit shall be tilted in lateral and longitudinal planes to simulate the maximum required grade and superelevation/roll, and shall be operated continuously for a period of 4 h at the specified conditions. During the test, no condensed water shall drop, run, or blow off the unit's casing.

All condensation from the evaporator coil shall be retained inside the drain pan. No condensate shall spill from the drain pan.

A miniature video camera and cold light source shall be installed in the evaporator compartment for this test. The camera shall allow observation of condensate carryover, should there be any.

### **16.3.5.5.9 Refrigerant Sample Test**

A sample of refrigerant shall be taken from the air-conditioning system of the tested unit and analyzed for contaminants by an approved laboratory. Test results shall satisfy the requirements of AHRI Standard 700, except moisture content shall not exceed 30 ppm and boiling residue shall not exceed 5%.

### **16.3.5.5.10 Watertightness and Water Eliminator Test**

The HVAC equipment system shall be watertightness tested as specified in the Watertightness Test section, below, in the Car Level Qualification Tests section. The testing shall be conducted without power to the unit (blowers inoperative) and with power to the unit (blowers functioning). Water eliminator performance shall conform to the requirements of Section 7.

#### **16.3.5.5.11 Noise Test**

The HVAC equipment shall be noise tested to determine conformance to the requirements of Section 2.

#### **16.3.5.5.12 Abnormal Heating Condition, Restricted Air**

During this test, the ambient temperature shall be maintained at approximately 70°F (21°C) with the system heaters activated independent of the thermostat and with the air conditioning compressor not operating, and with the air flow switch bypassed. The test shall be conducted by slowly restricting the mixed air inlet so that heater unit temperature rises 2°F/min (1 K/min), but not faster, until the high limit switch cycles off. The restriction shall be eased to the point where the high limit switch stays closed. The heating test shall continue, to simulate a dirty filter condition. The system shall operate until a steady condition is reached.

The test shall be performed at nominal, low, and high supply voltage specified limits. The test shall be successful when the following criteria are met:

- The back-up protection did not activate during the test;
- The temperature inside the unit did not cause damage to the equipment and components;
- There was an absence of any smoke and odors; and
- The high limit switch opened at the design set point +/-18°F (+/-10 K).

#### **16.3.5.5.13 Abnormal Heating Condition, with No Air**

The ambient temperature shall be maintained at approximately 70°F (21°C). The air conditioning compressor shall not be operating and the air flow switch shall be bypassed. Power shall be applied to the heaters with no air blowing over the heaters. The system shall be operated as the high limit switch cycles.

The criteria of this Section shall apply. Test shall be performed at nominal and high specified power voltage limits.

#### **16.3.5.5.14 Back-Up Protection Test**

The ambient temperature shall be maintained at approximately 70°F (21°C). The air conditioning compressor shall not be operating. Prior to power application to the heaters, the high limit switch and air flow switch shall be bypassed. The heaters shall be energized and the activation temperature of the back-up protection device shall be observed. The equipment interior temperatures shall be measured and recorded, at least once per min, from the start until all recorded temperatures start decreasing.

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The test shall be performed at nominal and high power supply voltage specified limits. The test shall be successful when the following criteria are met:

- The temperature inside the unit did not cause any damage to wiring, electrical components, motor, and unit insulation;
- There was an absence of any visible smoke; and
- There was an absence of any detectable odors.

### **16.3.5.5.15 Start-up Current Draw**

The start-up current draw profile (current versus time) characteristics of the unit shall be recorded under the following conditions:

- Design Cooling Conditions;
- Maximum Operating Cooling Conditions;
- Extreme Ambient Operating Conditions:

For these tests the data-sampling rate shall be no more than 10 ms.

### **16.3.6 Secondary Suspension System**

One set of secondary suspension equipment, including all associated sensors and controls shall be subject to qualification testing. The testing shall conform compliance system operation with the accuracy required Sections 2 and 11 over the temperature range specified in Section 2. Life cycle testing shall confirm that the equipment will function reliably over the life of the car. Testing may be combined with suitable parts of the truck testing specified in this Section. (Procedure: CDRL 16-50) (Report: CDRL 16-51)

### **16.3.7 Monitoring and Diagnostic System Integration Tests**

A laboratory test shall be conducted on the Monitoring and Diagnostics System (MDS) for one car set. The test shall consist of two parts.

Part 1 – Simulated MDS test. Desktop PC or a laptop and a test setup will simulate communication, battery level digital signals and necessary analog signals between vehicle systems and the MDS.

Part 2 – Integrated MDS test. Vehicle and vehicle systems' parts (i.e. Master Controller Group, Door Control Units, HVAC control, push-buttons and so on) and vehicle consist should be set up in the lab and connected to the MDS as close to the vehicle configuration as possible. The parts do not have to be production quality units. The Contractor and Sound Transit will finalize the laboratory set up after the vehicle equipment configuration is approved. Sound Transit may waive the requirements for the laboratory integrated MDS test if the Contractor demonstrates on one of its current vehicles the MDS functions requested in the Specifications. (Procedure CDRL 16-52) (Report CDRL 16-53)

### **16.3.8 AC Power Supply Integration Tests**

A laboratory test shall be conducted on one complete car set of Auxiliary Power supply with actual motor loads connected to a control panel that can simulate vehicle switching capabilities. The Contractor and Sound Transit will finalize the laboratory set up after the vehicle equipment configuration is approved. (Procedure CDRL 16-54) (Report CDRL 16-55)

### **16.3.9 Low-Voltage Power Supply Integration Tests**

A laboratory test shall be conducted on one complete car set of low-voltage power supply with simulated resistive, inductive and capacitive loads connected to a control panel that can simulate vehicle switching capabilities. The battery load shall be achieved with the battery selected for vehicle operation. The Contractor and Sound Transit will finalize the laboratory set up after the vehicle equipment configuration is approved. (Procedure CDRL 16-56) (Report CDRL 16-57)

### **16.3.10 Cab Signal Tests**

Cab Signal Qualification System tests shall verify the ATP functions and physical parameters necessary to ensure the safe operation of the system including but not limited to:

- Physical parameters of equipment and package;
- Lead cab selection ATP functions;
- Speed command decoding functions such as frequency sensitivities and adjustments, bandwidth characteristics, modulation sensitivity, and response times;
- Speed sensing, speedometer control, overspeed detection, and the overspeed scenario outputs and response times;
- Indication and control interfaces with vehicle cab panels and event recorder;
- Brake assurance equipment function and adjustment range. If pendulum method of detecting brakes is used, then tilting supports should be used;
- Receiver coil electrical characteristics and tolerances;
- Accelerometer test;
- Self-Diagnostic functions; and
- Cab signal unit power supply performance over full input voltage and current range and the capability of the other cab signal equipment to maintain tolerances throughout the voltage regulation range. Test short circuit protection. (Procedure CDRL 16-58) (Report CDRL 16-59)

## **16.4 Car Level Qualification Tests**

The following tests shall be conducted on the first vehicle and/or second vehicle constructed as required by Sound Transit. Sound Transit reserves the right to witness any portion or all of the

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tests required by this Section, and selection of the vehicles to be tested shall be approved by Sound Transit. The locations of the tests shall be agreed upon by Sound Transit.

### **16.4.1 Watertightness Test**

The fresh air and electric equipment ventilation intake ducts in the car roof shall be water tested with the ventilating fans running at full speed and with fans off, to determine the effectiveness of the water-excluding features of the duct work. At the conclusion of the test, there shall be no evidence of moisture in the ducts downstream of the water excluding features. (Procedure: CDRL 16-64) (Report: CDRL 16-65)

The watertightness test specified for all cars in this Section shall be performed on the first car as part of the vehicle qualification test.

Exterior equipment enclosures are required to be watertight. Enclosures shall receive a water test at the point of manufacture and after assembly to the LRV. During test of the boxes, the required spray is to be directed at the exposed sides, tops, cable glands/box, pneumatic, LRV interface points (i.e. HVAC to carbody, etc.) and ends of the boxes as would normally occur during car washing operations, heavy rain, or as a simulation of water spray from the wheels. At the conclusion of the test, there shall be no evidence of moisture in the underfloor or roof boxes.

### **16.4.2 Air Leakage**

To ensure a positive internal car body pressurization, the first car shall be given an air leak smoke bomb test with the interior pressurized to a minimum of 0.50 in of water (124 Pa). All openings related to ventilation shall be sealed during this test. All apparent leaks shall be corrected by the Contractor. (Procedure: CDRL 16-62) (Report: CDRL 16-63)

### **16.4.3 Door Operation**

Before shipment, the first two cars and two other cars, selected at random by Sound Transit, shall have all doors operated for 1,000 continuous trouble-free cycles. One of the four cars shall be loaded to AW4, uniformly distributed, for the cycle test. (Procedure: CDRL 16-64) (Report: CDRL 16-65)

Any door or door control failure occurring prior to completion of the test on each car will nullify the test, and the test shall be re-run completely after the fault has been corrected.

### **16.4.4 Vehicle Climate Room Test**

#### **16.4.4.1 General**

A complete climate room test shall be performed on the second car. The climate room test shall demonstrate the HVAC system's ability to comply with the temperature control and operational requirements of Section 7. Testing shall include a functional check of all apparatus including temperature sensors and controls, an air balance test, a pressurization test, and a temperature and relative humidity check to show compliance with the specified cooling requirements with all

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apparatus operating at nominal voltage except when specified otherwise. (Procedure: CDRL 16-66) (Report: CDRL 16-67)

The HVAC system shall be powered by the vehicle power systems, i.e., the auxiliary ac power supply and low voltage systems. During the air cooling tests, the following auxiliary ac power supply test points shall be monitored, recorded and incorporated into the test report:

- Input power;
- Output voltage per phase;
- Output current per phase;
- Output power; and
- Temperature of the most sensitive temperature critical component/components of the inverter, if used.

### 16.4.4.2 Test Facility Requirements

The climate room for the vehicle level HVAC testing shall be capable of achieving and maintaining any test temperature from 18°F (-7.8°C) DB to 115°F (46°C) DB and any relative humidity throughout that range between 25% and 90%. In addition the climate room facility shall be equipped to provide local elevated temperature for the full volume of condenser inlet air up to 125°F (52°C).

For the UA-Factor test the climate room shall be capable of simulating the effect of a wind wipe on the vehicle as required by the specified tests.

Temperature in the facility shall be uniform throughout. There shall be no more than 5°F (3°C) variation from 8 in (203 mm) above the running rail to 2 ft (610 mm) above the vehicle roof and from end to end of the vehicle. Fans may be used to circulate air. Passenger load shall be simulated by means of heaters and humidity generating equipment inside the vehicle. Solar and equipment loads shall be simulated by means of heaters inside the vehicle. Humidity introduced into the vehicle to simulate the latent heat load shall be carefully metered to ensure the accurate proportioning of sensible and latent design loads.

### 16.4.4.3 Instrumentation Requirements

- A proof of the calibration of all instruments, traceable to a master at the national standards organization of the applicable country, shall be submitted to Sound Transit, as part of the test procedure, for approval, prior to testing.
- Relative humidity of the vehicle interior and fresh air shall be measured with an approved motorized psychomotor at each return air grille and fresh air inlet.
- A minimum of 56 representative vehicle interior temperature locations, including the operating compartment, shall be provided, as agreed between the Contractor and Sound Transit.

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- Refrigerant pressure measurements shall be taken with one or more of the following instruments:
  - Bourdon tube gauge; or
  - Electronic pressure transducers.
- The accuracy of the refrigerant pressure measuring instruments shall permit measurements within  $\pm 2.0\%$  of value being measured. In no case shall the smallest scale division of pressure measuring instrument exceed 2-1/2 times the specified accuracy.
- Air pressure measurements shall be made with manometers, or approved equal, having an accuracy of  $\pm 0.01$  in of water (2.5 Pa).
- Electrical instruments used for measuring the electrical input to heaters shall be accurate to  $\pm 1.0\%$  of the quantity measured. Instruments used for measuring the electrical input to fan motors, compressor motors, or other equipment accessories shall be accurate to  $\pm 2.0\%$  of the quantity measured.
- Rotational speed measurements shall be made with either a revolution counter, tachometer or stroboscope having an accuracy of  $\pm 1.0\%$ .
- The air flow measurements shall be made with a "Flow Hood 8410", as manufactured by Shortridge Instrument Company or approved equal.
- An event recorder shall be used to monitor operation of relays and contactors.
- All data; i.e., temperatures, pressures, voltage, current, and speeds, shall be continuously recorded by an approved data acquisition system using appropriate transducers. The data acquisition system shall be capable of providing the graphical representation (strip chart) of the selected channels while test is in progress.
- For each of the specified steady state cooling and heating test requirements, all data shall be recorded every minute for 30 consecutive minutes in order to determine temperature variation as the air conditioning apparatus cycles.

### 16.4.4.4 Data Requirements

The following test data shall be taken during each test run. Only the pertinent data shall be selected and recorded which reflect the type of test in progress.

- Air Temperatures - °F
  - Return Air - °F DB and °F WB (9-point grid at return air grille)
  - Fresh Air - °F DB and °F WB (9-point grid)
  - Mixed Air - °F DB (9-point grid)
  - Air leaving evaporator °F DB (9-point grid)
  - Condenser inlet - °F DB (9-point grid)
  - Condenser outlet - °F DB (9-point grid)
  - Climate Room - °F DB and °F WB

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- High Limit Switch - °F DB
- Fusible Link - °F DB
- Vehicle interior: 56 thermocouples, minimum - °F DB
- Refrigerant System Temperatures - °F
  - Discharge at compressor (12 in (305 mm) away from compressor)
  - Suction at compressor (12 in (305 mm) away from compressor)
  - Liquid leaving condenser
  - Liquid at TXV #1
  - Liquid at TXV #2
  - Suction at evaporator #1
  - Suction at evaporator #2 (Modulation)
  - Compressor crankcase
- Refrigerant Pressures – lbf/in<sup>2</sup> gauge (MPa)
  - Discharge at compressor
  - Suction at compressor
  - Liquid leaving condenser
  - Liquid at TXV #1
  - Liquid at TXV #2
  - Suction at evaporator #1
  - Suction at evaporator #2 (Modulation)
- Air Pressures - Inches of Water (MPa)
  - Fan total or fan static pressure
  - Evaporator coil pressure drop
  - Air supply plenum
  - Condenser coil pressure drop
  - Vehicle pressurization
  - Cab pressurization
- Electrical Data
  - Input volts to HVAC units
  - Evaporator motor amps
  - Evaporator motor watts
  - Compressor motor amps
  - Compressor motor watts
  - Condenser motor amps
  - Condenser motor watts
  - Floor heat one (FH1) volts & amps
  - Floor heat two (FH2) volts & amps
  - Overhead heat one (OH1) volts & amps
  - Overhead heat two (OH2) volts & amps
  - Cab heater motor, volts & amps
  - Cab heater element, volts & amps

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- Event Data
  - Compressor operation
  - Solenoid Valve, SLV1 (Main Liquid Line)
  - Solenoid Valve, SLV2 (Modulation)
  - Floor Heat One (FH1)
  - Floor Heat Two (FH2)
  - Overhead Heat One (OH1) - Each end
  - Overhead Heat Two (OH2) - Each end
  - Duct Stat (OHDS)

### 16.4.4.5 Test Requirements

#### 16.4.4.5.1 Test Specimen

Prior to shipment to the climate room test facility, the HVAC system shall be given a complete production conformance test to verify the correct operation of all apparatus.

#### 16.4.4.5.2 Air Balance

Air balance shall be tested to confirm that it complies with the specified fresh air volume and vehicle pressurization requirements of Section 7. The cab air supply shall be also measured. The total measured return and fresh air volume of each system shall be within +/-10% of the total mixed air volume as measured by the equipment manufacturer during its Qualification Test. The outlet velocities at diffusers shall meet the requirements of Section 7.

Operation of the variable fresh air dampers, based on the passenger load shall be verified.

#### 16.4.4.5.3 Car Body Heat Transfer

Car body heat transfer tests (UA-Factor) shall be conducted to verify conformance with Section 7. Fresh air intakes shall be closed. The passenger and solar load simulating heaters shall be used during this test for calculating the UA-Factor. During the test, the overhead blowers may be used to equalize temperatures inside the vehicle.

#### 16.4.4.5.4 Scan Test

The climate room conditions shall be varied while the vehicle interior heat load is varied such that the thermostats operate the HVAC system through the full control range of cooling, heating, reheating, and ventilating modes of thermostat control.

All points of control shall be verified on temperature rising and temperature falling, including a demonstration of the pumpdown and/or bump-start, as applicable. The results of this test shall conform to the requirements of Section 7. A recording instrument shall register each event of automatic control. The test shall be conducted slowly to observe possible contactor chattering or short cycling, which shall be considered as being among the possible malfunctions. Any malfunction of the system components shall constitute a failure of the test.

#### **16.4.4.6 Cooling Test**

The cooling test sequence shall begin by "soaking" the vehicle at ambient condition B of Section 7 for at least 12 h. For the first 6 h, all passenger doors shall be open. The second 6-h "soak" time shall include simulated solar load and all passenger doors shall be closed. Vehicle instrumentation requirements and data requirements of this Section shall be met and the HVAC system shall be complete and functional.

##### **16.4.4.6.1 Pulldown Test with Solar Load**

That test shall be performed immediately after the 12-h soak at the ambient condition B of Section 7. After the air conditioning equipment is energized, record the length of time required to reach the design dry bulb control temperature, measured at the return air thermostat which shall meet the requirements of Section 7. The test shall be terminated when the vehicle interior temperatures become stabilized.

##### **16.4.4.6.2 Steady State without Passengers**

After the pulldown test and vehicle temperature stabilization, all data required shall be recorded. Interior vehicle temperatures, including temperature variations, shall meet the requirements of Section 7. If required, all necessary diffuser adjustments and air distribution corrections shall be made at this time.

##### **16.4.4.6.3 Steady State at Design Conditions**

This test shall be performed and ambient conditions A and B of Section 7. The specified heating loads of Section 7 shall be applied in this test. After system and temperature stabilization, all required data shall be recorded.

##### **16.4.4.6.4 Door Cycling**

Starting with steady state at design condition B of Section 7, a vehicle door cycling test shall be run to verify conformance to the door cycling temperature variation and restabilization requirements of Section 7.

##### **16.4.4.6.5 Steady State, Design Conditions, AW3 Passenger Load**

This test shall be performed at ambient condition B of Section 7. After system and temperature stabilization is obtained, record all data requirements during the system steady state of operation. The only criteria to be met are the temperature variation requirements of Section 7.

##### **16.4.4.6.6 Maximum Operating Conditions**

This test shall be performed at ambient condition C of Section 7 and with AW3 passenger load.

A successful test shall consist of continuous operation of the system at these conditions for 1 h without shutdown due to high pressure, modulation, circuit breaker trip, compressor motor overload, or any device failure. A shutdown for any reason while operating at these conditions

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shall constitute a failure of the test. All data shall be recorded every 5 min during the steady state of operation.

### **16.4.4.6.7 Extreme Ambient Operating Conditions**

This test shall be performed at ambient condition D of Section 7 and with AW3 passenger load.

A successful test shall consist of continuous operation of the system at these conditions for 1 h without shutdown due to high pressure, modulation, circuit breaker trip, compressor motor overload, or any device failure. A shutdown for any reason while operating at these conditions shall constitute a failure of the test. All data shall be recorded every 5 min during the steady state of operation.

At the end of 1 h of operation, the system shall be momentarily stopped and then restarted. The system shall continue to function properly with all components safe from malfunction. There is no capacity to be met. This test shall be conducted at nominal supply voltage.

Following this test, the condenser/fresh air ambient shall be slowly raised to the point when the high-pressure cutoff transducer or switch activates and shuts off the system. Record pressures and temperatures of the pressure switch cutoff and reset conditions

### **16.4.4.6.8 Modulation Pressure Switch Test**

This test shall be performed at ambient temperature above condition C and with AW3 passenger load.

A successful test shall consist of 1 h of continuous operation of the system without shutdown due to high pressure, cutoff, circuit breaker tripping, compressor motor overload, or any device malfunction.

### **16.4.4.6.9 Low Temperature Test with Passenger and Solar Loads**

This test shall be conducted at ambient condition E specified in Section 7 and with the passenger and solar load sufficient for the partial cooling operation.

After attainment of the specified and stabilized temperature conditions, the system shall be operated continuously for a period of 4 h. During the test, the air cooling system shall operate without damage to the equipment and without the formation of any ice or frost on the evaporator coil or piping. The data shall be recorded every 10 min during steady state operation

### **16.4.4.6.10 Condensate Carry-Over**

The system shall be tested for absence of the condensate carry over with ambient entering air temperature at 80°F DB (27°C DB) 75°F WB (24°C WB) and with AW3 passenger load, without solar load. The system shall be operated continuously for a period of 4 h at the specified conditions. All condensation from the evaporator coil shall be retained inside the drain pan. No condensate shall spill from the drain pan.

#### **16.4.4.6.11 Refrigerant Samples**

A sample of refrigerant shall be taken from the air conditioning system of the tested vehicle after all tests have been completed and analyzed for contaminants by an approved laboratory. Test results shall satisfy the requirements for permitted levels contaminants as defined in the Refrigerant Sample Test section, above. If contaminant levels exceed these requirements, a corrective action plan must be submitted to Sound Transit for approval and implemented following acceptance.

#### **16.4.4.7 Heating Tests**

The testing shall begin by "soaking" the vehicle at ambient condition F of Section 7 for at least 12 h without any vehicle interior heating loads. Instrumentation requirements and data requirements detailed in this Section, shall apply. The following tests shall be performed under the conditions described:

- Full heat warm-up test at ambient condition F of Section 7. Record the required warm-up time and all data as the vehicle interior warms up and stabilizes. Warm-up time shall meet the requirements of Section 7;
- Steady State without passengers at ambient condition F of Section 7;
- Steady State without passengers at ambient condition F of Section 7 and door cycling on one vehicle side as in this Section;
- Steady State with AW3 passenger load at ambient condition F of Section 7;
- Layover control demonstration at ambient condition F of Section 7;
- Warm-up from Layover condition after HVAC equipment is energized;
- Abnormal Heating Condition, Restricted Air (this test shall be conducted at conditions specified in this Section);
- Abnormal Heating Condition, No Air (this test shall be conducted at conditions specified in this Section);
- Back-Up Protection Device (this test shall be conducted at conditions specified in this Section);
- Cab Heater - The cab heater capacity shall be tested for conformance with the requirements of Section 7. The high limit switch operation shall be verified;
- Cab Side Windows Defroster-Demister - The side window defroster-demister shall be tested for conformance with the requirements of Section 7. The high limit switch operation shall be verified; and
- Windshield Defroster-Demister - The heated glass windshield window defroster-demister shall be tested for conformance with the requirements of Section 7.

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### **16.4.5 Light Intensity**

Light intensity readings shall be taken (without light from other sources) on one completed vehicle to verify conformance with the requirements in Section 8. (Procedure: CDRL 16-68) (Report: CDRL 16-69)

### **16.4.6 Weight Distribution**

Weight distribution tests shall be performed on one completed vehicle to verify compliance with the requirements of Section 2. (Procedure: CDRL 16-70) (Report: CDRL 16-71)

### **16.4.7 Coupled Vehicle Clearance**

The first two completed vehicles, or as selected by Sound Transit, shall be coupled and checked for proper articulation, truck, anticlimber, car body, coupler, cable and hose clearance under the worst case geometric requirements for these elements specified in Sections 3, 4, and 11. The vehicle ends shall be checked for proper intercar clearance. All articulation interior, exterior, roof, and underfloor surfaces and linkages shall be checked for smoothness of operation and clearance. The couplers shall be checked for proper vertical and horizontal swing and for clearance from the truck, undercar components, skirts, anticlimber and ground (top of rail). All truck, trainline, and coupler cables and hoses shall be checked for clearance and the absence of stretching and chafing. The trucks shall be checked for proper vertical and horizontal swing and for clearance from undercar components and the skirts. (Procedure: CDRL 16-72) (Report: CDRL 16-73)

These tests shall be repeated two additional times with LRVs selected at random by Sound Transit.

### **16.4.8 Trainline**

The first eight LRVs, or as selected by Sound Transit shall be tested to demonstrate that all trainline functions perform satisfactorily between vehicles when coupled together. These tests shall include running as well as static tests. Vehicles shall be coupled in all possible combinations. Tests shall confirm normal operation with two, three, and four vehicle trains and emergency operation with four, six, and eight vehicles and the requirements of Sections 2 and 9. (Procedure: CDRL 16-74) (Report: CDRL 16-75)

These tests shall be performed at Sound Transit's facilities after arrival of the first two vehicles. Any modifications required as a result of these tests shall be incorporated in all vehicles prior to shipment.

These tests shall be repeated on the third, through eighth vehicles after arrival at Sound Transit's facilities.

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### **16.4.9 Vehicle Performance**

#### **16.4.9.1 General**

NOTE – Before any vehicle testing is performed on mainline track, a safety test must be conducted where braking, ATP, TWC and other safety related systems are verified to function properly.

Dynamic tests shall be performed on systems related to propulsion and braking on single vehicles. The tests shall verify the requirements of Section 2. This series of tests shall also be used to determine the equipment settings and calibrations to be used for the vehicle acceptance program. A two, three and a four car train shall also be tested to verify proper operational performance. (Procedure: CDRL 16-76) (Report: CDRL 16-77)

The Contractor shall select, with Sound Transit's approval, a suitable test segment and determine where each test will start.

The Contractor is allowed to simulate passenger loads using ballast when performing vehicle dynamic testing. The ballast must be distributed to simulate actual passenger loading. The ballast shall be secured properly for the intended testing and the interior shall be protected from damage caused by the ballast. The dynamic test procedure shall include description of the measures taken to secure the ballast and a loading diagram to ensure that the ballast is properly placed and correctly distributed inside the vehicle.

As a minimum, two runs in each direction shall be made for each test condition.

The relationship of motor current (or torque) vs. load weigh signal, and brake cylinder pressure vs. load weigh signal shall be developed for a continuous range of passenger loadings (AW0 to AW3). These relationships shall be referenced to evaluate the performance of all other cars, which may then be tested without load during limited performance tests.

All recorded data shall be corrected for voltage and grade as part of the Contractor's test report.

If any vehicle under any load condition or train configuration, or any apparatus fails to satisfy the specified performance and design criteria, the cars, with the necessary adjustments, shall be retested at the Contractor's expense. If modifications are necessary, they shall be verified by appropriate retest, as determined by Sound Transit, and implemented on a fleetwide basis at the Contractor's expense.

#### **16.4.9.2 Instrumentation**

Proof of the calibration of all instruments, traceable to a master at the national standards organization of the applicable country, shall be submitted to Sound Transit for approval as part of the test report.

For these tests, each car shall be instrumented with a data acquisition system which shall produce a permanent test record. The Contractor shall supply all recorders, sensors, transducers, pickups,

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equipment racks, test wiring termination panels, calibration equipment, wiring, and inverters to operate this instrumentation using the car low voltage power system supply.

The equipment shall function over the low voltage power system voltage range described in Section 2. Isolation amplifiers and voltage dividers shall be provided as part of the instrumentation package to isolate the inside car instrumentation wiring and equipment from high voltages; no exposed terminals with potential differences greater than 50 V will be permitted.

The data acquisition system shall be capable of interfacing with all major systems through the PTU Ethernet network to select signals needed to verify vehicle performance.

The accuracy and response of the instrumentation shall be sufficient to demonstrate compliance with the Specifications and design criteria.

Unless otherwise required, tests shall be performed on single cars. For each test, the following channel assignments shall be permanently recorded simultaneously, as specified:

- Acceleration (positive and negative). The signal shall be provided by an independent accelerometer (acceleration/deceleration rates calculated by the propulsion and/or friction brake system will not be considered acceptable for this requirement, but should be recorded for verification of accuracy);
- Traction motor torque or effort (each truck);
- Spin-slide system operation (each truck);
- Brake cylinder pressure (each truck);
- Brake disc temperature on one motor truck axle and on one center truck wheel;
- Catenary voltage;
- Total catenary current drawn by each car;
- Speed;
- Auxiliary power supply voltage and frequency outputs;
- Propulsion and braking trainline command signals (or multiplexed to a single analog channel);
- An independent time base with 1 s and 0.1 s time intervals;
- Such channels as the Contractor feels necessary to record the voltage transients of Section 10; and
- Five spare analog and ten spare digital channels for additional signals which may be requested by Sound Transit.

### **16.4.9.3 Propulsion Performance Tests**

This series of tests shall be run at passenger loads of AW0, AW2 and AW3. Compliance with the performance requirements in Section 2 and Section 10 shall be demonstrated. (Braking shall be monitored during the propulsion tests.)

### **16.4.9.4 Braking Performance Tests**

This series of tests shall be run at AW0, AW2, and AW3. For the all-friction brake stop tests, brake discs shall be cooled to a maximum of 250°F (121°C) as measured by thermocouples before initiation of any test. Compliance with the performance requirements in Sections 2, 10 and 12 shall be demonstrated.

### **16.4.9.5 Thermal Capacity Tests**

The vehicle shall be instrumented and tested to verify compliance with the duty cycle requirements specified in Sections 2, 10 and 12.

### **16.4.9.6 Wheel Spin/Slide**

All power and braking modes shall be tested to verify compliance with Section 2. Each axle of the spin/slide test train shall be monitored and recorded.

### **16.4.9.7 Auxiliary AC Power Supply**

The Contractor shall operate the auxiliary ac power supply test instrumentation throughout all car performance testing to verify that the requirements of Sections 2 and 9 are met. The data recordings so taken shall be available for inspection by Sound Transit and shall be furnished to Sound Transit by the Contractor upon delivery of cars for acceptance. Data recordings which contain representative samples of the power supply operating characteristics, taken during the auxiliary ac power supply conformance tests and these car performance tests, shall be copied and included in an auxiliary ac power supply test report.

### **16.4.10 Operational**

The first car shall be given an operational test of 4000 mi (6400 km) before conditional acceptance by Sound Transit. The operational tests shall be performed in Seattle after arrival of the car but prior to formal delivery of the car to Sound Transit for conditional acceptance. The car shall be instrumented during these tests to determine that all systems are functioning properly and to confirm the capability and accuracy of the MDS. The instrumentation shall be as specified in this Section. The test shall be conducted in simulated revenue service, with an AW3 passenger load, stopping at every station and cycling the doors. The data recordings shall become part of the permanent record for the cars and shall be turned over to Sound Transit with the test report. With Sound Transit approval, the car diagnostic system may be used instead of instrumentation, if it can provide sufficient information to evaluate and document test results. (Procedure: CDRL 16-78) (Report: CDRL 16-79)

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During the last 1000 mi (1600 km) of the test, there shall be no failures of equipment. If a failure occurs, the 1000 mi (1600 km) portion of the test for the car on which the failure occurred shall be repeated following correction and documentation of the failure.

### **16.4.11 Ride Quality**

Ride quality tests shall be performed on one car and two car trains. The tests shall prove compliance with the ride quality requirements of Section 2. (Procedure: CDRL 16-80) (Report: CDRL 16-81)

As a minimum, ride quality tests shall consist of operating the trains at speeds of 25, 40, and 55 mph (40, 64, and 89 km/h) over track selected by Sound Transit, under two load conditions: AW0 and AW3. Instrumentation capable of measuring the magnitude of the vertical, longitudinal, and lateral shocks and vibrations experienced, shall be provided and monitored by the Contractor on at least one car of the test trains. Sensing units shall be located on the car floor above the intersection of the car longitudinal center line and a power truck transverse center line, on the articulation truck transverse centerline, at the center of the car between trucks, and at three seat locations to be determined by Sound Transit. Provision shall be made for recording vertical, lateral, and longitudinal shocks and vibrations concurrently.

Weights used in simulating passenger load shall be provided by the Contractor.

Acceptability of the ride quality will be determined by an analysis of the recorded root-mean-square accelerations.

In the event that the dynamic behavior of the trains do not meet the Specification requirements, the Contractor shall submit for Sound Transit review, within 60 calendar days, a program containing a mathematical analysis of the problem and a course of action for its correction. If authorized by Sound Transit, the corrective measures shall be installed on the test train within 90 days at the expense of the Contractor, the train shall be retested, and, if the measures are successful, they shall be applied to all cars. If not successful, the analysis and corrective action steps shall be repeated, and the train retested until Specification compliance is attained.

### **16.4.12 Noise and Vibration**

After equipment installation, noise and vibration tests shall be performed on the first vehicle to confirm compliance with the requirements of Section 2. (Procedure: CDRL 16-82) (Report: CDRL 16-83)

Compliance with the Specifications is to be based on measurements taken in essentially a free-field environment such as outdoors, away from any reflecting surfaces other than the ground, ties, and ballast, on track with newly ground, welded rail. Reflected sound shall be such as to not influence the directly radiated sound from the equipment measured by more than 2 dB. All measurements shall be made with an ambient sound level in the vicinity of the test measurement locations of not less than 10 dB below the noise produced by the equipment being measured, when evaluated using the same scale or octave band.

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The interior noise requirements for vehicles operating in tunnels in Section 2 should be tested in both the North Link and East Link tunnels.

For these tests, the following shall be recorded:

- Description of noise or vibration source being measured, including pertinent statistical information;
- Description of the environment where the noise or vibration source is measured, including a sketch showing source position;
- Operating conditions of noise or vibration source during measurements;
- Pertinent meteorological data;
- Locations and orientations of microphones with respect to noise source;
- Equipment used for making measurements;
- Description and measurements of ambient noises;
- Data obtained, including range of variation; and
- Instrument settings, corrections, and calibration records.

The results shall be evaluated and any corrective action required shall be approved by Sound Transit. After corrective action is taken, the applicable tests shall be rerun. If the corrective action is successful, it shall be applied to all cars. If not successful, these steps shall be repeated until Specification compliance is attained.

### **16.4.13 Ground Borne Vibration**

The Contractor shall develop and conduct a test incorporating the test elements described in this section. Approval of the car level qualification test procedure and results is contingent upon the vehicle passing the train vibration tests at the Sound Transit facilities. (Procedure CDRL 16-85. Report CDRL 16-86)

- The test procedure for determining the FDLs should follow the methodology described in the FTA Guidance Manual (FTA-VA-90-1003-06), dated May 2006.
- The FDL tests entail measuring the wayside vibration levels from train passbys by installing transducers at several distances from the track centerline. The transducers shall be located at least 15 feet from the track centerline and no more than 200 feet from the track centerline. An example transducer configuration for the FDL tests can be 15, 25, 50 and 100 feet from the track centerline. Another example configuration is 25, 50, 75, 100, 150 and 200 feet from the track centerline.
- A drop-weight hammer shall be used to impact the ground. The drop-weight shall be sufficient (weigh at least 30 lbs) to produce reasonable signal at the farthest response transducer. The impacts shall be performed at multiple points along the track. At each

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impact location, there shall be sufficient number of impacts (at least 10 impact hits) to ensure acceptable signal to noise ratio at the response transducers. The forces generated by the hammer shall be measured using a load cell at the point of impact and the vibration response of the ground shall be measured at the same transducer positions where train vibration levels were measured. The response levels in relation to the input force from the hammer at each of the impact point provides the “point source” transfer function.

- The multiple “point source” impacts shall be numerically integrated to simulate a line vibration source along the centerline of the track to get the measured Line Source Transfer Mobility (LSTM). The FDL of the trains shall be derived using the relation:

$$\text{FDL} = \text{Train Vibration} - \text{LSTM}$$

- These FDL tests shall be conducted by a qualified acoustical firm with more than 10 years of transit experience and prior experience with these tests on other projects including FDL from ST1 fleet.
- The maximum allowable 1/3 octave band FDL at 30 mph (48km/h) on tangent track with standard RE115 continuous welded rail with resilient direct fixation(DF) fasteners is shown in a table in Section 2, ground borne vibration. The FDL spectra are based on measurements performed on Sound Transit’s existing track with standard rail fasteners for standard RE115 continuous welded rail with no corrugation. The rail fasteners have a nominal vertical static spring rate of 145,000 lb/in (26,270 N/mm) for vertical loads between 4,500 lb (2,040 kg) and 12,000 lb (5,445 kg). The dynamic-to-static stiffness of the fasteners in this load range is 1.4. The fasteners are spaced at 30 in (760 mm).

The rail roughness of the track measured using the ISO 3095 procedures shall be within Sound Transit’s reference roughness limit as shown in Figure 2-1, Sound Transit’s Reference Rail Roughness Limits for the FDL Test. The Sound Transit’s roughness limit in Figure 2-1 is based on measurements performed using a Corrugation Analysis Trolley (CAT).

For meeting the specified FDL limit, the contractor shall do the following:

- Perform FDL tests for the 1<sup>st</sup> vehicle at the manufacturers test track facility at a minimum speed of 25±1 mph. The test shall be performed by a qualified acoustic firm with at least 10 years’ experience in measuring FDLs and prior experience measuring train vibration for ST1 fleet. The FDL from the manufacturer’s test track for the 1<sup>st</sup> vehicle shall be based on an energy average of at least 10 train passbys at the nominal train speed. If the tests cannot be performed at 25 mph or higher speeds at the manufacturer’s test track, the FDL tests may be performed at a lower train speed after written approval from Sound Transit. Note that approval for lower train speed shall be allowed only for the manufacturer’s test track.
- Measure the wheel condition including out-of-roundness and rail condition including rail roughness of the test track.

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- Before shipping the 1<sup>st</sup> vehicle, submit a technical report documenting the measured FDL on the manufacturer's test track, the wheel condition including out-of-roundness and wheel stiffness, rail condition including roughness, stiffness of the track components, and other relevant information. (CDRL 16-84)
- Upon arrival of the 1<sup>st</sup> vehicle to Sound Transit facilities, the train vibration tests shall be performed on this vehicle at train speeds of 30 mph in Sound Transit tunnels with resilient DF fasteners. The 1<sup>st</sup> vehicle shall meet the FDL limits in Table 2-1. Any exceedance of the FDL limits will be inferred as failing to meet the wayside vibration design criteria for the LRVs.
- Failure to meet this requirement will prohibit shipment of additional vehicles until a solution has been identified and implemented on the first vehicle and the wayside vibration levels are verified to be compliant with the FDL limits.
- If the 1<sup>st</sup> vehicle is verified to be compliant with the FDL limits, develop an "adjusted FDL limit" based on the relationship between the FDL measured at the manufacturer's test track and the FDL at 30 mph measured on Sound Transit's DF tracks in tunnels.
- The "adjusted FDL limit" shall be developed under ST's guidance and the limit shall be used by the manufacturer as a pre-shipment quality control test for all of the production LRVs at their test track. Only vehicles that comply with the "adjusted FDL limit" shall be shipped to Sound Transit facilities.

### 16.4.14 Horn and Bell

The horn and bell, as mounted on a completed vehicle, shall be tested for compliance to the requirements of Section 5. This requires testing of both ends of a vehicle. (Procedure: CDRL 16-87) (Report: CDRL 16-88)

### 16.4.15 Electromagnetic Compatibility

An electromagnetic compatibility test shall be performed on the first vehicle by methods referenced in Section 2 for compliance with those requirements and for the compatibility with Sound Transit's traction power distribution, railway signal, and communications systems. (Procedure: CDRL 16-90) (Report: CDRL 16-91)

The Contractor shall also meet basic electromagnetic compatibility requirements with four vehicle operation.

In addition to demonstrating that the EMC plan requirements are satisfied, the EMI testing shall demonstrate both statically and dynamically that the vehicle does not interfere with the carborne cab signal system, TWC systems, or the wayside signal system.

### 16.4.16 Magnetic Perturbation

The contractor shall develop and conduct a test incorporating the test elements described in this section for magnetic perturbation. Upon arrival of the 1<sup>st</sup> vehicle to Sound Transit facilities, the train magnetic perturbation tests shall be performed on this vehicle on the same section of track

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where the existing ST1 vehicle was tested to determine the maximum allowed magnetic perturbation – namely the tracks at the intersection of MLK Jr. Way S. and S. Norfolk St. Approval of the car level qualification test procedure and results is contingent upon the vehicle passing the magnetic perturbation tests at the Sound Transit facilities. An example of the test reports generated during measurements on the existing ST1 vehicles is attached for reference.

- The Contractor shall conduct magnetic perturbation tests at the Contractor’s test track facility. The magnetic perturbation shall be an average of the peak values measured during at least 3 train passbys with the A-end cab leading, and 3 train passbys with the B-end cab leading.
- Before shipping the 1<sup>st</sup> vehicle, submit a technical report documenting the measured magnetic perturbation on the manufacturer’s test track. (CDRL 16-89).
- Upon arrival of the 1<sup>st</sup> vehicle to Sound Transit facilities, the magnetic perturbation tests shall be performed on the same section of track where the existing ST1 vehicle was tested to determine the maximum allowed magnetic perturbation. The 1<sup>st</sup> vehicle shall meet the magnetic perturbation limits in Section 2. Any exceedance of the limits will be inferred as failing to meet the design criteria for the LRVs.
- Failure to meet this requirement will prohibit shipment of additional vehicles until a solution has been identified and implemented at the on the first vehicle and the magnetic perturbation levels are verified to be compliant.
- If the 1<sup>st</sup> vehicle is verified to be compliant with the magnetic perturbation limits, develop an “adjusted perturbation limit” based on the relationship between the perturbation measured at the manufacturer’s test track and the perturbation measured on Sound Transit’s test location.
- The “adjusted perturbation limit” shall be developed under ST’s guidance and the limit shall be used by the manufacturer as a quality control test for all of the production LRVs at their test track. Only vehicles that comply with the “adjusted perturbation limit” shall be shipped to Sound Transit facilities.

### 16.4.16.1 Description of post-shipment test elements for magnetic perturbation.

The following items describe the test procedure used when testing the current fleet of vehicles, and should be incorporated when developing the pre- and post-shipment test procedures for magnetic perturbation:

- The test track alignment orientation will be as close to North / South orientation to replicate the final alignment under the University of Washington campus.
- A Magnetometer (MEDA FVM400 or approved equal) will be positioned perpendicular to the test track at 40 meters (131 feet) from the test track centerline. The magnetometer shall be set to sample at a rate of 5 Hz, and the probe shall be oriented to have the x-axis in the vertical direction, y-axis pointing north and the z-axis pointing west.

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- Test speeds may be between 10 and 15 mph; a minimum of three runs capturing clean mG readings and must be completed in each orientation.
- The LRV must be tested for both LRV orientations. If the test track runs North / South the LRV must be tested with the “A” end North, and then turned and tested with the “B” end North.
- While the test LRV is moving through the test array, no other vehicle movement will be allowed. Traffic control must be considered to avoid any influence to data results.
- No cell phones, radios, or stationary vehicles or equipment can be within 20 feet of the test array.
- Testing for perturbation is conducted with all power removed and the LRV coasted by the test array. An option is to power the LRV to the required speed, and then lower the pantograph so no power is being delivered to the LRV, and coast through the test array.
- Any additional vehicles on the test track must have all pantographs lowered and not be receiving any traction power.
- All traffic will be stopped and held during testing.
- Once all traffic is cleared, notice will be given to the Test Equipment Operator to start data recording. A minimum of 60 seconds of data must be recorded prior to any LRV movement.
- After the 60 seconds of data recording, notice will be given to the LRV operator who will accelerate to required test speed.
- As the test LRV reaches the required test speed the LRV operator will place the LRV in coast and lower the pantograph.
- The test LRV will coast unpowered through the test array and once clear apply brakes and come to a full stop.
- Once the run is complete and the LRV has come to a complete stop, and additional 60 seconds of data recording must continue before stopping the data recording.

The Contractor shall submit for Sound Transit review and approval the magnetic perturbation test procedure. (Procedure: CDRL 16-92) (Report: CDRL 16-93)

### 16.4.17 ATP System

The Contractor shall submit for Sound Transit review and approval the Cab Signal Vehicle Level Qualification test procedure. Vehicle Level Qualification tests shall consist of static and dynamic tests. (Procedure: CDRL 16-94) (Report: CDRL 16-95)

As a minimum, the static tests shall test functions necessary for dynamic operation. The static tests shall verify the ATP functions and vehicle interfaces identified in this Section with each cab in control. Use a wire loop at track level underneath the receiver coil areas to apply a 2340 Hz

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modulated signal to simulate the speed commands. Simulate the speed command signal over the wayside signal current level and frequency range to verify sensitivity.

As a minimum, dynamic testing shall include testing of all cab signal functions (refer to this Section) at each speed. Test shall include verification of dynamic cab signal functions such as brake assurance calibration at all speeds, no-motion detection (or interface), speed sensor signal sensitivity, and speedometer accuracy.

The tests shall also verify that carborne cab signal equipment is compatible with the wayside train control system, including EMC readings with wayside and adjustments of some track circuits to minimum and maximum signal strength to ensure proper speed decoding sensitivity.

### **16.4.18 TWC System**

The Contractor shall submit for Sound Transit review and approval the TWC Vehicle Level Qualification test procedure, consisting of static and dynamic tests. (Procedure: CDRL 16-96) (Report: CDRL 16-97)

As a minimum the static tests shall verify each of the TWC functions specified in Section 14 including the cab panel indication under all operational conditions. TWC manufacturer receiver, decoder logic and antenna loop shall be used during the static tests.

As a minimum the dynamic tests shall test simulated revenue conditions including speed variations, braking and message functioning.

### **16.4.19 Vehicle Dynamic Envelope Tests**

The Contractor shall design and build a test fixture which when installed on a vehicle will simulate the vehicle dynamic envelope. The Contractor shall prepare two set-ups. One outfitted vehicle shall be tested in the tightest passages and stations and two coupled vehicles shall be tested on the tight curves. The set ups shall be removable and reusable to test other places on the Central Line as the line construction progresses. (Procedure CDRL 16-98) (Report CDRL 16-99)

### **16.4.20 Parking Brake**

A parking brake system test shall be performed on one vehicle. Design compliance with Section 2 shall be demonstrated by measuring the force required to move the vehicle with the parking brake applied. The test shall be performed with bedded in brake shoes.

Alternatively, a vehicle can be parked on a steep section of the alignment with the parking brakes applied. Compliance with the requirement can then be shown by extrapolation for weight and brake force from all parking brakes.

## **16.5 System Conformance Tests**

All equipment on each vehicle shall be given functional tests at the Contractor's or sub-contractors facility prior to the vehicle's shipment to Sound Transit. The test to be performed on each component, system or the car shall be in accordance with the standards listed in the

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Specifications and the approved test plan for the component, system or vehicle. The test reports of all Production Conformance tests, after approval by Sound Transit, shall be included in each "Car History Book" as specified in Section 19.

### **16.5.1 Electrical Apparatus**

Each component that is separately assembled, housed, and wired into a package unit prior to installation in the vehicle shall be tested at its point of manufacture and a certified test report, signed by the responsible Quality Assurance representative of the manufacturer, shall be furnished to Sound Transit. Control and communications equipment shall be tested for function according to a procedure prepared by the manufacturer and approved by Sound Transit, each test of electrical equipment shall include an insulation test. See section 16.1.4 for parameters related to this test. (Procedure: CDRL 16-100) (Report: CDRL 16-101)

### **16.5.2 Air Conditioning Unit**

Each air conditioning unit shall be placed in a test cell with a continuous heat load, sufficient to maintain fully loaded operation, applied to both the evaporator and condenser coils. The unit shall be operated for at least 5 h. (Procedure: CDRL 16-102) (Report: CDRL 16-103)

The unit shall be given a complete functional test to verify compressor unloading, control points of all pressure switches and all return air and fresh air thermostatic control points. Power consumption of all motors, evaporator and condenser fan motor speed, system pressures and temperatures, and the applied loads to the evaporator and condenser shall be recorded. The system refrigerant charge and the refrigerant condition (wet or dry) in both liquid sight glasses shall be recorded. Noise and vibration levels shall also be measured and recorded on each unit.

The unit heat staging and the functioning of the high limit switch, as specified in Section 7, shall be verified.

Refrigerant samples shall be taken from the first six units following the test run and analyzed by an independent laboratory according to a plan approved by the Sound Transit, to verify the adequacy of the cleaning and evacuation/dehydration. If the results from the first six units are acceptable (refer to this Section), a sampling plan of one unit in six shall be employed thereafter. If the first six units are not acceptable, the affected units shall be reprocessed and retested to a Sound Transit approved plan, and in addition, the second six units shall be sampled and the refrigerant and oil analysis cycle repeated.

The manufacturer shall conduct insulation resistance and high potential tests on each unit according to this Section.

All HVAC units shall be water tested similarly to the test described in the Watertightness and Water Eliminator Test section, above, in the System Qualifications Test section.

### **16.5.3 Motors**

Each traction motor, ac auxiliary motor, and dc motor shall be given a "routine" test by the manufacturer in accordance with IEC Publication 60349-1 or -2 or IEEE Standard 11, as

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appropriate and as approved by Sound Transit. Motor balance shall be dynamically tested in accordance with IEC 60349. (Procedure: CDRL 16-104) (Report: CDRL 16-105)

### 16.5.4 Propulsion Gear Units

Each propulsion gear unit shall be given the manufacturers "routine" test, which shall include, as a minimum, the following: (Procedure: CDRL 16-106) (Report: CDRL 16-107)

- Gear tooth mesh shall be checked to verify that it is within the manufacturers tolerances before the gear unit is operated; and
- No load operation at 55 mph (89 km/h) equivalent vehicle speed for 10 min in each direction. Noise and vibration produced by each gear unit and gear sump oil temperature shall be continuously monitored. All gear units which produce abnormal oil temperature or noise shall be rejected.

### 16.5.5 Propulsion Power Control

With control power connected and propulsion power disconnected, each propulsion power control system shall be tested for correct sequences of operation in both powering and braking modes by simulating the operation of the control lock and master controller and observing the functioning of the various pieces of apparatus involved. (Procedure: CDRL 16-108) (Report: CDRL 16-109)

### 16.5.6 Auxiliary Power Supply

Each auxiliary power supply shall be given a "routine" test by the manufacturer to verify compliance with all aspects of the following for the nominal conditions defined in Section 2: (Procedure: CDRL 16-110) (Report: CDRL 16-111)

- All output and control requirements;
- Performance requirements;
- Fault detection and annunciation requirements; and
- Insulation and isolation requirements. Insulation shall be tested as required in the Insulation Testing section, above.

### 16.5.7 Low-Voltage Power Supply and Battery Charger

Low-voltage power supply and battery charger conformance tests shall include the following: (Procedure: CDRL 16-112) (Report: CDRL 16-113)

- All units shall be subjected to an insulation resistance and high potential test in accordance with the requirements of this Section;
- Output voltage shall be adjusted to be within +/-1% of the specified nominal output voltage;

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- Output current limit shall be adjusted to be within +10, -0% of the Contractor's stated nominal rated output current. In the event the power supply design for current limit function incorporates two or more break points, the current or voltage setting at the additional points shall be adjusted to be within +10, -0% of the Contractor's stated nominal value;
- Over voltage and under voltage shut off points shall be adjusted to be within +/-1% of the specified values;
- Each unit shall be run for 0.5 h at rated output voltage, current and nominal input voltage;
- Proper functioning of safety interlocks shall be demonstrated; and
- All other features, such as time delay relays and layover shutdown, shall be exercised and adjusted, if required, to be within +/-10% of the Contractor's stated values where appropriate.

### 16.5.8 Battery

Five percent of all batteries supplied, selected at random by Sound Transit, shall be given a capacity test at the point of manufacture. The test shall be at the 5-hr rate, at 68°F (20°C) ambient temperature in accordance with IEC 60623. (Procedure: CDRL 16-114) (Report: CDRL 16-115)

### 16.5.9 Friction Brake Equipment

(Procedure: CDRL 16-116) (Report: CDRL 16-117)

- All electrical and electronic assemblies shall be subjected to an insulation resistance and high potential test as required in this Section.
- Each hydraulic pump unit shall be given a functional test and a capacity test.
- All valves shall be functionally tested and certified for performance in accordance with manufacturer's specifications and test codes, as approved by Sound Transit.
- All electrical and electronic assemblies shall be functionally tested and certified for performance in accordance with manufacturer's specifications and test codes, as approved by Sound Transit.

### 16.5.10 Communications, Passenger Information, GPS and CCTV Systems

All electrical and electronic assemblies shall be subjected to an insulation resistance and a high potential test in accordance with the requirements of this Section.

All electrical and electronic assemblies shall be functionally tested and certified for performance in accordance with manufacturer's specifications and test codes, as approved by Sound Transit. (Procedure: CDRL 16-118) (Report: CDRL 16-119)

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### **16.5.11 Radio System**

The radio power supply shall be subjected to an insulation resistance and a high potential test in accordance with the requirements of the Insulation Testing section, above.

The complete installed radio system shall be functionally tested. (Procedure: CDRL 16-120)  
(Report: CDRL 16-121)

### **16.5.12 Cab Signal System**

All electrical and electronic assemblies shall be functionally tested and certified for performance and safety in accordance with manufacturer's specification and as approved by Sound Transit. (Procedure: CDRL 16-122)

Test report shall record serial numbers of all subassemblies and vital relays or PC boards. Tests shall include as a minimum the testing of performance parameters, including the response times, bandwidth tolerances, self-diagnostics, wiring, and physical parameters. (Report: CDRL 16-123)

### **16.5.13 TWC**

The Train-to-Wayside Communications system shall be tested for electrical integrity, function and conformance to the requirements of Section 14 and this Section. (Procedure: CDRL 16-124)  
(Report: CDRL 16-125)

All electrical and electronic assemblies shall be functionally tested and certified for performance in accordance with manufacturer's specifications and test codes, as approved by Sound Transit.

### **16.5.14 Truck Quality Testing**

#### **16.5.14.1 General**

All production truck welds including the frame, bolster and any other primary structural members shall be subjected to magnetic particle or dye penetrant inspection. Critical welds shall be inspected by radiography, or by section and etch, on 5% of the trucks chosen at random. Sound Transit may accept sampling inspection or reduced sampling inspection, based on initial good inspection results or on demonstrated acceptable welding and inspection performance by the truck manufacturer on other recent and similar work. Magnetic particle inspection shall be in accordance with ASTM E709. Dye penetrant inspection shall be in accordance with ASTM E165/E165M. Cast trucks shall be 100% magnetic particle inspected. (Procedure: CDRL 16-126)  
(Report: CDRL 16-127)

If defects are found during sampling inspection, the Contractor shall positively locate the beginning of such defects in previous truck frames and apply appropriate corrective action.

#### **16.5.14.2 Bearing Lateral Clearance**

A 10% sample of mounted journal bearings shall be measured to verify conformance to installed lateral clearance requirements of Section 11.

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### **16.5.14.3 Wheel Back-to-Back Distance**

All wheel-axle assemblies shall be measured to verify conformance with back-to-back distance requirements in Section 2.

### **16.5.14.4 Shunt Resistance**

All wheel-axle-wheel and wheel-axle-ground brush assemblies shall be measured to verify conformance to shunt resistance requirements of Section 11.

### **16.5.14.5 Axle Runout**

All wheel-axle assemblies shall be measured to verify conformance to axle runout (concentricity) requirements in Section 11.

### **16.5.14.6 Tire Runout**

All tires on wheel-axle assemblies shall be measured to verify conformance to lateral and radial runout requirements in Section 11.

### **16.5.14.7 Tram and Axle Parallelism**

All truck assemblies shall be measured to verify conformance to tram and axle parallelism requirements in Section 11.

### **16.5.15 Event Recorder**

Each Event Recorder shall be tested to comply with requirements in Section 14, and demonstrate the ability to record each of the approved listed signals over its full possible range. (Procedure: CDRL 16-128) (Report: CDRL 16-129)

### **16.5.16 Data Monitoring System**

Each Monitoring and Diagnostic System shall be tested to comply with requirements in Section 9. (Procedure: CDRL 16-130) (Report: CDRL 16-131)

## **16.6 Pre-Shipment Tests**

The tests listed in this Section shall be performed on each completed vehicle prior to shipment to Sound Transit. Test reports for each test shall be included in the Car History Book for the appropriate vehicle. The Contractor's Production Vehicle Functional Tests shall include all tests and adjustments which can be made prior to shipment in order to keep the Post-Shipment and Acceptance Testing, specified in this Section and any subsequent adjustments to a minimum. Refer to Section 19.

The following vehicle tests shall be performed by the Contractor, or under its direction.

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### **16.6.1 Watertightness Tests**

For each vehicle, all areas of the vehicle sides, ends, and roof, including doors and windows, shall be given two complete tests for watertightness. The first tests shall be made before installation of sound deadening material, thermal insulation, articulation section linings, and interior finish. Water shall be sprayed from nozzles which are spaced no more than 3 ft (0.91 m) from, and aimed directly at, the surface being tested, providing at least 0.625 gpm/ft<sup>2</sup> (13.2 l/h/m<sup>2</sup>). The nozzle velocity of the water shall be not less than 150 ft/s (46 m/s). (Procedure: CDRL 16-132)

All spray applications shall run for 10 min before the inspection for leaks begins, and shall run continuously during the inspection. Individual exterior equipment enclosures shall be watertightness tested as indicated in this Section.

The vehicle or box shall pass the test if no leaks are observed.

The second tests shall be on the fully assembled vehicle.

### **16.6.2 Weighing**

The Contractor shall weigh each vehicle at the time of shipment. (Procedure: CDRL 16-133) The weight of each truck shall be provided separately. A weighing device which provides a permanent record of the weight shall be used, and a copy shall be included in the Car History Book. The weighing device shall be maintained within an accuracy of 0.2%. Sound Transit shall be given the opportunity to witness the weighing and to verify calibration of the equipment.

### **16.6.3 Vehicle Wiring**

Vehicle wiring acceptance testing shall be performed on all vehicles after the wiring and equipment installation is completed and shall consist of the tests described below. (Procedure: CDRL 16-134)

#### **16.6.3.1 Wiring Continuity Checks**

All circuits shall be tested to ensure continuity and correct polarity of equipment and devices. All frame grounds and terminal connections shall be checked for tightness.

#### **16.6.3.2 Insulation Testing**

The insulation of all car circuits shall be subject to insulation resistance and high potential testing. Refer to section 16.1.4 for parameters related to this test.

#### **16.6.4 Battery Commissioning**

Each battery shall be commissioned by the contractor in accordance with the battery vendor requirements prior to delivery to Sound Transit.

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### **16.6.5 Doors, Operators and Controls**

The doors and their operating equipment including visual and audio devices shall be tested and adjusted to ensure smooth functioning, attainment of the required speed of operation, and proper functioning of controls, signals and interlocks, as specified in Section 6. (Procedure CDRL 16-135)

All doors shall be operated a minimum of 100 consecutive, successful cycles. Initiation of the cycling shall be through the trainline. Proper forces for opening and closing shall be verified on every door before and after the above cycling.

The obstruction detection features shall be checked for proper operation and adjusted, if necessary, as specified in Section 6, prior to the start of the cycling test. This feature shall operate properly, without the need for readjustment, at the end of the cycling tests. Obstruction test shall be reported on all doors

Any door or control failure occurring prior to completion of the test will nullify the test, requiring that the test be restarted from the beginning following documented correction of the failure.

### **16.6.6 Air Conditioning**

The air conditioning system shall be functionally tested by simulation of temperature inputs with the Portable Test Units (PTU) in all vehicles. The automatic operation of the thermostatic control system, throughout the entire operation range, shall be demonstrated by monitoring the PTU. The sequence of compressor unloading, all pressure control switches, functioning, expansion and solenoid valve operation, system modulation, and system pump-down shall be verified. The system refrigerant charge and the refrigerant condition (wet or dry) in both liquid sight glasses shall be recorded. (Procedure: CDRL 16-136)

### **16.6.7 Heating**

The heating system, including layover heat, shall be functionally tested in all cars by simulation of temperature inputs with the PTU. The automatic operation of the thermostatic control system shall be demonstrated throughout the entire operation range, by monitoring the PTU. Heat shall also be applied to the overhead heaters without air flow and the high limit control switch shall be cycled three times. The test shall be successful when the fusible link back-up protector shall not melt.

Function of the heated windshield and cab side windows shall be tested. During the test, power consumption shall be recorded and proper operation of all controls shall be verified. (Procedure: CDRL 16-137)

### **16.6.8 Lights**

The function of all lights shall be confirmed. The headlights and railway headlights on each vehicle shall be aimed and adjusted to meet the requirements of Section 8. (Procedure: CDRL 16-138)

### **16.6.9 Propulsion Power Control**

With propulsion power disconnected, each propulsion power control system shall be tested for correct sequence of operation in both powering and braking modes by operating the master controller, observing the functioning of the various pieces of apparatus involved with the PTU. (Procedure: CDRL 16-139)

### **16.6.10 Friction Brake**

The Contractor shall perform a complete functional test of the friction brake system including, as a minimum, verification of brake cylinder pressure settings, control and indicator verification, response to dynamic brake feedback signals, sanding, track brake and a functional test of the brake fault detection system. In addition, pad force measurements shall be performed to verify that forces are within specified limits on all disks of the first three vehicles or until consistency of forces can be demonstrated. (Procedure: CDRL 16-140)

### **16.6.11 Hydraulic System Leakage Test**

A hydraulic system leakage test shall be performed as per the following, both at the Contractor's facility and prior to track operation at Sound Transit's facility: (Procedure: CDRL 16-141)

- Place all cut-out valves in their normal operating position;
- Install a test gauge at each accumulator;
- After each hydraulic pump cuts out after charging the system, record the hydraulic pressure at each accumulator and start the clock; and
- After 10 min record the pressure at each of the accumulator gauges. Inspect all piping for evidence of leakage. The vehicle should record no greater than a 5% pressure drop and show no evidence of fluid leakage. The hydraulic pumps shall not be allowed to start during the 10-min test period.

If the car fails to meet the above requirements, the leakage must be corrected and the car retested until the requirements are met.

### **16.6.12 Pneumatic System Leakage Test**

A pneumatic system leakage test shall be performed on each car both at the Contractor's facility and prior to track operation at Sound Transit's facility as per the following: (Procedure: CDRL 16-142)

- Place all cut-out valves in their normal operating position;
- Allow the air suspension system to become fully charged and determine that the leveling valves are in the "lap" position;
- Install a test gauge at the main reservoir;

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- Adjust the variable load valve pressures and compressor governor to their normal operation pressures;
- After the system is fully charged, slowly bleed the air from the main reservoir until the compressor starts. Close the main reservoir bleed, and allow the compressor to charge the system;
- After the compressor cuts out and after any drain valve action has terminated, record the main reservoir test gauge reading and start the clock;
- After 3 min (to allow for temperature effect), again record the main reservoir test gauge reading;
- Wait 5 min more and record the main reservoir test gauge reading again; and
- Main reservoir pressure drop shall not exceed a total of 10 lbf/in<sup>2</sup> (0.07 MPa) for the full 8-min test period, and a total of 5 lbf/in<sup>2</sup> (0.03 MPa) for the last 5 min of the test period. The compressor shall not be allowed to start during the 8-min test period.

If the car fails to meet the above requirements, the leakage must be corrected and the car retested until the requirements are met.

### 16.6.13 Communication and Automatic Passenger Information System

The complete communications and automatic passenger information system, shall be tested for proper operation, including level settings, data transmission, sign and display information, automated announcement content, and clarity of voice transmission and reception. In addition, each camera, monitor, and recorder shall be setup and checked for proper operation. (Procedure: CDRL 16-143)

### 16.6.14 ATP

The ATP system shall be tested to verify proper installation and interface. (Procedure: CDRL 16-144) As a minimum the tests shall verify:

- Speed command frequency and decoding bandwidths
- Response times
- Interface wiring and panel, speedometer (including calibration), event recorder, and trainline functions
- Simulated overspeed scenarios in both street running settings (25 and 35 mph)
- No-motion function and interface
- Self-Diagnostic function

The tests shall be performed from each cab.

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### **16.6.15 TWC**

After installation of the TWC equipment, a functional system test shall be conducted to verify proper installation and interface. During this test all TWC equipment and all interfaces shall be operated. (Procedure: CDRL 16-145)

### **16.6.16 Load Leveling System**

The Contractor shall perform a test to confirm that the truck suspension elements are set properly and the vehicle load leveling system is functioning properly. (Procedure: CDRL 16-146)

### **16.6.17 Trainline**

The Contractor shall verify the accuracy of each car's trainline connections on the coupler's electric head. The test shall verify that the proper trainline wires are energized when all car controls are operated. (Procedure: CDRL 16-147) Coupler functionality shall also be verified during trainline tests.

### **16.6.18 Monitoring and Diagnostics System**

Each Monitoring and Diagnostics system shall be tested to verify functionality requested in Section 9, particularly information necessary for vehicle operation and maintenance. When checking for proper fault testing, the use of a PTU to simulate faults is not acceptable. (Procedure: CDRL 16-148)

### **16.6.19 Event Recorder**

Functionality of each Event Recorder shall be verified by recording vehicle data for 30 min, actuating all inputs sequentially, downloading, and verifying the downloaded data. (Procedure: CDRL 16-149)

### **16.6.20 System Functional Verification**

After completion of each car, the Contractor shall demonstrate that each car subsystem is operational and that each car and cab can properly control a train. The tests shall be conducted by applying nominal OCS voltage described in Section 2 to the car and functionally testing all car systems. (Procedure: CDRL 16-150)

### **16.6.21 Low-Speed Dynamic Car Performance Testing**

Low-speed car testing shall be carried out on each car prior to the car shipping inspection. The low-speed testing is to confirm propulsion and braking systems performance. Successful completion of this testing is a prerequisite for shipment to Sound Transit. Refer to Section 19. (Procedure: CDRL 16-151)

## 16.7 Post Shipment Testing

The following tests shall be performed by the Contractor on each vehicle after shipment to Sound Transit property. The tests shall be satisfactorily completed by the Contractor as one of the conditions of formal delivery and acceptance of the car.

Test reports for each test shall be included in the Car History Book for the appropriate car. Sound Transit may choose to witness all of these tests, and 24 hours advance notice of each test shall be provided to Sound Transit. Acceptance or Notice of Rejection will be provided to the Contractor within ten calendar days of receipt by Sound Transit of complete test results for each car.

After receipt of each car at Sound Transit's property, and before it is operated, it shall be jointly inspected by Sound Transit and the Contractor. The Contractor shall make such adjustment, repair, or replacement as required for proper operation or as deemed necessary by Sound Transit before testing is begun.

The following adjustments shall be performed on-site on each vehicle prior to track operation:

- Carbody leveling
- Truck clearances
- Track brakes
- Sanding hoses and nozzles
- Pantograph carbon shoe alignment and pressure
- Coupler alignment
- Air spring pressure

Should a repair or replacement be required which is the result of inadequate pre-shipment Car Conformance Testing the Contractor shall provide to Sound Transit evidence that the inadequacy has been corrected prior to shipment of additional vehicles.

Successful completion of all of the Contractor's post-arrival tests shall be required before the vehicle will be considered to have been delivered to Sound Transit. At that time, the time period allocated for Sound Transit acceptance shall commence.

### 16.7.1 Hydraulic System Leakage Test

After shipping each car to Sound Transit, the Contractor shall perform a hydraulic system leakage test as described in the Hydraulic System Leakage Test section in the Pre-shipment Tests section, above. (Procedure: CDRL 16-152)

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### **16.7.2 Pneumatic System Leakage Test**

After shipping each car to Sound Transit, the Contractor shall perform a pneumatic system leakage test as described in the Pneumatic System Leakage Test section in the Pre-shipment Tests section, above. (Procedure: CDRL 16-153)

### **16.7.3 Functional Tests**

A complete, orderly, and comprehensive test of each and every vehicle system shall be performed to verify proper and faulted operation and interface. These tests shall be performed at the Sound Transit facility on each car prior to track operation at Sound Transit.

Functional verification of the vehicle systems at speeds of 20 mph will be required prior to beginning Cab Signal and TWC functional tests (refer to this Section). Successful completion of functional tests described in this Section as well as cab signal and TWC tests are prerequisites for vehicle performance tests described in this Section. (Procedure: CDRL 16-154)

### **16.7.4 Cab Signal Functional Tests**

If cab signal equipment or its components were dismantled from the vehicle during shipping, the static tests shall be repeated. (Procedure: CDRL 16-155)

The vehicle shall be tested using the wayside signal system for all speeds. Simulated speed commands can only be used to observe the cab signal functions prior to dynamic testing.

As a minimum the dynamic carborne cab signal system tests for each end of the train shall verify:

- Cab signal detection for all speed commands;
- Overspeed detection and overspeed responses and response times. Perform one test with operator acknowledging and one test with no acknowledgement to verify ATP penalty brake application;
- Panel indications and speedometer accuracy;
- No-motion function; and
- Brake assurance function for normal conditions. Also simulate abnormal condition such that service brake application does not satisfy the brake assurance deceleration rate. This shall apply one ATP emergency brake application at low speed in each direction.

### **16.7.5 TWC Functional Tests**

TWC apparatus shall be dynamically tested on Sound Transit track to ensure that the system is operating properly. (Procedure: CDRL 16-156)

### 16.7.6 Vehicle Dynamic Performance Test

The Contractor shall demonstrate that each car's tractive power, dynamic brake, friction brake, and track brake system is compliant with the requirements of Section 2. (Procedure: CDRL 16-157)

Instrumentation requirements for the performance test shall be as specified in the Instrumentation section of the Car-Level Qualification Tests section, with the exception of the channel assignments. Minimum channel assignments shall be as follows:

- Acceleration (positive and negative). The signal shall be provided by an independent accelerometer (acceleration/deceleration rates calculated by the propulsion and/or friction brake system will not be considered acceptable for this requirement);
- Traction motor torque or effort (each truck);
- Spin-slide system operation (each truck);
- Brake cylinder pressure (each truck);
- Catenary voltage;
- Total catenary current drawn;
- Speed;
- Auxiliary power supply voltage and frequency outputs;
- Propulsion and braking trainline command signals (or multiplexed to a single analog channel);
- No motion
- Overspeed
- Car wash
- An independent time base with 1 s time intervals; and
- Five spare analog and 10 spare digital channels for additional signals which may be requested by Sound Transit.

Any adjustments required as a result of Contractor tests, to obtain values corresponding to the specified performance shall be made by the Contractor prior to start of burn-in testing and shall be noted in the car's history book.

### 16.7.7 Ground Borne Vibration

A sample set of at least 20% of the production vehicles shall be tested at train speeds of 30 mph in Sound Transit tunnels with resilient DF fasteners and they shall meet the FDL limits specified in the table in Section 2. The sample set may be increased to up to 100% of production vehicles based on Sound Transit's discretion. Vehicles that do not meet the FDL limit will not be

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accepted by Sound Transit. This test may be performed by Sound Transit's in house staff or Sound Transit's consultants based on availability of resources. Alternately, the testing could be performed by a qualified acoustical firm hired by the vehicle manufacturer and acceptable to Sound Transit.

### **16.7.8 Magnetic Perturbation**

A sample set of at least 20% of the production vehicles shall be tested on the same section of track where the existing ST1 vehicle was tested to determine the maximum allowed magnetic perturbation, and utilizing the test elements described in Section 2. Vehicles that exceed the magnetic perturbation limit will not be accepted by Sound Transit. The sample set may be increased to up to 100% of production vehicles based on Sound Transit's discretion. (Procedure CDRL 16-158)

### **16.7.9 Burn-In Test**

The Contractor shall demonstrate the reliability of the vehicles and help locate "infancy" failures by operating the first vehicle in simulated revenue service for 1,000 miles (1,600 km), and 300 miles (480 km) on each subsequent vehicle, the last 100 (160 km) miles for each vehicle to be trouble free. The tests will commence after successful completion of all other Contractor run tests prior to delivery of the car at Sound Transit for acceptance. The vehicle performance shall be monitored during the test by the car diagnostic system. The Contractor shall repair any defects found during the testing and include a report on each in the test report. If failures occur during the last 100 miles of the test, the car is to be repaired and the car run for another 100 miles (160 km), which must be trouble free. Any additional failures shall require repair and repeat of the 100 mile (160 km) test sequence until it is run trouble free. A report on the burn-in test and any necessary repairs shall be noted the car's history book before delivery of the vehicle to Sound Transit for acceptance. (Procedure: CDRL 16-159)

### **16.8 Acceptance**

The Contractor shall present the completely tested, inspected, and documented vehicle to Sound Transit for acceptance after it has passed all tests, the test reports completed, and the car history books completed and verified. Sound Transit will then process each vehicle as described in Commercial Provisions Special Provisions.

After completing acceptance processing, Sound Transit reserves the right to accept vehicles that are usable but still have open design, inspection, or test issues. Sound Transit will issue a Certificate of Acceptance with an attached list of open items. Refer to Commercial Provisions Special Provisions.

After the Contractor has addressed and Sound Transit closed all open items on the Acceptance list, Sound Transit will issue a Certificate of Final Acceptance. Refer to Commercial Provisions Special Provisions.

## 16.9 Deliverables

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 16-1 Master Test Plan (Section 16.1.3)
- 16-2 Door panel qualification test procedure (Section 16.2.2)
- 16-3 Door panel qualification test report (Section 16.2.2)
- 16-4 Window qualification test procedure (Section 16.2.3)
- 16-5 Window qualification test report (Section 16.2.3)
- 16-6 Seat qualification test procedure (Section 16.2.4)
- 16-7 Seat qualification test report (Section 16.2.4)
- 16-8 Ac traction motor qualification test procedure (Section 16.2.5.1)
- 16-9 Ac traction motor qualification test report (Section 16.2.5.1)
- 16-10 Ac auxiliary motor qualification test procedure (Section 16.2.5.2)
- 16-11 Ac auxiliary motor qualification test report (Section 16.2.5.2)
- 16-12 Dc auxiliary motor qualification test procedure (Section 16.2.5.3)
- 16-13 Dc auxiliary motor qualification test report (Section 16.2.5.3)
- 16-14 Propulsion gear unit qualification test procedure (Section 16.2.6)
- 16-15 Propulsion gear unit qualification test report (Section 16.2.6)
- 16-16 Auxiliary power supply qualification test procedure (Section 16.2.7)
- 16-17 Auxiliary power supply qualification test report (Section 16.2.7)
- 16-18 LVPS and Battery Charger qualification test procedure (Section 16.2.8)
- 16-19 LVPS and Battery Charger qualification test report (Section 16.2.8)
- 16-20 Battery qualification test procedure (Section 16.2.9)
- 16-21 Battery qualification test report (Section 16.2.9)
- 16-22 Truck qualification test procedures (Section 16.2.10)

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- 16-23 Truck qualification test report (Section 16.2.10)
- 16-24 Coupler and draft gear qualification test procedure (Section 16.2.11)
- 16-25 Coupler and draft gear qualification test report (Section 16.2.11)
- 16-26 Equipment noise qualification test procedure (Section 16.2.12)
- 16-27 Equipment noise qualification test report (Section 16.2.12)
- 16-28 Car body preliminary structural tests data (Section 16.2.13.1)
- 16-29 Car body structural test photographic record (Section 16.2.13.1)
- 16-30 Car body structural test procedure (Section 16.2.13.2)
- 16-31 Car body structural test report (Section 16.2.13.12)
- 16-32 Elemental energy test procedure (Section 16.2.13.13.1)
- 16-33 Elemental energy test report (Section 16.2.13.13.1 )
- 16-34 Car body energy test procedure (Section 16.2.13.13.2)
- 16-35 Car body energy test report (Section 16.2.13.13.2)
- 16-36 This has been removed from the Specifications.
- 16-37 This has been removed from the Specifications.
- 16-38 Collision post elastic-plastic test procedure (Section 16.2.14)
- 16-39 Collision post elastic-plastic test report (Section 16.2.14)
- 16-40 Communication system qualification test procedure (Section 16.3.1)
- 16-41 Communication system qualification test report (Section 16.3.1)
- 16-42 Propulsion system qualification test procedure (Section 16.3.2 )
- 16-43 Propulsion system qualification test report (Section 16.3.2 )
- 16-44 Friction brake system qualification test procedure (Section 16.3.3)
- 16-45 Friction brake system qualification test report (Section 16.3.3)
- 16-46 Door system qualification test procedure (Section 16.3.4)
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- 16-159 Burn-in test procedure (Section 16.7.9)

### 16.10 Cited References

The following standards or references were cited in this Section at the referenced location:

AAR M-1001	Design, Fabrication, and Construction of Freight Cars (Section 16.2.11.2)
AMCA Standard 300	Reverberant Room Method for Sound Testing of Fans (Section 16.3.5.2)
ANSI/ASHRAE Standard 37	Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment (Sections 16.3.5.2, 16.3.5.3, 16.3.5.4, 16.3.5.5.3)
ANSI/ASHRAE Standard 41.1	Standard Method for Temperature Measurement (Sections 16.3.5.2, 16.3.5.3)
ANSI Z26.1	Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways – Safety Code (Section 16.2.3)
AHRI Standard 700	Specifications for Refrigerants (Section 16.3.5.5.9)
ASTM E165/E165M	Standard Practice for Liquid Penetrant Examination for General Industry (Section 16.5.14.1)

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ASTM E709	Standard Guide for Magnetic Particle Testing (Section 16.5.14.1)
AWS D1.1/D1.1M	Structural Welding Code – Steel (Sections 16.2.11.2, 16.2.11.5)
49 CFR 223	Safety Glazing Standards-Locomotives, Passenger Cars (Section 16.2.3)
IEC 60349-1	Electric traction – Rotating electrical machines for rail and road vehicles – Part 1: Machines other than electronic-fed alternating current motors (Sections 16.2.6.2, 16.2.6.3, 16.5.3)
IEC 60349-2	Electric traction – Rotating electrical machines for rail and road vehicles – Part 2: Electronic converter-fed alternating current motors (Sections 16-2.6.1, 16.2.6.2, 16.5.3)
IEC 60623	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Vented nickel-cadmium prismatic rechargeable single cells (Section 16.5.8)
IEEE Std 11	IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles (Sections 16.2.6.1, 16.2.6.3, 16.5.3)

### **END OF SECTION 16**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 17  
MATERIALS AND WORKMANSHIP**

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## **SECTION 17: MATERIALS AND WORKMANSHIP**

### **17.1 General**

#### **17.1.1 Quality**

Material and workmanship shall be in accordance with the stated standard or as specified, unless written approval for substitution is obtained.

Inclusion of a material or method in this Section does not indicate approval for application or use in a specific situation. When a material or method is specified in this Section, this Section shall be applicable; however, specific requirements detailed in appropriate Technical Specifications take precedence over this Section.

#### **17.1.2 Standards**

The following domestic standards and specifications define materials for this contract: Federal or Military Specifications or Standards, the Specifications of the Aluminum Association of America, AAR, ANSI, ASME, ASTM, FRA, IEEE, and additional requirements, as specified. Where other or foreign standards are proposed by the Contractor, the Contractor shall submit documentation to Sound Transit for review and approval demonstrating that the proposed standards are the equivalent of the specified standards and specifications. Proposed substitute specifications shall be submitted in both English and the language of the country of origin.

#### **17.1.3 Material Testing**

Testing required to confirm physical properties shall be performed on actual material used in the construction of this vehicle and performed post-NTP of this Contract.

#### **17.1.4 Marking and Storage**

All materials intended for use on these vehicles shall be marked or stored so as to be readily identifiable, and shall be adequately protected during handling and storage.

All stored material subject to corrosion shall be protected by waterproof covers, coatings, or packaging.

Equipment covers, cable entrances, and openings shall be closed to prevent ingress of water or dirt.

All dated material shall have the expiration date clearly marked. Expired material shall not be used.

Material or components which require maintenance during storage shall be properly maintained per the component(s) manufacturer's instructions. The Contractor shall document such maintenance, and provide these records as requested by Sound Transit.

Rejected material shall be clearly marked and stored in an area specifically designated for that purpose.

Rejected material shall be dispositioned by material review board. Material dispositioned as “repair” shall require Sound Transit authorization. Repaired material, components, parts or assemblies must meet the form, fit and function of the as built configuration drawings.

### **17.1.5 Cleaning Agents**

A list of recommended cleaning agents shall be provided for all materials exposed to normal cleaning operations. The recommended cleaning agents shall be available and not prohibited in the U.S. and are subject to Sound Transit review and approval. (CDRL 17-1)

### **17.1.6 Prohibited Materials**

Submit certification that no prohibited materials are used in the vehicle (CDRL 17-2)

The following materials shall not be used in the construction of the vehicle:

- PVC;
- Asbestos;
- Lead, all applications, including in paint and coatings, except for electronics solder;
- Cadmium (except for battery)
- PCBs
- Urethane foam;
- Chlorinated fluorocarbons that may cause environmental problems or handling hazards; Materials that, in their normal installed state, emit products that are known to be toxic or irritants;
- Carcinogenic materials as listed by current Publication of the American Conference of Governmental Industrial Hygienists (ACGIH); and
- Materials in the List of Highly Hazardous Chemicals, Toxics and Reactives, 29 CFR 1910.119, Appendix A

### **17.1.7 Dissimilar Materials**

Dissimilar materials are materials that corrode or otherwise become damaged when in contact with each other.

Connection of dissimilar materials is permitted only at permanent connections and with suitable electrochemical isolation. Such isolation treatments shall be permanent and not require maintenance or replacement for the life of the vehicle.

Dissimilar materials are not permitted at electrical connections or connections requiring disassembly for maintenance or for removal and replacement of equipment.

A list of dissimilar mating surface assemblies proposed by the contractor to be submitted to Sound Transit for approval.

### **17.1.8 Material Reporting Requirements**

Whenever a commercial material is not covered by a specification or standard, the Contractor shall identify the material by the commercial trademark, name, and address of the Supplier. The Contractor shall submit a description and the technical data specifications of the material composition for approval. (CDRL 17-3)

Single-source materials shall not be used unless approved. Approval will be determined on a case-by-case basis. Specification equivalency/benefit data for any substitution to a cited standard shall be submitted to Sound Transit for review and approval.

The Contractor shall keep on file Safety Data Sheets (SDSs) and Technical Data Sheets (TDSs) for all materials (paints, solvents, adhesives, insulation etc.) used in the manufacture of the vehicle, and provide SDS and TDS information to Sound Transit for review. SDSs shall comply with 29 CFR 1910.1200 (g), Safety Data Sheets. A copy of each SDS and TDS shall be submitted to Sound Transit for information. (CDRL 17-4)

The Contractor shall maintain records that trace all materials to their manufacturers and production lots, and shall help verify compliance with quality standards specified or cited in this Specification.

### **17.1.9 Units of Measure**

U.S. inch-standard and metric measurement standards may be used in construction of the vehicle. Each major component and device on the vehicle shall be manufactured to a single standard, and their assembly into the vehicle shall minimize the intermixing of the two standards. U.S. inch and ISO metric parts shall not be intermixed between components of the same system located within the same equipment box, locker, or enclosure.

## **17.2 Standards of Workmanship**

### **17.2.1 Workers**

Vehicle components shall be constructed by workers experienced in the appropriate trades.

Comply with worker training and supervision requirements included in the manufacturing control requirements specified in Section 19, Program Control and Quality Assurance.

### **17.2.2 Use of Drawings**

Design and/or construction drawings shall be readily available where manufacturing is occurring, and shall be used by workers to accomplish and verify their tasks.

Use tooling as defined by the design and/or construction drawings.

Work not expressly detailed on the Contractor's drawings shall conform to the minimum standards of workmanship in this Section.

### **17.2.3 Use of Manufacturing Tools and Interchangeability**

Attachment points in the vehicle and on subassemblies shall be located by jigs, fixtures, laser levels, and similar methods to ensure accurate placement and per-design tolerances.

Like components shall be constructed to the same dimensions and tolerances, hole and subassembly locations, materials and finishes, and shall be interchangeable in the vehicle and between vehicles without modification.

### **17.2.4 Prohibited Practices**

Cut-to-fit, match drilling, filing, and other hand-fitting practices are strictly prohibited. Where such practices appear necessary in construction, perform a prompt review of design and construction methods and implement corrections to avoid these practices, in accordance with manufacturing control requirements specified in Section 19.

### **17.2.5 Metal Fabrication**

Comply with the following requirements:

- In rolled-steel members, camber and sweep, as received, shall not exceed AISC specifications.
- Flat plates shall be sheared or cut using modern metal-cutting technology such as laser cutting or waterjet cutting.
- Structural shapes, pipe, and tube shall be cut to length using band saw or cold cut blade saw. Cut to length by hand held torch is not permitted.
- Holes shall be drilled or die punched. Bolt holes shall not be burned by hand torch. Holes 1.5 in (38 mm) and larger may be cut by modern metal-cutting technology such as laser cutting or waterjet cutting.
- Spacing of holes on connection plates shall have a tolerance of maximum 1/32 in (0.8 mm).
- All metal edges shall be deburred and all sharp edges removed.

### **17.2.6 Machining**

Comply with the following requirements:

- Machine fits shall adhere to ASME B4.1.
- Surfaces receiving power machine cutting or profiling shall have a surface finish of maximum 125  $\mu\text{in}$  (0.003 mm) rms.
- Shafting shall have the ends squared by face off in an engine lathe.
- Chamfers shall be machined on shaft edges; and at edge of bore of press on parts.
- Cut edges shall be de-burred.

## **17.3 Joining**

### **17.3.1 Joint Fitting**

Joints shall be properly fitted, whether exposed or concealed. When not otherwise specified in drawings or specifications, gaps between joints shall be held to a dimension not greater than 10% of the thinner material being joined, or 0.002 in (0.05 mm), whichever is greater. Gaps shall be uniform in width. The edges of panels shall have a smooth, finished appearance.

Where excessive gaps (greater than those permitted by approved drawings or standards) are found to exist at the faying surfaces of structural bolted or riveted connections, metal shims of the same material as that of the deficient part may be used, but only with the written permission of Sound Transit. Shims, if used, shall be permanently fastened to one of the base parts being joined. The use of epoxy or other plastic filler at such locations is expressly prohibited.

### **17.3.2 Metal-to-Metal Connections**

Where metals contact each other, the contact surfaces shall be free of dirt, grease, rust, and scale. Unless specified otherwise, the contact surfaces shall be coated with an epoxy primer as specified below under Paints and Coatings. Metal primer may be omitted for like-stainless steel to like-stainless steel joints.

For proper treatment of a connection involving aluminum, refer to the Aluminum section, below.

### **17.3.3 Wood-to-Metal Connections**

Where wood and ferrous metal surfaces are placed together or holes drilled into or through the wood, the wood shall be coated with two coats of epoxy paint, and the metal shall be coated with primer, as specified in the Paints, Graphics, and Coatings section, below.

All bolts or rods passing through wood shall be coated with primer.

If aluminum parts are used for any purpose, wood-to-metal connections shall be in accordance with ALCOA Technical Report No. 524 "Specifications Covering Use of Aluminum in Passenger Carrying Railway Vehicles."

### **17.3.4 Wood-to-Wood Connections**

Where wood and wood are placed together, both abutting surfaces shall be coated with two coats of epoxy.

## **17.4 Fasteners**

### **17.4.1 General**

#### **17.4.1.1 Scope**

Fasteners include threaded fasteners, associated nuts and washers, quick release fasteners, rivets, and locking pins. Submit a design package. Fasteners of the same configuration used by the same

vendor shall utilize the same part number throughout the vehicle. The Contractor shall provide a fastener list for all car body, interior, exterior, and subsystems including vendor, part number and manufacturing standard the fastener is manufactured to. All fastener types shall be readily available within the USA. (CDRL 17-5)

#### **17.4.1.2 Design**

The Contractor shall be responsible for selecting fastener types, sizes, styles, lengths, materials, grades, and finishes that will satisfy the requirements of the design and meet the requirements of the Specifications.

The Contractor shall minimize the number of different sizes and styles of fasteners used.

A single standard, either inch-standard fasteners or ISO-Metric fasteners, shall be adopted for the fasteners used in the vehicle.

#### **17.4.1.3 Material**

Bolts, screws, nuts, washers, and other related fastening devices shall be steel or stainless steel. Aluminum fasteners are generally prohibited except where specifically specified and approved by Sound Transit. Aluminum threaded fasteners are prohibited.

Use of stainless steel fasteners is acceptable for most exterior applications. Where stainless steel fasteners are used shall be assembled using anti-seize lubricants. Application of anti-seize will reduce or eliminate galling between mating threads of the fastener.

Except for fasteners internal to electrical or electronic components, plastic screws, bolts, nuts, or other plastic fastening components shall not be used unless specifically approved.

#### **17.4.1.4 Plating**

Carbon steel, alloy steel, and martensitic stainless steel fasteners shall be plated with zinc, unless specifically waived by Sound Transit. Zinc plating shall conform to ASTM B633, Type II, and SC2, SC3, or SC4.

Plating materials other than zinc, and plating of any type on high strength fasteners, are subject to approval by Sound Transit. See Coatings other than Zinc section, below, for requirements for other than zinc plating, if approved by Sound Transit.

Cadmium plated fasteners are not permitted.

#### **17.4.1.5 Prohibited**

The following are prohibited:

- Protruding fastener heads including screws, mounting bolts or similar items on the vehicle interior or exterior, except for those appointments that cannot be built into the structure in any other manner.

- Self-drilling and self-tapping screws.
- Tapped holes in structure, brackets, and other vehicle assemblies. Tapping plates shall be used when installing fasteners into vehicle structure or subassemblies.
- Thread-sealing compounds, except for anti-vibration treatments (such as Loctite) where approved.

## **17.4.2 General Requirements for Threaded Fasteners**

### **17.4.2.1 Threaded Fastener Types**

Provide through bolts, floating nuts, hex nuts and similar devices. Threaded fasteners shall have hex or hex socket grip for use with common hand tools. Where specified by the equipment section(s) of the Specifications, anti-tamper head designs shall be used. Philips, flat head, or other designs are prohibited except in small electronic assemblies or where specifically approved. Threaded insert fasteners are not permitted.

Tamper proof fasteners shall be considered as hex socket head type or otherwise proposed by the contractor to Sound Transit for approval.

### **17.4.2.2 Identification**

Inch fasteners shall be identified as required by applicable U.S. standards as defined by ASTM, SAE and IFI. Metric fasteners shall be identified as required by applicable ISO standards.

### **17.4.2.3 Maintenance Access**

Provide access for maintenance or replacement of threaded fasteners and nuts. Bolts used to secure apparatus where the bolt head is inaccessible shall not be permitted.

All fasteners used for the assembly of a component, assembly, bracket or any other assembled joint must be accessible utilizing standard commercially available tools. Tools not meeting this requirement shall be deemed as “special tools” which shall be provided by the contractor minimum 5 each or as approved by Sound Transit depending on use requirements.

### **17.4.2.4 Thread Projection**

At proper torque, a minimum of 1-1/2 full screw threads shall project beyond the nut or tapped hole or any other captive fastener. Special considerations may be proposed to Sound Transit for approval.

When used without elastic stop nuts, comply with the following:

- Bolts 1/4 in (6.4 mm ) diameter or less shall project a maximum of 1-1/2 full threads plus 1/4 in (6.4 mm); and
- Bolts greater than 1/4 in (6.4 mm) diameter shall project a maximum of eight full threads, unless otherwise approved by Sound Transit.

With elastic stop nuts, bolt threads shall not project more than 1/4-in (6.4 mm), regardless of bolt size.

#### 17.4.2.5 Bolt Hole Size

Bolt hole clearances shall not exceed the recommendations of Industrial Fasteners Institute (or ISO 273).

#### 17.4.2.6 Tapping Plates

If tapping plates are used, comply with the following requirements:

- Minimum Thickness: Equal to diameter of the bolt for which the tapping plate is intended.
- Strength: Same standards as the equivalent nut.
- Installation:
  - Attach to the structure with mechanical fasteners unless otherwise approved.
  - Drill a clearance hole in the structure for the bolt.

#### 17.4.3 Special Requirements for Structural Fasteners

##### 17.4.3.1 Scope

This Section applies to structural and load carrying bolts. It includes structural bolts for undercar and roof equipment. Fasteners used on the side sill to attach heavy equipment brackets are considered structural fasteners.

##### 17.4.3.2 Material and Property Grade (or Class)

Structural or load carrying bolts shall be medium carbon steel.

Structural or load carrying bolts in any application and general-purpose bolts for undercar equipment shall be sized to the design strengths for Grade 2 bolts, but actual hardware used shall be a minimum Grade 5. Inch (or metric) bolts and nuts shall conform to minimum requirements as indicated in the table below, including markings. Stronger fasteners shall be used if required for the application.

<b>Structural or Load Carrying Bolts: Minimum Grade</b>		
	<b>Standard</b>	<b>Property Grade (Class)</b>
<b>Bolts</b>	SAE J429 or ASTM A449 (ISO 898-1 )	5 (8.8)
<b>Nuts</b>	SAE J995 (ISO 898-2)	According to bolt strength (see below)

Nuts shall have a material proof strength equal to or greater than the material ultimate tensile strength of the fastener with which it is used. For applications where this is not achievable, submit

specific calculations showing that the nut is stronger than the bolt to prevent undetected internal thread stripping.

#### **17.4.3.3 Minimum Size**

Bolt diameter shall be minimum 3/8 in (10 mm), regardless of design load. Stronger fasteners shall be used if required for the application.

#### **17.4.3.4 Application Requirements**

Under-vehicle equipment shall not be supported by bolts in tension.

#### **17.4.3.5 Required Documentation**

Structural fasteners shall have documentation identifying manufacturer; purchase specifications; fastener material or grade; and finish, including plating material and specifications, when applicable. This documentation shall be available for examination by Sound Transit at the Contractor's QA department. Obtain and hold the documentation for a period not ending before expiration of the last vehicle's warranty period, whether the buyer is a subcontractor, supplier, or the Contractor.

### **17.4.4 Additional Requirements for Safety-Related Fasteners**

#### **17.4.4.1 Scope**

Safety-related fasteners include, but are not limited to, those applied to trucks, bolsters, brake equipment, couplers, and power collection devices.

A fastener is safety related if failures cannot be tolerated; that is, if even a single fastener fails, there is a possibility of brake failure, derailment, or accident.

In the event of a dispute, Sound Transit will make the final determination of which fasteners are safety related.

#### **17.4.4.2 Testing for Conformance to Purchase Specifications:**

The Contractor shall have a representative sample of each production lot of fasteners tested for conformance to purchase specifications by an independent laboratory accredited by the American Association of Laboratory Accreditation (AALA), or approved equal:

- A production lot is defined as one size of fastener, from one manufacturer, and produced during one continuous production run. Fasteners not meeting this definition of production lot shall be treated as separate lots.
- Testing shall be performed using sample quantities as proposed by the Contractor and approved by Sound Transit.
- Tests conducted shall confirm that fastener material meets specified chemistry and strength requirements.

The Contractor shall obtain certified test results from the testing laboratory and hold the documents for a period not ending before expiration of the last vehicle's warranty period. (CDRL 17-6)

#### **17.4.4.3 Testing for Hydrogen Embrittlement**

Safety-related fasteners that are plated or chemically cleaned shall have certification of hydrogen-embrittlement testing:

- The certification shall be based on a representative sample of actual production fasteners that have been tested by the original equipment manufacturer, Contractor, or a supplier for hydrogen embrittlement following SAE USCAR 7 procedures. The plating process shall be certified to ASTM F519 procedures
- An ASTM F606 wedge-test sample may be used in place of the ASTM F519 standard samples.
- Test loads shall be a minimum of 80% of yield strength or proof load and held for a minimum of 168 h. Any failures shall result in the rejection of the entire lot.

The Contractor shall obtain certified test results from the testing laboratory and hold the documents for a period not ending before expiration of the last vehicle's warranty period.

#### **17.4.5 Coatings other than Zinc**

Coatings other than zinc are permissible only if approved by Sound Transit. If approved, they must be qualified by testing per ASTM B117 with no red rust or visible corrosion products after 96 h of exposure.

The Contractor shall submit qualification results for each process used at each Supplier applying the proposed coating. In order to use an alternate coating, the vendor shall submit the following:

- Coating manufacturer's product data including required thickness;
- ASTM B117 test results from an accredited third party laboratory;
- Documentation of torque/tension characteristics; and
- A statement from the coating manufacturer regarding the propensity for the coating process to cause hydrogen embrittlement of the fastener during coating.
- Examples of plating use by other agencies and/or applications with similar application and environment with a minimum 5 year history.

For fasteners less than Grade 5 (or 8.8), if the coating has the possibility of causing hydrogen embrittlement, each lot shall be tested for hydrogen embrittlement. For fasteners Grade 5 (or 8.8) or higher, each lot shall be tested for hydrogen embrittlement regardless of the coating's propensity for hydrogen embrittlement, including OEM plated zinc or yellow bolts, in accordance with the Testing for Hydrogen Embrittlement section, above.

If the proposed coating results in a change in the K-value for the plated fastener to outside the range of 0.13-0.15, as defined by IFI-143, the Supplier shall use the alternate coating on all fasteners within the particular LRU. The LRU shall contain an indelible label identifying the coating type used within the LRU and the required torque values for each size fastener used. Fasteners internal to a subcomponent within an LRU may use the standard coating system if they are not subject to removal during Sound Transit's maintenance activities.

#### **17.4.6 Self-Locking Nuts and Washers**

##### **17.4.6.1 Self-Locking Nuts**

Self-locking nuts (locknuts) shall be used throughout, where appropriate for the application. Non-self-locking nuts with lock washers may be used in non-structural applications upon approval by Sound Transit, or where required by the Specifications.

Prevailing-torque-type locknuts shall be regular-height, nylon-insert type, self-locking ESNA stop nuts, or approved equal conforming to inch fastener standards found in the IFI Inch Fastener Standards Book (or IFI ISO Standards Handbook) or NASM21044.

Nylon insert lock nuts shall not be used near heat sources that will exceed the locknut manufacturer's recommended maximum temperature.

All-metal prevailing torque-type locknuts shall be used only where there is insufficient clearance to install ESNA type locknuts, or where the locknut is exposed to temperatures above manufacturer's recommended maximum temperature.

##### **17.4.6.2 Safety Wire**

Safety wire shall be installed per the methods described in FAA Advisory Circular AC43.13-1B, chapter 7.

##### **17.4.6.3 Washers**

Washers shall be suitable for the application and matched with the property grade (or class) of the bolt with which it is used. Where high strength fasteners are applied, washers shall be hardened. Washers shall comply with inch fastener standards found in the Industrial Fasteners Institute (IFI) Inch Fastener Standards Book (or ISO standards found in the IFI ISO Standards Handbook).

Provide washers under the heads of bolts and under nuts. Provide flat washers on both sides of electrical connections, that is, under the bolt head and the nut.

Split-ring lock washers are prohibited except where specifically approved. Lock washers, if used, shall conform to IFI standards. Lock washers shall not be used in structural applications or in fatigue applications where the fastener must be torqued and marked. If applicable, prevailing torque nuts shall be used for these applications.

Other types of washers, including Belleville washers, may be used for special applications with approval by Sound Transit.

### **17.4.7 Torquing**

Specify fastener torque value on the Shop Assembly Drawing. Torque threaded fasteners to a value assigned by the designer, to standard torque values recommended by the fastener manufacturer as appropriate to the application.

Safety-related fasteners, including truck and brake equipment bolts and all fasteners exposed to fatigue loads, shall be torqued to a minimum preload equal to 75% of their proof load and "torque striped" after torquing by paint or other approved means.

Fastener installation torque for standard oiled or waxed bolts with standard or heavy hex nuts shall be calculated from Industrial Fasteners Institute equations in "Torque Book for Fasteners." Use a value for coefficient of friction, "K", of 0.18 for unplated and 0.15 for plated threads unless another coefficient of friction was established during qualification of an alternate thread plating or coating.

Self-locking nuts shall be torqued in accordance with their manufacturer's recommendations, or the Contractor may conduct tests to determine the proper installation torque.

Torquing shall be performed only by calibrated torque wrench.

For those nuts or bolts requiring "torque striping," Sound Transit may require bolt torque-tension tests to verify that installed preload is equivalent to 75% of proof loads. All fasteners ¼" (6mm) and larger shall be torque striped.

The contractor and its sub-contractors shall utilize different color torque striping in order to identify the source of the last torque applied.

### **17.4.8 Other Fasteners**

#### **17.4.8.1 Quick Release Fasteners**

Quarter-turn fasteners shall have a minimum shank diameter of 1/4 in (6.4 mm), be of adequate strength, and as manufactured by Southco, or approved equal.

Quarter-turn or other quick-release type fasteners may have Philips, tamper proof, hex socket or hex heads.

#### **17.4.8.2 Rivets and Lock Pins**

Rivets and lock pins shall be austenitic stainless steel or aluminum as appropriate to the materials being joined. Structural steel rivets shall conform to ASTM A502.

Rivets shall not be exposed to passengers.

Rivet holes shall be drilled within the sizes and tolerances specified by the rivet manufacturer.

Removed and replaced rivets shall not exceed the manufacturer rivet hole size requirements. In the event a rivet hole has exceeded the manufacturer's requirements, the rivet hole shall be reamed to the size required such that the next larger rivet may be driven securely.

Rivet mandrels after installation process shall not protrude beyond the head of the rivet. Rivet heads shall remain smooth and not have sharp edges.

Swage-locking (Huckbolt-type) fasteners shall conform to MIL-P-23469.. Swage locking fasteners shall be installed in accordance with the manufacturer's instructions. Collars or pins not meeting the manufacturer's requirements shall be removed by the contractor and the installation repeated. Sound Transit will make the final determination whether an application is hazardous to maintenance personnel.

## **17.4.9 Location- and Application-Specific Requirements**

### **17.4.9.1 Interior – Fasteners Exposed to Passengers**

In the event the proposed fastener is approved by Sound Transit, the Contractors shall provide bright or finished fasteners to match the surfaces being joined. Install such that the fastener head is flush with the mating surface:

- Bright finished fasteners may be either austenitic or plated martensitic stainless steel.
- Bright finished fasteners used for stanchions shall be austenitic grade stainless steel.
- Screws, bolts, and nuts shall be used only if specifically approved.

### **17.4.9.2 Exterior – Fasteners Exposed to Passengers**

Stainless steel vehicle body: Fasteners shall be austenitic stainless steel.

Aluminum vehicle body: Fasteners shall be austenitic stainless steel or aluminum alloy fasteners, as appropriate to the design and appearance requirements.

### **17.4.9.3 Access Required**

For access panels, equipment box covers, or other areas requiring access, comply with the following:

- Fasteners shall be captive to the panel or cover in which they are used.
- Captive fasteners shall incorporate standard head designs.
- Where operator or maintenance access is expected more often than every five years, provide quarter-turn fasteners.
- Where accessible to passengers, provide tamper-resistant type fasteners of a single style.

#### **17.4.9.4 Heat Producing Equipment**

When making connections to heat producing apparatus, take into consideration the thermal expansion of the components for selection of fastener materials:

- If the joined components are high expansion alloys such as copper or austenitic stainless steel, use austenitic stainless steel fasteners.
- If the joined components are low expansion materials such as carbon steel or ferritic stainless steel, use zinc plated carbon steel fasteners of minimum Grade 5 (Class 8.8).
- Cadmium plated fasteners are not permitted.
- Use only fasteners rated by fastener manufacturer for maximum ambient temperatures.

### **17.5 Stainless Steel**

#### **17.5.1 General**

Permitted uses of structural stainless steels are specified throughout this Specification. Ferritic stainless steels shall be painted where exposed to passengers or the weather. Austenitic stainless steels may be unpainted. Unpainted stainless steels exposed to passengers shall be a single grade of austenitic stainless steel in which both the color and surface finish of abutting pieces shall match, except where the design specifically calls for contrasting appearance.

#### **17.5.2 Austenitic Stainless Steel**

All structural or non-structural austenitic stainless steel components assembled by fusion or resistance welding shall conform to APTA PR-CS-S-004-98. Structural austenitic stainless steel components assembled by fusion or resistance welding that will be visible to passengers in the finished vehicle shall be of UNS S20153 or S30153 conforming to the requirements of APTA PR-CS-S-004-98. Other stainless steels conforming to ASTM A666 are acceptable for non-welded applications.

General requirements for delivery of stainless steel shall be as required by the Certification Provisions of APTA PR-CS-S-004-98 or ASTM A666 as applied above. Stainless steel to be used in structural applications shall be tested for susceptibility to intergranular corrosion in accordance with ASTM A262. Practice A of ASTM A262 shall be used to accept material only; Practice E is required for final determination of acceptance or rejection of material that is not acceptable by Practice A.

#### **17.5.3 Ferritic Stainless Steels**

When specified, ferritic stainless steel conforming to ASTM A176 may be used for car body structural sheeting up to 4 mm thickness. Ferritic stainless steel sheet shall have a ductile-to-brittle transition temperature (DBTT) or nil-ductility temperature (NDT) below 0°C. Weld heat-affected-zones shall also have a DBTT or NDT below 0°C. Ferritic stainless steel sheet shall have a balanced composition (low carbon and/or suitable titanium content) that will, for all conditions of fabrication and assembly into the car body, inhibit formation of martensite and limit chromium depletion in

weld-heat-affected zones so that material shall meet ASTM A763 requirements for resistance to intergranular corrosion.

General requirements for delivery of stainless steel shall be as required by ASTM A480/A480M.

Where ferritic stainless steels are welded to other structural steels, the less-noble steel shall be painted with weld-through primer.

#### **17.5.4 Testing**

The Contractor shall prepare (or have prepared), submit, and receive approval of a test and inspection plan for acceptance of all stainless steel to be used in welded applications prior to purchasing any such material. The tests and inspections shall verify that the stainless steel conforms to specified requirements. For austenitic stainless steels, the test and inspection plan shall include frequency of submittal of certifications in accordance with Certification Provision of APTA PR-CS-S-004-98 or ASTM A666 and frequency of submittal of checks for susceptibility to intergranular corrosion in accordance with ASTM A262. For ferritic stainless steels, the test and inspection plan shall include frequency of submittal of checks for susceptibility to intergranular corrosion in accordance with ASTM A763. (CDRL 17-6)

### **17.6 High-Strength Low-Alloy Steel**

#### **17.6.1 General**

High-Strength, Low-Alloy (HSLA) steel structural shapes, plates, and bars shall, as a minimum, conform to the requirements of ASTM A588/A588M, where available. Plate steel may alternatively conform to ASTM A710/A710M, Grade A, Class 1 or Grade C, Class 1. Where not available in A588, hot rolled or formed structural shapes conforming to ASTM A36/A36M may be used for limited applications including equipment supports and jack pads. General requirements for delivery of HSLA shapes, plates, and bars shall be as required by ASTM A6/A6M.

Welded HSLA steel shall develop 15 ft-lbs (20 Nm) Charpy V Notch impact strength in the CGHAZ (Coarse grain heat affected zone) 0.04 in (1 mm) from fusion area at -20°F (-29°C).

Cold and hot rolled HSLA sheet and strip shall, as a minimum, conform to the requirements of ASTM A606/A606M, Type 4. General requirements for delivery of these products shall be as required by ASTM A568/A568M.

Other low-alloy, high-tensile steel that meets or exceed the above minimum requirements may be used, provided its detailed specifications are submitted and approved as equivalent, or better material, for the proposed applications. All HSLA steel shall be applied according to its specification properties.

#### **17.6.2 Testing**

The Contractor shall prepare (or have prepared), submit, and receive approval of a test and inspection plan for acceptance of all structural steel in accordance with the requirements of this Section before purchasing any such material. The test and inspection plan shall include provisions

for submission of reports and certification to Sound Transit for each shipment in accordance with the applicable requirements of Purchase Specification and specified CGHAZ impact tests. (CDRL 17-6)

## **17.7 Steel Castings**

### **17.7.1 General**

The Contractor shall be responsible for selecting casting grade, composition, strength, and finishing. However, steel castings used in the truck structure, bolster, and center bearing arrangement shall, as a minimum, meet AAR Specification M-201, Grade "B", plus 2% nickel. These castings shall be heat treated to develop a minimum tensile strength of 75,000 lbf/in<sup>2</sup> (517 N/mm<sup>2</sup>), a minimum yield strength of 48,000 lbf/in<sup>2</sup> (331 N/mm<sup>2</sup>), elongation of not less than 25% in 2 in (50 mm), and reduction of area of not less than 50%. Also, steel castings used for coupler, drawbars, and anchors shall meet AAR Specification M-201, Grade "C" quenched and tempered. All structural steel castings shall be magnetic particle inspected over the entire surface after heat treatment.

### **17.7.2 Design Qualification of Structural Castings**

One casting, selected by Sound Transit from the first lot of production castings, shall be subjected to a qualification test of the casting design by the Contractor. Qualification tests shall include radiographic examination for material soundness in accordance with the Non-Destructive Testing and Inspection section, below, and any mechanical testing, including static and fatigue load testing of truck frames and bolsters.

Acceptance levels for the design qualification radiographic examinations shall be selected by the Contractor as appropriate for the service intended, subject to approval by Sound Transit before any castings are produced. Radiographs shall meet the requirements of ASTM E94 with quality level in the area of inspection at least 2% (2-2T).

Submit a qualification test report. (CDRL 17-6) The production of any castings before receipt of Sound Transit's approval of this report shall be at the Contractor's risk. All radiographs that resulted from the qualification test shall be made available to Sound Transit for review. In case the casting selected for qualification fails to qualify, a plan of action including details of how failed material will be handled shall be included in the qualification test report. Once a design is qualified and accepted by Sound Transit no changes shall be made in the casting pattern, technique, heat treatment, or material composition without requalification in accordance with the requirements of this Section.

### **17.7.3 Quality of Structural Castings**

All structural castings supplied shall be equal to or better than the design qualification castings in all respects. The casting Supplier or Contractor shall test, inspect and accept castings in accordance with procedures described in AAR M-201. In addition, the inspections below shall be performed, and a written report of the results of the tests and inspections shall be furnished for each lot of castings produced. (CDRL 17-6)

### **17.7.3.1 Magnetic Particle Inspection**

Magnetic particle inspections of all surfaces of each casting shall be conducted according to ASTM E709, by personnel certified to NAS 410 or an employer-based or centrally certified program with equivalent or better requirements. With respect to structural castings, including coupler, bolster, articulation (where applicable), gear unit and truck castings, the maximum permissible magnetic particle indications shall be 1/4 in (6.4 mm) in the direction transverse to the usual direction of loading, and 3/4 in (20 mm) in the direction parallel to the usual direction of loading.

### **17.7.3.2 Radiographic Inspection**

Radiographic inspection shall be conducted according to the requirements of ASTM E94 using reference radiographs to ASTM E446. A sampling frequency shall be proposed by the Contractor and submitted for Sound Transit approval. (CDRL 17-6)

All structural castings shall be 100% inspected. Structural castings shall not exceed severity Level 3 of ASTM E446 in all critical areas of such castings and shall not exceed Level 5 in all other areas of the castings. During demonstration that the stated severity level requirements of ASTM E446 have been met, successively-produced castings shall be reinspected by radiography in the defective areas shown in the prior radiographic inspection.

### **17.7.4 Repair Welding and Cast-Weld Design**

Repair welding of castings will be permitted, provided the casting Supplier performs all repair welds according to the structural welding requirements of ASTM A488/A488M. Castings shall be heat treated after all welding is completed.

For cast-weld designs, the entire length of all assembly welds on any welded assembly of several separate castings selected for design qualification shall be radiographically and magnetic particle inspected in accordance with the Non-Destructive Testing and Inspection section, below, except use reference radiographs from ASTM E390.

### **17.7.5 Disposal of Non-conforming Castings**

If castings are found to be non-conforming to requirements determined by the design qualification castings, the material shall be repaired, re-tested, and re-inspected or destroyed at the Contractor's expense.

## **17.8 Aluminum**

### **17.8.1 General**

Aluminum alloy mill products shall be identified by Unified Numbering System designations and shall conform to "Aluminum Standards and Data" published by the Aluminum Association. Aluminum alloy castings used for door thresholds shall conform to ASTM B26/B26M, ASTM B85/B85M, or ASTM B108/B108M. Aluminum alloy forgings shall conform to ASTM B247. Copies of all test reports for sheet, extrusion, and forgings used in the car structure shall be submitted to Sound Transit. (CDRL 17-6)

### **17.8.2 Design Stresses**

Aluminum structural members shall be designed so that calculated stresses under the specified AW4 passenger load do not exceed the allowable stresses listed in the "Aluminum Design Manual," published by The Aluminum Association, for bridge and similar type structures. Make proper allowance for the effects of fatigue, for column and plate stability effects, and for strength reduction at welded regions. Permissible fatigue stresses under the specified AW4 passenger load shall be established, with approval based on available relevant research data or on prototype testing under the variable load patterns expected to occur in service.

The use of aluminum as structural members must be approved by Sound Transit.

### **17.8.3 Fabrication and Fastening**

The forming of aluminum parts; joining of parts by bolting, riveting, and welding; and the protection of contact surfaces shall, as a minimum, conform to the requirements of ALCOA Technical Report No. 524, "Specifications Covering Use of Aluminum in Passenger Carrying Railway Vehicles", except as otherwise specified.

Fabrication techniques shall be such that the strength and corrosion resistance of the aluminum shall not be impaired nor the surface finish permanently marred or discolored during construction.

### **17.8.4 Protection of Contact Surface**

Take measures suitable to the design involved to prevent the risk of direct metal-to-metal contact and resultant possible electrolytic corrosion. Specific measures proposed by the Contractor shall be approved. The following instructions shall be the minimum protection.

Aluminum alloy surfaces shall not be secured to or make direct metal-to-metal contact with the surfaces of copper, copper-bearing aluminum alloy, brass, bronze, silver, nickel, nickel alloys, nickel-plated parts, lead, tin, or wood.

The contact surfaces of aluminum alloy with aluminum alloy shall be painted with zinc chromate primer before securing.

The surfaces of aluminum alloy parts secured to steel parts shall be protected with a one-part polysulfide sealant, zinc chromate paste, mica insulation joint material, or an approved equivalent material which completely covers the faying surfaces. The insulating material shall be non-hygroscopic and, if fibrous, shall be impregnated with bitumen or an approved, non-corrosive, water- and moisture-repellant substance. After driving, fasteners shall be primed and painted with red oxide or aluminum paint.

Stainless steel and carbon steel fasteners plated with zinc shall be coated with zinc chromate paste before installation. Where possible, only the head and the shank of the bolt shall be in contact with the aluminum part when secured in place. Suitable bushings may be used in place of the zinc-chromate paste.

### **17.8.5 Interior Trim**

Where unpainted aluminum is exposed to contact by passengers, it shall have a clear (natural) anodic finish. The finish process shall be ALCOA's "Alumilite 204" with a minimum coating thickness of 0.0004 in (0.01 mm) and a minimum coating weight of 21 mg/in<sup>2</sup> (3.25 mg/cm<sup>2</sup>), or approved equal process.

### **17.9 Welding and Brazing**

#### **17.9.1 General**

The Contractor shall be responsible for the quality of its own welding and brazing and that done by its Suppliers and Subcontractors. Cleaning prior to welding shall be in accordance with applicable parts of MIL-HDBK-132, Section 2, Cleaning Materials and Processes, or AWS recommended practices.

#### **17.9.2 Structural Welding**

All structural welding practices shall be according to requirements of AWS D1.1/D1.1M (for steel 1/8 in (3.2 mm) and thicker), AWS D1.2/D1.2M, AWS D1.3/D1.3M (for steel thinner than 1/8 in (3.2 mm)), AWS D1.6/D1.6M, AWS D15.2/D15.2M and the AWS Welding Handbook. Requirements for cyclically loaded structures shall be applied. Cast steel welding shall be according to ASTM A488/488M. Resistance welding shall be in accordance with AWS D17.2/D17.2M.

Weld heat-affected zones (HAZ) and weld metal shall be limited to maximum allowable stress values in ASME BPVC, Section VIII, Table UHA-23 for UNS S20100 stainless steel and Table UW-12 rating of welds. Fatigue allowable stresses shall not exceed the lesser of fatigue limits in AWS D1.1/D1.1M, or 50% of the joint strength level calculated from ASME maximum allowable stress values. Higher values shall be used only if qualified by Contractor tests.

#### **17.9.3 Welding Procedure Qualification**

Structural welding procedures shall be qualified in accordance with the applicable AWS requirements for steel, stainless steel or aluminum. Qualification of dissimilar metal welding (stainless to HSLA) shall be qualified in accordance with the requirements of AWS D1.6/D1.6M. Procedure qualification records for dissimilar metal welds shall include a microhardness traverse encompassing the weld, both base metals, and both heat affected zones (HAZ), showing that the hardness never exceeds 400 HV. Structural welding procedures shall be qualified to meet impact requirements specified in the Toughness of Welded Assemblies section, below. No structural welding procedures shall be exempt from qualification by testing. Pre-qualified welding procedures will not be accepted. Structural welding procedures shall be in accordance with AWS and submitted for review and approval as specified in the Contractor Documentation section, below.

#### **17.9.4 Welder Qualification**

Welders shall make only those welds for which they have been qualified according to the requirements of the AWS, ASME BPVC Section IX, ASTM A488/488M, or other approved

qualifying procedures. Records of welder qualification tests shall be available for review at Sound Transit's request.

### **17.9.5 Inspection**

The Contractor shall inspect all structural welds according to the applicable AWS or ASTM specification. In addition to visual inspection specified for all welds, nondestructive surface inspection (dye penetrant or magnetic particle methods, as appropriate) shall also be used to inspect all first production welds. The Contractor shall specify a sample nondestructive inspection rate for all subsequent welds, prior to the start of production. (CDRL 17-7)

On the first structure, all full penetration welds shall be nondestructively, volumetrically inspected (ultrasonic or radiographic methods) according to the applicable AWS requirements. The Contractor shall specify an appropriate sampling plan for volumetric inspection of subsequent full penetration welds for approval prior to the start of production. (CDRL 17-7) The proposed test welds shall be selected from among welds that are most critically loaded as decided by calculations or load test results. With approval, destructive sectioning and metallurgical examination may be substituted for some or all of the required volumetric inspection requirements for production welds. Sound Transit reserves the right to inspect any weld at any time in the manufacturing process. The contractor shall specify hold point inspections for structural welding and witnessed by the Sound Transit representative.

On the first structure, all dissimilar metal stainless steel to carbon/HSLA steel welds shall be nondestructively inspected by dye penetrant methods. Sample welds shall be sectioned and examined metallographically to determine HAZ hardness, which shall not exceed 400 VH (Vickers Hardness). The Contractor shall submit a random sampling plan for additional metallographic examinations of welds for approval. (CDRL 17-7) The minimum acceptable sampling plan shall require inspection of one weld sample for every 300 production welds made.

### **17.9.6 Post-Weld Cleaning Requirements**

All welds exposed to passengers or on sliding contact surfaces of truck frames and bolsters shall be completely cleaned of all spatter. Stainless steel welds to be exposed either to passenger view or to potentially corrosive elements, such as weather or car cleaning agents, shall be cleaned to bright metal, free of any oxidation or tinting.

### **17.9.7 Contractor Documentation**

All welding procedures and documents, including Welding Procedure Specifications (WPS), Procedure Qualification Records (PQR), and Resistance Spot Welding Schedules (RSW), shall be submitted for approval before application. (CDRL 17-7) Specifications for purchase of welding electrodes, welding wires, and cover gases shall be submitted for approval before their application. (CDRL 17-7)

### **17.9.8 Special Welding**

Procedures for structural welding of stainless steel to HSLA, or other combinations of metals or conditions not covered by AWS specifications or codes, shall be submitted for approval. (CDRL 17-7)

Austenitic stainless steel electrodes or wire shall be used to join carbon or HSLA steels to stainless steels.

### **17.9.9 Resistance Welding**

Resistance welding of stainless or carbon steels shall be according to AWS D17.2/D17.2M, Class B for structural applications and Class C for non-structural applications. Contractor-proposed deviations from AWS D17.2/D17.2M, including, but not limited to, weld nugget diameter, tension shear strength, and minimum spacing, shall be submitted and approved before application on production hardware. (CDRL 17-7)

Design strengths higher than standard certification and production strength requirements shall be qualified according to AWS D17.2/D17.2M. This requires a test lot size of 180 spot welds for Class B and 50 welds for Class C. Additional thickness combinations with the same increased strength ratio may be qualified by 25 spot weld shear tests plus 3 macrosections. Of the 25 shear test specimens, 20 may be recorded from production witness tests taken from 20 consecutive production days (not calendar days). The Contractor shall submit records of the settings, ultimate shear strength, weld diameter, and weld penetration for approval. (CDRL 17-7)

Surface indentation shall not exceed 20% of material thickness (t) or 0.01 in (0.25 mm), whichever is greater. However, for exterior resistance-welded areas exposed to passenger view, indentation shall not exceed 10% of t or 0.005 in (0.13 mm) whichever is greater. For exposed welds, vary welding parameters and conditions within their acceptable ranges to minimize indentations. Remove surface burn and discoloration by chemical cleaning, or an approved equal method, and sanding or polishing to match the surrounding surface.

Production witness welds shall be made and tested in accordance with the requirements of AWS D17.2/D17.2M for the applicable class of welds (B or C). Production witness specimens shall also be tested whenever a change in any of the following occurs:

- Operator;
- Material, material thickness, or combination of thicknesses;
- Electrodes; or
- Settings.

In lieu of the production witness specimens required by AWS D17.2/D17.2M, the Contractor may demonstrate that sufficient weld quality is maintained either by a regimen of in-situ nondestructive testing (NDT) of 100% of the actual production resistance welds or by the use of computerized adaptive controls of the resistance welding equipment. The Contractor must demonstrate that the NDT process or adaptive control procedures can achieve reliability of at least 99.5% of that accomplished by the standard destructive testing regimen.

### **17.9.10 Resistance, Spot Weld and Intermittent Weld Spacing**

Spacing of resistance and spot welds shall be according to approved structural drawings. Spacing shall not exceed 2 in (50 mm) plus twice the weld nugget diameter for any structural application, including car body side sheets. Intermittent fusion-weld spacing pitch shall not exceed 5 in (127 mm) for 2 in (50 mm) (minimum) weld lengths (40% minimum of length welded).

### **17.9.11 Toughness of Welded Assemblies**

The Contractor shall prove all welded steel structures are above the ductile-brittle transition temperature for the specified environmental exposure. Specifically, the weld metal, heat-affected zone (HAZ), and base metal shall resist service impact loads at the lowest specified operating temperature without brittle failure. In the absence of prior operating history, and if the Contractor's approved design does not require greater toughness, the minimum impact value for Charpy V-notch specimens shall be 15 ft-lbf (20.4 J) of absorbed energy at the lowest specified operating temperature. Welding procedure qualifications require impact tests to verify the specified toughness.

### **17.9.12 Torch Brazing**

All brazing, defined as heating above 840°F (450°C), shall follow the recommendations contained in the AWS Welding Handbook, Volume 2. Procedures and personnel who perform brazing work shall be qualified in accordance with AWS B2.2/B2.2M.

### **17.9.13 Torch Soldering**

All structural (not electrical) soldering, defined as heating below 840°F (450°C), shall follow the recommendations contained in the AWS Welding Handbook, Volume 2 . Procedures and personnel who perform torch soldering shall be qualified through the preparation and testing of samples of production torch soldering. Test samples shall be prepared and submitted for approval before production torch soldering. (CDRL 17-7)

## **17.10 Non-Destructive Testing and Inspection**

### **17.10.1 Magnetic Particle Testing**

Where specified or required, perform magnetic particle testing in accordance with ASTM E709, using wet fluorescent particles. Inspections shall be by personnel certified to NAS 410.

### **17.10.2 Dye Penetrant Inspection**

Where specified or required, perform dye penetrant inspection in accordance with ASTM E165/E165M, using fluorescent dye.

### **17.10.3 Radiographic Inspection**

Where specified or required, perform radiographic inspection meeting the requirements of ASTM E94. For castings, use ASTM E446 reference radiographs. Submit a proposed sampling frequency if not specified.

## **17.11 Elastomers**

### **17.11.1 General**

All elastomeric parts shall be of neoprene or EPDM unless otherwise specified or approved. Elastomers shall be compounded and cured to perform as intended in the Seattle environment specified in Section 2. Elastomers shall have high resistance to ultraviolet and other solar radiation, and to all Sound Transit car washing fluids. All elastomeric parts shall be resistant to ozone, oxidation, heat, oil, grease and acid.

All resilient mounts shall be of natural rubber. Synthetic rubber compounds will not be permitted without prior Sound Transit approval.

### **17.11.2 Tests**

Conduct tests according to the specified ASTM test procedures, unless otherwise specified. All elastomeric materials used shall meet the relevant testing requirements of this Section.

Cut out test specimens from the extruded material, and perform at least one tensile strength and elongation test and one accelerated aging test on the material used for each order. If the compound or cure, or both, are changed during the production of material for one order, perform at least one test of each type for each different batch.

When testing the ASTM "dumb bell" type test specimen (6 in by 1/2 in (150 mm by 13 mm)) or smaller size if the size of the part necessitates) by the methods specified in ASTM D3182, D3183, D3190, and D412, the tensile strength shall not be less than 1,500 lbf/in<sup>2</sup> (103 MPa) and elongation shall be minimum 350%. The tensile strength of the neoprene shall not be reduced more than 25% when subjected to accelerated aging by the methods specified in ASTM D573, for a period of 96 h in an air oven at 158°F (70°C).

The ozone resistance of the neoprene shall be tested in accordance with ASTM D1149 using an ozone concentration of 100 ppm, an exposure time of 100 h at 100°F (38°C), and a specimen elongation of 20%. The neoprene shall not exhibit any cracks during the test period.

Test resilient, natural rubber mounts and elastomeric truck suspension components in accordance with the Flammability, Smoke Emission, and Toxicity Requirements section, below, and submit the test results. (CDRL 17-8) However, the performance of the elastomers in these applications, and only these applications, will not be bound by the performance requirements for elastomers in the Flammability, Smoke Emission, and Toxicity Requirements section.

### **17.11.3 Life Expectancy**

Elastomers shall have the longest possible life consistent with other specified characteristics. Resilient parts shall have a design life of minimum ten years.

Premature failure of a part made by vulcanizing an elastomer to metal shall be considered a defect of materials or workmanship when the failure occurs between the metal and elastomer or in the elastomer and the parts are used in normal service and according to the provisions of the

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Specifications. Premature failure is defined as a failure in less than five years after acceptance of the vehicle.

### **17.11.4 Bonded Metal Parts**

Metal parts to which neoprene or other such material is cured shall be made of SAE 1020 or 1045 hot-rolled steel or approved equal, suitable for brass plating after pickling.

### **17.11.5 Bonding**

The joining of elastomeric pieces shall be accomplished by a hot vulcanization process. Bonding of elastomers shall not be allowed unless the Contractor submits the application, bonding procedure, and bonding agent technical data for approval prior to the purchase of any materials. (CDRL 17-8)

### **17.11.6 Seals**

Glazing strips shall be of neoprene conforming to ASTM C542, or approved equal material.

All door mating edges, door and window seals, and glazing strips shall be of neoprene material and shall be free of defects of material and workmanship. The durometer hardness measured with a Shore Type "A" durometer at a temperature between 70°F (21°C) and 90°F (32°C) shall be 70 +/-5.

## **17.12 Glazing Materials**

### **17.12.1 General**

Glass panes for use in the vehicles shall ensure maximum safety, as well as providing comfort, economic use, and aesthetics. Windows shall be safety glass complying with ANSI Z26.1 Item 1, Table 1; or 49 CFR 223 Type I or II test, as specified or as appropriate for the application. Refer to Sections 5 and 15.

Corners and burrs shall be ground smooth and all edges shall be seamed in accordance with SAE J673, Edge No. 4.

### **17.12.2 Quality Requirements**

#### **17.12.2.1 Flat Test**

Glass shall not indicate a bow of more than 0.030 in (0.8 mm) per lineal foot when laid on a surface plate or other truly flat surface.

#### **17.12.2.2 Dimension Tolerance**

The dimensions, except thickness, of glass shall be held within 0.060 in (1.5 mm) of the nominal design dimensions.

### **17.12.2.3 Overlap Tolerance**

The overlap of one sheet of glass with respect to the other at an edge shall not exceed 0.03 in (0.8 mm).

### **17.12.2.4 Color**

There shall be no more than +/-4% variation in color in the individual lights of laminated sheet glass when examined over a white background.

### **17.12.2.5 Haze**

All lights of laminated sheet glass shall be so nearly free from haze that the glass shall have approximately the same clarity as a light of the same nominal thickness of plate glass when viewed against a North light.

### **17.12.2.6 Specks and Scratches**

Occasional specks of foreign material or scratches are permissible, provided such specks do not exceed 0.020 in (0.5 mm) in greatest dimension or scratches do not exceed a total of 3 in (75 mm) in length and neither are within the central three-quarters area of the light. Sound Transit reserves the right to determine which lights are to be rejected.

### **17.12.2.7 Bond Separation**

The bond between the glass and the membrane shall be such that when the glass is broken by twisting or by direct impact, there is no separation between the laminations.

Lights that contain unbonded areas (“let-go’s”) at any point of the manufacturing process or during the assembly of the vehicle or during the warranty period shall be rejected and scrapped.

### **17.12.2.8 Distortion**

Safety sheet glass shall produce minimal distortion on a line of 45 degrees to the plane of the glass. Safety plate glass shall meet the requirements under Item 2, Table 1 of ANSI Z26.1.

### **17.12.2.9 Quality**

All questions regarding the quality of safety glass shall be determined by the test methods prescribed in ANSI Z26.1.

### **17.12.3 Marking**

All safety glass shall be marked with proper identification in accordance with ANSI Z26.1, and appropriate FRA Type designation.

All lights shall be installed so that the identification marking can be read from inside the vehicle.

## **17.13 Rubber Floor Covering**

### **17.13.1 Material**

Rubber floor covering shall contain 20% (nominal, by weight of compound) butadiene styrene rubber, shall be non-staining, non-discoloring, and 100% non-oil extended. Only high quality hard clay shall be used as a filler.

No whitening (limestone) shall be used in the compound.

At room temperature, the rubber flooring shall bend around a 3/4 in (20 mm) diameter mandrel without breaking, cracking, crazing, or showing any change in color. The rubber flooring material shall be fully homogeneous throughout, and shall meet the requirements of ASTM F1344.

### **17.13.2 Quality Criteria and Repair Methods**

Rubber flooring shall conform to the criteria below.

#### **17.13.2.1 Thin-Skinned Blister**

Definition: A blister that when finger-pushed, will collapse upon itself.

Thin-skinned blisters are not permitted. Floor covering repair procedures, materials used and final repair result shall be approved by ST prior to any repairs made.

#### **17.13.2.2 Thick-Skinned Blister**

Definition: A blister that when finger-pushed, will collapse and then return to its original condition.

Thick-skinned blisters are not permitted. Floor covering repair procedures, materials used and final repair result shall be approved by Sound Transit prior to any repairs made.

#### **17.13.2.3 Lumps**

Definition: A blister without a void, consisting of solid material.

Lumps are not permitted. Floor covering repair procedures, materials used and final repair result shall be approved by ST prior to any repairs made.

#### **17.13.2.4 Holes**

Definition: A defect that ranges from 25% or more through the material.

Holes of any size or population are not permitted and may not be repaired.

#### **17.13.2.5 Thin Area**

Definition: A defect where the sheet is below thickness locally.

Thin areas of any size is not permitted.

#### **17.13.2.6 Color and Marbling Distribution**

Color and marbling distribution is an appearance judgment and shall be the subject of discussion between Sound Transit and the Supplier. If the base coloring is not within 5% between production runs, or the marbling is not consistent over the entire surface, the roll shall be rejected. The color and marbling distribution and appearance shall be subject to Sound Transit review and approval. (CDRL 17-9)

### **17.14 Piping and Tubing**

#### **17.14.1 General**

Piping, valves, fittings, installation methods, and testing shall be in accordance with the ASME B31.1.

Straight runs of pipe shall be continuous and without fittings unless otherwise approved.

Clean all piping systems after installation by flushing with an approved cleaning solution. Pressure test all piping systems after installation in accordance with ASME B31.1. Repair leaks and retest until the system is leak free.

Piping shall be supported at least at every floor beam and at each bend and connection. Piping locations shall not interfere with access to, and removal of, other components. Clearances between piping and any other components shall prevent contact due to any combination of car loading and deflection, car dynamics and thermally induced movement. In no case shall less than 0.125 in (3.2 mm) clearance be provided.

Piping shall be rigidly clamped where it passes through holes in fixed members.

Clamps shall not be welded, brazed, or otherwise permanently fastened to any piping. Piping clamps shall be insulated with an approved elastomeric or woven mineral fabric tape to protect and acoustically insulate the piping from structure. Pipe clamps shall rigidly clamp piping to support structure. Cantilevered or other piping supports with a strength less than that of service-proven designs are prohibited.

Piping connections to resiliently mounted or moving equipment shall be via hose or other resilient device, as appropriate. Piping shall be clamped within 2 in (50 mm) of the resilient connection.

#### **17.14.2 Hydraulic Piping, Tubing, and Fittings**

Hydraulic pipes, tubing, and fittings shall be sized for the function intended without experiencing a pressure drop of more than 15% from control to function. Fittings shall be high-quality and produced by the same manufacturer. Fittings should all be a common type, readily available within the USA. Exposed tubing, piping, and fittings shall be stainless steel complying with SAE AMST 6845 or SAE AMS 5567. Wall thickness shall be Schedule 80 for truck mounted piping and

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sufficient to maintain a safety factor of 6 at the maximum system pressure. Wall thickness in other locations shall be sufficient to maintain a safety factor of 6 at the maximum system pressure.

Joints shall be welded, brazed, flared to an angle of 37 degrees in accordance with SAE J533, or made with compression fittings, Swage-Lock, or equal. Connections to manifold ports, valve bodies, and other hydraulic system components shall use straight thread fittings with separate O-ring seals.

Rubbing / chaffing of other parts, components, assemblies, hoses or harnesses against rigid piping caused by vehicle deflection or dynamic forces shall not be allowed.

Hose used within the hydraulic system shall conform to SAE J517 and hose fittings shall conform to SAE J516. Hose shall be rated to withstand four times the maximum operating pressure without bursting. Hose application limits shall conform to SAE J1273, SAE J343, and SAE J1405. Hose shall not be used in locations where the temperature may exceed 200°F (93°C). Hose shall be supplied clean and with both ends capped.

There shall be no inaccessible joints. Tubing shall be bent using a bending tool designed specifically for bending of the tubing to be used. Deburr tubing and piping after cutting. Clean and cap openings of tubing, fittings, and subassemblies after fabrication. Caps shall remain in place until immediately prior to incorporation into the final assembly.

Upon completion of all piping installations to the vehicle the entire hydraulic system shall be flushed and filtered to the requirements listed in Section 12 of this specification.

Pipe fabrication, including bending, cutting, deburring, flaring, and fitting, shall be by automatic machinery to ensure consistent quality.

Truck piping shall not be run on the bottom of truck side frames, transom, or bolster.

Connections to manifold ports, valve bodies, and other hydraulic system components shall use straight thread fittings with separate O-ring seals, unless otherwise approved.

Use of tapered pipe threads on any fluid-carrying system component is expressly prohibited.

Quick-connect couplings shall be double shutoff with valves built into both of the mating parts and conform to the requirements of MIL-DTL-25427, or commercial couplings that provide equivalent performance, subject to Sound Transit review and approval.

Cutout cocks shall be designed to automatically depressurize the portion of the system that is being isolated by the cutout cock.

### **17.14.3 Air Piping, Tubing, and Fittings**

Air pipes shall be sized in accordance with the function intended and shall be either ASTM A53/A53M Schedule 80 pipe or seamless Type K annealed copper tubing per ASTM B88. Joints for copper tubing shall use fittings of wrought copper or non-porous cast brass in accordance with ASME B16.22 and ASME B16.18.

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Where ASTM A53/A53M piping is provided, its application shall also comply in all respects to AAR MSRP S-400. Approved copper tube shall comply with any relevant requirements of AAR S-400.

Air piping shall be installed in a manner to provide drainage away from devices, or branch pipes leading to devices, when the function of those devices could be impaired by the accumulation of water or ice.

Air hoses shall conform to AAR M-618 with AAR-approved reusable fittings meeting AAR M-927.

Cut-out cocks shall be of the vented type, except where function prohibits. Cut-out cock handles and their arrangements shall be as described in Section 12.

Air piping on the trucks shall be 0.5 in (13 mm) ASTM A53/A53M Schedule 80, or approved equal. Low spots (traps) are strictly prohibited on the trucks.

Where steel piping is used on trucks and disassembly for service may be required, connections and joints shall use swivel type butt-welded flange fittings with an “O” ring type seal. The use of threaded fittings is expressly prohibited.

### **17.14.4 Air Conditioning System Piping and Fittings**

Air conditioning refrigerant lines larger than 3/8 in (10 mm) outside diameter shall be of seamless copper tubing, “ACR” type, drawn to H58 temper as defined by ASTM B280. Air conditioning refrigerant lines smaller than 3/8 in (9.5 mm) outside diameter may be annealed to the O60 condition. Wrought copper sweat type fittings shall be used. Joints shall be kept to a minimum; wherever possible, use formed or bent tubing, bent using a bending tool designed specifically for bending of the tubing used, in preference to fittings. All inaccessible runs of tubing shall be without joints, and all joints shall be readily accessible for inspection and repair.

Suction lines shall be designed and installed without traps. The suction line shall be sized for 3 lbf/in<sup>2</sup> (21 kPa) maximum system pressure drop and the liquid line shall be sized adequately to prevent flashing due to pressure drop.

Lines subject to condensation shall be insulated with an approved insulation, applied with an approved contact cement. The liquid line shall be insulated in all areas where required to provide additional mechanical or thermal protection. Insulation at joints and fittings shall be mitered and sealed with an approved material. The insulation, adhesive, and sealant shall meet the Specification requirements for thermal, flammability, smoke emission, and toxicity performance.

Refrigerant piping and pipe subassemblies shall be deburred, cleaned, dried, and capped with tight fitting plastic caps, or approved equal on all openings after fabrication. Caps shall remain in place until immediately prior to incorporation into the final assembly.

Vibration eliminators shall be used in piping at any location where there is relative motion between sections. Tubing installations shall be designed to allow any single length of tubing to be replaced without dismantling or removing surrounding equipment, piping, wiring, or other appurtenances.

Condensate drain lines shall be seamless copper tubing, Type “K”, in either the O60 annealed or H58 tempered condition, as defined by ASTM B88, or seamless stainless steel tubing.

#### **17.14.5 Soldering of Piping and Fittings**

Refrigerant and air system copper piping shall be joined using silver solder, Sil-Fos, or approved equal conforming to Federal Specification QQ-B-654, BAg-5 or BcuP-5. Refrigeration tubing shall be internally swept with a continuous flow of an inert gas such as dry nitrogen during brazing.

Condensate drain tubing and air piping shall be joined using 95-5 solder or silver solder as above. Solder fittings shall be wiped and have flux cleaned from tubing and fittings after soldering. After fabrication, the system shall be cleared of all dirt and foreign matter, evacuated, dried and charged and leak free according to a Sound Transit approved procedure. Refer to Section 7 for run-in testing and additional refrigeration system cleanliness requirements.

#### **17.14.6 Pressure Vessels**

Pressure vessels shall conform to ASME BPVC, Section VIII, Rules for Construction of Pressure Vessels Division 1. Test reports shall be furnished for each pressure vessel, and each pressure vessel shall be stamped to document the test. (CDRL 17-10)

#### **17.15 Air Filters**

##### **17.15.1 Low Pressure Air Filters**

Filters shall meet the equipment manufacturer's recommendations. Filters shall be framed, throw away types and shall be freely accessible for maintenance.

Unless otherwise required by the equipment manufacturer, filters shall be resin-bound, spun-glass fiber materials having an uncompressed thickness not less than 3-1/2 in (90 mm). Filters shall be non-absorptive of fluids and gases, be processed in such a manner that material density increases progressively from air inlet to air exit side, and shall be coated with not less than 24 g/ft<sup>2</sup> (258 g/m<sup>2</sup>) of a dust-retaining, viscous adhesive film. This film shall be stable at temperatures up to 150°F (66°C).

The filter pad shall be cut oversize to ensure adequate sealing between the edge of pad and its case.

##### **17.15.2 High Pressure Air Filters**

Provide air filter assemblies with replaceable filter elements in the air line that connects each subsystem to the air supply system. The air filter filtering capability, flow rate capability, and overall size shall be appropriate for the application so that the filter replacement interval is greater than one year. It shall be possible to gain access to the filter element for replacement without requiring any pipe fittings to be disconnected or loosened.

## **17.16 Paints, Graphics, and Coatings**

### **17.16.1 General**

Paint exterior surfaces of the car body in accordance with the color scheme, lettering, and numbering as submitted and approved under Section 15.

Paint, graphics, and coatings materials shall be repairable by Sound Transit with materials and processes conforming to applicable local, state, and federal requirements.

All paints, primers, fillers and other finish coatings shall be compatible and readily available within the USA.

The Contractor and its liquid paint and powder coat Suppliers shall supply touch-up procedures and assure that a continuing supply of touch-up paints in colors used on the vehicle, suitable for spot application by spray or brush, will continue to be available in the United States.

### **17.16.2 Materials Requiring Painting**

All metals on the vehicle shall be painted, with the following exceptions:

- Austenitic stainless steel portions of the car body, equipment enclosures exteriors or bracketry shall not be painted, unless otherwise specified by Sound Transit for cosmetic reasons.
- For interior applications not exposed to passengers, aluminum may be unpainted, but if unpainted must be anodized.

Equipment or parts of equipment that would be damaged or suffer impaired operation from painting shall not be painted and shall be corrosion resistant, including but not limited to the following:

- Flexible conduit and fittings;
- Copper tubing, piping and fittings;
- Wire and cable;
- Power resistors;
- Heat transfer surfaces;
- Electrical insulators;
- Elastomeric parts; and
- Grounding pads.

The following truck-related items shall not be painted:

- Wheels;
- Axles;
- Elastomeric parts;
- Grease fittings;
- Linkages;
- Threaded parts used for adjustments;

- Electrical equipment;
- Current pick-up devices;
- Wearing surfaces;
- Grounding pads; and
- Wire and cable.

### **17.16.3 Paint and Powder Coat Materials**

#### **17.16.3.1 General**

Painting materials for all surfaces shall be a high quality finishing system resistant to corrosion, chipping, and fading and shall retain the gloss level.

Paint and filler materials that are to be superimposed to form a finish system shall be mutually compatible and shall be warranted for use as a system by the manufacturer of the components.

All material finishes, colors and textures shall be provided to Sound Transit in sample form on 3 x 5 inch plaques and organized within a 3 ring binder, minimum 3 copies. (CDRL 17-11)

All paint system materials must be available for purchase and use within the USA and meet Washington State and Federal EPA requirements.

#### **17.16.3.2 Primers**

Where specified, primers shall comply with the following requirements:

- Wash (etch) primer: A primer with anti-corrosion properties for application as a first coat on metal surfaces, as recommended by the manufacturer of subsequent primer and top coat.
- Epoxy primer: Compatible with the polyurethane top coat.
- Truck primer: Compatible with truck paint.

#### **17.16.3.3 Topcoats**

Where specified, top coats shall comply with the following requirements:

- Polyurethane: Two-part, high solids, low VOC, polyurethane paint system with a solids content between 50% and 70%. Alternate paint systems, such as waterborne coatings, or direct-to-metal paint systems will be considered if the paint performance equals or exceeds two-part polyurethane.
- Anti-skid: For surfaces requiring anti-skid paint, mix an approved non-skid additive into the paint, such as fine glass or plastic beads. Application of anti-skid additive must be uniform across entire applied surface. Clotting, clumping or population texture differences of additive will not be permitted.
- Truck paint: Select truck paint that will not hide structural cracks.

The Supplier shall submit color samples and corresponding tri-stimulus values for approval. The exterior finish shall have a minimum gloss level of 90 as measured with a 60 degree glossometer. (CDRL 17-11)

#### **17.16.3.4 Powder Coat**

Where specified, powder coat shall comply with the following requirements:

- Interior and exterior applications: Thermosetting, resin based, polyester or epoxy powder tailored to the individual application.
- All non-ferrous equipment enclosure exterior surfaces shall be powder coated and match the surrounding application area.
- All equipment enclosure interiors to be white thermosetting, resin based, polyester or epoxy powder coat.

#### **17.16.4 Preparation and Paint or Powder Application**

##### **17.16.4.1 General**

Prepare the substrate surface in accordance with the paint or powder Supplier's recommendations.

Prepare and apply paint and powder materials in accordance with the paint manufacturer's recommendations, including environmental conditions (clean, dry atmosphere at an ambient temperature as recommended by the paint manufacturer).

Paint materials shall be used at the consistency recommended by the paint Supplier. If thinners are necessary, they shall be approved by the paint manufacturer and shall be used only to the extent recommended.

Paint and powder coating shall be uniformly applied over all surfaces to be covered and shall be free from foreign matter, runs, sags, orange peel, fisheyes, feather edge shrinkage or other application defects.

##### **17.16.4.2 Applicator Qualifications**

Painting and powder coating shall be done by experienced labor, using proper equipment under competent supervision.

##### **17.16.4.3 Car Body**

After fabricating metal portions of the car body not constructed of stainless steel, prepare and prime by one of the following methods:

- Grit blast, then immediately after grit blasting apply epoxy primer;
- Wash with an alkaline solution and properly rinse; apply a coat of phosphate or a coat of wash (etch) primer; and then coat with epoxy primer; or

- As recommended by the manufacturer and approved by Sound Transit, if the manufacturer does not recommend the specified methods.

In addition, comply with the following corrosion prevention requirements for the car body locations indicated:

- Concealed surfaces capable of rusting or oxidation: After cleaning and applying epoxy primer, paint with polyurethane or other approved coating suitable for the vehicle design life.
- Arc welds between stainless steel and other materials: De-scale the joint, clean, apply wash primer, apply epoxy primer, and apply polyurethane top coat.
- Concealed aluminum: Apply one coat of primer and one coat of an approved sealer, except to framing structures.
- Closed-section tubular beams of the structure frame: The inside and outside of the beam shall be cleaned and coated with epoxy primer. The outside shall have a polyurethane top coat over the epoxy primer. Demonstrate adequate corrosion resistance by testing representative scribed samples to failure in accordance with ASTM G85 Annex A5. (CDRL 17-11)

#### **17.16.4.4 Exterior Not Visible to Passengers**

Surfaces that are on the exterior of the vehicle but not visible to passengers shall be prepared as specified above for the vehicle body, and painted as follows:

- Underfloor: After erection of the framing structure and body sheets, all undercar metal, except stainless steel, shall receive a black polyurethane finish as specified above.
- Roof:
  - Apply one polyurethane top coat. Use anti-skid paint on roof surfaces as specified in Section 15.
  - Other parts of the vehicle not exposed to view: Apply one polyurethane top coat.

#### **17.16.4.5 Exterior Visible to Passengers**

Before painting car surface that is exposed to view, rectify dents, gashes, nicks, roughness, and other surface imperfections or depressions. Remove imperfections so far as possible by straightening. After straightening, wash prime the surface, fill remaining imperfections with an approved epoxy-based filler, and sand smooth.

The filler thickness shall be maximum 0.125 in (3.2 mm), or as recommended by the filler manufacturer for the environment and service to which it is to be exposed, whichever is less. Maximum deviation from flatness after filler application shall be 0.063 in (1.6 mm), peak to valley, measured with a 36 in (915 mm) straight-edge placed anywhere on the car exterior.

Apply epoxy primer and two polyurethane top coats. The finished exterior shall present a high quality appearance free from sags, drips, scratches, variations in gloss, and other imperfections. The

first vehicle will be inspected by Sound Transit, and if approved, shall set the standard of quality for all remaining vehicles.

#### **17.16.4.6 Paint Performance Type Test**

The final painted surface shall be tested on the first vehicle (CDRL 17-11) to the following criteria:

##### **17.16.4.6.1 Hardness**

Perform Pencil Hardness tests according to ASTM D3363. The range of acceptance shall be between H and 2H and shall be the average of ten readings taken from typical surface locations. This is a destructive test and will require the tested surfaces to be repaired.

##### **17.16.4.6.2 Adhesion**

Test Adhesion per ASTM D4541 and achieve a minimum rating as provided by the paint manufacturer. This is a destructive test and will require the tested surfaces to be repaired.

##### **17.16.4.6.3 Thickness**

The minimum and maximum dry film thicknesses shall be provided by the paint Supplier. Dry film thicknesses beyond the manufacturer's recommendations will not be accepted. Non-destructive testing shall be performed to verify final dry film thickness.

##### **17.16.4.6.4 Paint Cure**

Perform a solvent rub test per ASTM D5402. The test procedure requires no less than 50 double finger rubs with a cloth wetted in acetone or methyl isobutyl ketone to the painted surface. No paint color should transfer to the cloth. After 72 h the painted surface must retain all original characteristics such as gloss and hardness.

#### **17.16.5 Truck Painting**

Truck paint shall be selected such that structural cracks will not be hidden. Submit truck paint selection. (CDRL 17-11)

All truck components to be painted shall be painted as follows:

- Apply a full coat of primer prior to assembly.
- Following assembly, clean trucks by blowing off with compressed air and wiping with solvent to remove all dirt and grease.
- Spray with one coat of an approved black truck paint and air dry.

### **17.16.6 Stainless Steel and FRP**

Comply with the following requirements:

- Painted stainless steel: Where required to be painted, the painting procedures shall be as recommended by the paint manufacturer for that application.
- Unpainted exterior stainless steel: Clean with an approved alkaline cleaning solution that will not damage any previously painted surfaces.
- FRP: Where required to be painted, apply one coat of epoxy primer and top coat with polyurethane, using the number of coats recommended for the application.

### **17.16.7 Apparatus and Equipment Enclosures**

Underfloor- and roof-mounted apparatus and equipment enclosures (motors, control boxes, junction boxes, brake valves, and other equipment as specified) shall be primed and painted in accordance with the following requirements unless otherwise indicated.

The exterior surfaces of equipment enclosures and apparatus, other than propulsion control equipment, HVAC, APSE, battery box, brake resistors and air reservoir tank made from carbon steel shall be prepared, primed, and painted as specified above for Underfloor Paint and Exterior Visible to Passengers. The interior surface of all propulsion, APSE, HVAC, battery box control equipment enclosures shall be coated with an approved insulating, thermosetting, resin-based, powder coating or polyurethane paint system. The interior of the boxes, including insides of covers, shall be white and the exteriors shall match the surrounding paint scheme unless the enclosure is made of stainless steel.

Parts of equipment enclosures made from plastic or fiberglass shall be painted in accordance with the above requirements for metal portions except that the paint system shall be compatible with the plastic used, and an insulating coating need not be applied.

For roof mounted apparatus and equipment enclosures, provide an exterior finish of polyurethane to match the roof color, specified in Section 15. Underfloor apparatus and equipment enclosures shall be painted to match the underfloor paint color.

### **17.16.8 Interior Surfaces**

Exposed interior surfaces, including molding and trim, shall be as specified in Section 15.

Interior surfaces requiring protective finish shall be coated with powder coating as specified in the Paint and Powder Coat Materials section, above. Parts which are to be powder-coated shall be cleaned and prepared in accordance with the Preparation and Paint or Powder Application section, above.

Samples of each powder coat application that will be used in the vehicle shall be subjected to an accelerated test to show that the finished product will maintain its appearance over time when exposed to UV light, oils (hands), cleaning products and other normal wear. (CDRL 17-11)

### **17.16.9 Other Coatings**

Apply under-coatings and other coatings and acoustic insulating materials where specified or required to properly cleaned and primed surfaces and members in accordance with the Supplier's recommendations. Insulating materials shall be as specified in Section 15 and shall meet the requirements in the Flammability, Smoke Emission, and Toxicity Requirements section, below.

### **17.16.10 Graphics**

Graphics such as stripes, logos, or vehicle numbers shall be 3M vinyl graphic film. Install in accordance with manufacturer's recommendations using manufacturer recommended tools.

Graphics shall be formulated and applied such that removal does not damage the underlying paint or surface.

### **17.16.11 Paint Process Documentation**

The Contractor shall prepare a detailed paint coating and application document containing manufacturer's product data sheets, procedures for surface cleaning and preparation, priming, surfacing, dry and recoat times, and painting for the car body and all equipment that is painted or powder coated, whether by itself or by its manufacturers and Suppliers. Touch-up and repair procedures shall also be provided. A detailed paint schedule showing the equipment painted, paint type and manufacturers, recommended thickness, and other pertinent information shall also be included. This information shall be made part of the maintenance manuals. This document shall be submitted for Sound Transit review and approval prior to painting of any surfaces or components. (CDRL-17-11)

## **17.17 Flammability, Smoke Emission, and Toxicity Requirements**

### **17.17.1 General**

All combustible material used in the construction of the vehicle shall satisfy the flammability, smoke emission, and toxicity requirements in this Section. For all materials, submit Sound Transit approved, U.S. independent laboratory test results indicating successful compliance with these requirements. (CDRL 17-12)

Testing must be conducted within three years from NTP, and on a production batch of material. Each laboratory must have tested a standard test sample no more than 30 days prior to performing the tests that will be submitted to Sound Transit. The Contractor shall be responsible for complete conformance with these standards for itself and its Subcontractors and Suppliers.

Sound Transit may, at its discretion, require that the current batch of material being provided for this contract be retested for conformance with these standards.

### **17.17.2 Flammability and Smoke Emission**

As a minimum, all materials used in the construction of the vehicle shall meet the requirements of NFPA 130 Chapter 8, Vehicles.

Submit a matrix during detailed design review showing the following (CDRL 17-12):

- The total weight of all materials
- Where used
- Flammability and smoke emission test identity
- Test facility
- Test requirements
- Test results
- Nature and quantity of the products of combustion
- Supplier's name

The Contractor may request a waiver from testing for a material if it believes the quantity of that particular material is such that it would not contribute significantly to a fire. The waiver shall be submitted in writing accompanied by proper justification and will be subject to Sound Transit review and approval on a case-by-case basis. Include the following information:

- The total weight of the material to be used,
- The location of the material and the distribution in the car
- Any previous test reports available. (CDRL 17-12)

### 17.17.3 Toxicity

Those materials and products generally recognized to have highly toxic products of combustion shall not be used.

Test all materials used in the vehicle construction, except for materials used in small parts (such as knobs, rollers, fasteners, clips, grommets, and small electrical parts) that would not contribute significantly to fire propagation or to smoke or toxic gas generation, for toxicity using Bombardier SMP 800-C. Materials shall meet the following maximum toxic gas release limits (ppm) as determined per SMP 800-C.

<b>Bombardier SMP 800-C Toxic Gas Release Limits</b>	
<b>Toxic Gas</b>	<b>Limit</b>
Carbon Monoxide (CO)	3,500 ppm
Hydrogen Fluoride (HF)	100 ppm
Nitrogen Dioxide (NO <sub>2</sub> )	100 ppm
Hydrogen Chloride (HCL)	500 ppm
Hydrogen Cyanide (HCN)	100 ppm
Sulfur Dioxide (SO <sub>2</sub> )	100 ppm

The tests shall be run in the flaming mode after 240 s using the NBS Smoke Density Chamber for sample combustion. The gas sampling may be conducted during the smoke density test. The test report shall indicate the maximum concentration (PPM) for each of the above gases at the specified sampling time. Results shall be subject to Sound Transit review and approval. (CDRL 17-12)

#### **17.17.4 Total Combustible Content**

The design of the vehicle shall minimize the total combustible material content of the vehicle. All combustible materials shall be tested in accordance with ASTM E1354, at a heat flux of 50 kW/m<sup>2</sup>, to determine the effective heat of combustion and heat release rate.

The total BTU content of the vehicle shall be no more than 90,000,000 BTU (95 GJ). The average heat release rate shall be no more than 45,000,000 BTU/h (47.5 GJ/h) per vehicle.

The Contractor shall prepare a report with a matrix to identify all materials and their properties to identify the maximum total heat release rate vs. time. Each combustible material shall be specifically identified by Supplier's name and type, use in the vehicle, total weight, and heating value in Btu/lb (J/kg) and Btu/h (J/h). The report shall be submitted no later than 180 days after NTP. Results shall be subject to Sound Transit review and approval. (CDRL 17-12)

#### **17.17.5 Floor Assembly Testing Requirements**

The Contractor shall test the floor assembly (structural) in accordance with ASTM E119 to demonstrate a 30-min endurance rating. The section of the floor to be tested, test procedure, test facility, and test results shall be subject to Sound Transit review and approval, and approved prior to the Contractor's procurement of any flooring material necessary for vehicle production. (Procedure: CDRL 17-12, Report: CDRL 17-12)

The test criteria shall be as specified in NFPA 130 Section 8.5, Fire Performance.

#### **17.17.6 Roof Assembly Testing Requirements**

The Contractor shall test the roof assembly in accordance with ASTM E119, to demonstrate a 15-min endurance rating. The test procedure, test facility, and test results shall be subject to Sound Transit review and approval, and approved prior to the Contractor's procurement of any roofing material necessary for vehicle production. (Procedure: CDRL 17-12, Report: CDRL 17-12)

The test criteria shall be as specified in NFPA 130 Section 8.5, Fire Performance.

#### **17.18 Wood and Panels**

Surfaces exposed to passengers shall not deviate from the specified contour by more than 3/32 in (2.4 mm) in any 36 in (0.91 m) distance. The slope of any such deviation shall not exceed 3/32 in (2.4 mm) in 12 in (300 mm).

##### **17.18.1 Lumber**

Lumber shall be thoroughly air seasoned or kiln dried before using and shall be dressed on all surfaces to full dimensions and treated to meet the testing requirements of the Flammability, Smoke Emission, and Toxicity section. (CDRL 17-12) Lumber shall be straight grained, free from dry rot, knots checks, and other defects which may impair its strength and durability or mar its appearance.

The use of wood in the vehicle, except where specified, shall be limited to specifically approved applications.

### 17.18.2 Plymetal

The term "plymetal" as used in this Specification covers metal-faced plywood and shall conform to the table below.

Plymetal Requirements	
Test Conditions	Minimum Metal to Wood Average Shear Value (or 80% Wood Failure)
Dry shear	250 lbf/in <sup>2</sup> (1.7 MPa)
Boil shear, 3 h boil, tested wet at room temperature	150 lbf/in <sup>2</sup> (1 MPa)
Soak shear, 48 h soak wet at room temperature	150 lbf/in <sup>2</sup> (1 MPa)
Creep or cold flow, under static load for 48 h, at room temperature	250 lbf/in <sup>2</sup> (1.7 MPa)

Plymetal that is faced with melamine shall have the melamine bonded to the metal sheet in accordance with the Honeycomb Panels section, below, and the melamine-faced metal sheet shall then be laminated to the plywood core in accordance with this Section.

### 17.18.3 Plywood

Plywood shall comply with the requirements of NIST PS 1 panel grade Structural I, and shall be stored under cover. Plywood panels shall be formed from one piece and shall be sealed with two coats of an epoxy paint on all edges and cutouts as soon as possible after fabrication.

Treat exposed edges of the panels, joints between panels, fastener heads, and openings of panels used in areas accessible to moisture before installing in the car, as follows:

- Before sealing edges, plug splits showing on edges with wooden wedges dipped in adhesive conforming to Federal Specification MMM-A-181.
- Seal the exposed edges with an approved epoxy or polyurethane moisture barrier coating.
- Allow minimum 24 h drying time between each coat.

### 17.18.4 Honeycomb Panels

The term "honeycomb panels" as used in this Specification refers to an assembly of honeycomb material bonded to melamine-faced metal panels or to metal panels.

Aluminum honeycomb material shall be commercial-grade meeting the requirements of SAE AMSC 7438. Bonding shall be sufficient to develop the full strength of the honeycomb material.

For stainless steel honeycomb panels the adhesive bond strength of the honeycomb core to the stainless steel face shall not be less than 15 lb/in (2.7 kg/cm) climbing drum strength when tested in accordance with SAE AMSSTD 401. The adhesive bond strength of the integral stainless frame to stainless steel face shall not be less than 30 lb/in (5.4 kg/cm) climbing drum strength when tested in accordance with SAE AMSSTD 401. Stainless steel honeycomb panels shall be tested in accordance with SAE AMSSTD 401 to demonstrate the requirements in the table below. Submit test results (CDRL 17-13):

<b>SS Honeycomb Panels SAE AMSSTD 401 Test Requirements</b>	
<b>Mechanical Property</b>	<b>Value</b>
Core shear yield at 200°F (93°C)	250 lbf/in <sup>2</sup> (1.72 MPa)
Flatwise tension at 200°F (93°C)	250 lbf/in <sup>2</sup> (1.72 MPa)
Beam flexure at 200°F (93°C)	75,000 lbf/in <sup>2</sup> (517.13 MPa)
Core shear fatigue at R.T.	150 lbf/in <sup>2</sup> @ 10 <sup>6</sup> cycles (1.03 MPa)
Flatwise tension at R.T.	250 lbf/in <sup>2</sup> @ 10 <sup>6</sup> cycles (1.72 MPa)
Beam flexure at R.T.	50,000 lbf/in <sup>2</sup> @ 10 <sup>6</sup> cycles (344.75 MPa)

Honeycomb panels shall meet the relevant requirements in the Flammability, Smoke Emission, and Toxicity section, above. Submit test results. (CDRL 17-12)

No other honeycomb materials are permitted.

### 17.18.5 Melamine-Faced Aluminum

Melamine-faced aluminum panels shall be constructed by laminating melamine to aluminum sheets as follows:

- The melamine impregnated papers shall be directly molded to the aluminum sheets at minimum temperature 270°F (132°C) and minimum pressure 1000 lbf/in<sup>2</sup> (6.9 MPa).
- The surface characteristics, after manufacture, shall be no less than that required of NEMA LD 3 type GP (General Purpose).
- The melamine and the required binder sheets shall be 0.020 +/- 0.005 in (0.51 +/-0.13 mm) thick.
- When used as facing on plywood, the aluminum sheets shall be minimum 0.025 in (0.64 mm) thick.
- When not laminated to a substrate such as plywood, the aluminum sheets shall be minimum 0.08 in (2 mm) thick.
- Aluminum sheets shall be properly cleaned by etching, sanding or other approved process to ensure full, permanent, acceptable adhesion.

The use of any adhesives to bond the melamine sheets to the aluminum backing will not be acceptable.

The bond between the melamine and aluminum sheets shall, as a minimum, meet the requirements of the table below.

<b>Melamine to Aluminum Bond Requirements</b>			
<b>Mechanical Properties</b>	<b>ASTM Method</b>	<b>Condition</b>	<b>Value</b>
Internal bond	ASTM D952		2,600 lbf/in <sup>2</sup> (17.9 MPa)
Flexural strength - (S) with grain	ASTM D790	with grain	26,500 lbf/in <sup>2</sup> (183 MPa)
		cross grain	25,300 lbf/in <sup>2</sup> (174 MPa)
Modulus of elasticity - (E)	ASTM D790	with grain	2.8 x 10 <sup>6</sup> lbf/in <sup>2</sup> (19.3 GPa)
		cross grain	3.1 x 10 <sup>6</sup> lbf/in <sup>2</sup> (21.4 GPa)
Tensile strength	ASTM D638	with grain	22,300 lbf/in <sup>2</sup> (154 MPa)
		cross grain	20,300 lbf/in <sup>2</sup> (140 MPa)

Melamine-faced aluminum panels shall meet the relevant flammability, smoke emission, and toxicity requirements in the Flammability, Smoke Emission, and Toxicity section, above. Results shall be subject to Sound Transit review and approval. (CDRL 17-12)

#### 17.18.6 Melamine Panels

Unbacked melamine panels may be used in the vehicle interior. The panels shall be a minimum of 0.125 +/-0.005 in (3.2 +/-0.1 mm) thick. The surface characteristics shall be no less than that required of NEMA LD 3 type GP (General Purpose). Melamine panels shall meet the relevant flammability, smoke emission, and toxicity requirements in the Flammability, Smoke Emission, and Toxicity section, above. (CDRL 17-12)

Sidewall panels shall be of unbalanced melamine. However, ceiling panels located under air ducts must be balanced melamine to prevent warpage from duct condensation.

#### 17.18.7 Phenolic Composite Floor Panels

Phenolic composite floor panels shall be designed to withstand the physical test requirements below with none of the following results:

- Visible or audible indications of delamination of the panel skin from the core.
- Permanent deformation of the top surface more than 0.010 in (0.25 mm) unless otherwise specified.
- Puncture or damage to fibers of the top surface.
- Separation of any internal core from the top or bottom skin.
- Fracture of the balsa core.

Physical Test Requirements:

- Indentation Resistance – The floor panel shall withstand a concentrated load of 300 lbs (136 kg) applied to a test dowel that has an overall 0.375 in<sup>2</sup> (242 mm<sup>2</sup>) surface area, with a 0.0625 in (1.6 mm) radius on bottom edge of test dowel.
- Static Load Test - Average Loading – A representative sample section of the flooring (without rubber floor covering attached) shall be supported on beams spaced at the maximum spacing used on the car using production bonding and fastening techniques. A uniformly distributed load in accordance with the crush loading requirements of Section 2 shall be applied to both sides of the joint (butt and/or shiplap). There shall be less than 0.088 in (2.2 mm) deflection.
- Static Load Test – Maximum Loading – Using the identical floor panel-mounting configuration as described above, a uniformly distributed load of 200 lb/ft<sup>2</sup> (976 kg/m<sup>2</sup>) shall be applied to both sides of the joint (butt or shiplap).
- Small Area Static Load Test – Using the identical floor panel mounting configuration as described above, a 300 lb (136 kg) load shall be applied to a 1.0 in by 3.0 in (25 by 75 mm) contact area directly over the midspan, 6 in (150 mm) from the outer car body sidewall edge. The footprint shall be machined flat within 0.010 in (0.25 mm) and the edges shall have a radius of not more than 0.125 in (3.2 mm). There shall be less than 0.20 in (5 mm) deflection as a result of the load applied.
- Small Object Impact Test – Using the identical floor panel mounting configuration as described above, a 16 lb (7.26 kg) standard bowling ball shall be raised directly over the mid-span, 24 in (610 mm) from the edge of the panel and dropped from height of 60 in (1500 mm). Permanent deformation of the top surface shall be less than 0.0625 in (1.587 mm).
- Large Object Impact Test – Using the identical floor panel mounting configuration as described above, a 150 lb (68 kg) load shall be dropped upon a 3.0 in by 8.0 in (75 mm by 200 mm) contact “footprint” pad located directly over the midspan, 24 in (610 mm) from the edge of the panel and dropped from a height of 12 in (300 mm). The “footprint” pad shall have a rubber pad on the downside surface with a Shore D 70 minimum, at a 1 in (25.4 mm) thickness machined flat within 0.060 in (1.524 mm) with edges having a radius of not more than 0.030 in (0.8 mm). Permanent deformation of the top surface shall be less than 0.030 in (0.8 mm). Some damage to the top phenolic composite skin will be allowed.
- Rolling Load Test – Using the identical floor panel mounting configuration as described above, a four-wheeled cart with a load of 200 lbs (91 kg) per wheel shall be rolled on the panels laterally, longitudinally and in a circular path 24 in (610 mm) radius. The wheels shall be 3 in (75 mm) in diameter, 1 in (25 mm) wide with a 0.125 in (3 mm) radius on each edge with a Shore A durometer of 80.
- Floor panels shall meet the relevant requirements in the Flammability, Smoke Emission, and Toxicity section, above.

Submit test results. (CDRL 17-13)

## **17.19 Fiberglass Reinforced Plastic (FRP)**

### **17.19.1 General**

Fiberglass Reinforced Plastic (FRP) shall be a laminated material, composed of a gel-coated surface, fiberglass reinforcement, and a polyester, phenolic or acrylic resin.

FRP shall withstand the environmental conditions described in Section 2 without any physical deformation or structural damage and shall be resistant to acids, mild alkaline solutions and those cleaning solutions recommended by the Contractor.

FRP shall meet the relevant requirements of the Flammability, Smoke Emission, and Toxicity section, above. Submit test results. (CDRL 17-12)

### **17.19.2 FRP Construction**

FRP shall be manufactured by hand-laminated open molding or as appropriate for the part and approved by Sound Transit. Production techniques shall ensure that the glass fiber reinforcement is uniformly distributed throughout the final product in such a manner as to avoid resin-rich or resin-starved sections.

An analysis shall be performed to confirm that the construction method chosen is adequate for its intended purpose and meets the requirements in the Strength Requirements section, below.

Finished gel-coated surfaces shall have a minimum gloss value of 85 when measured with a 60 degree glossometer and shall exhibit no print through of the reinforcements or have any appreciable orange peel. Reinforced plastic parts shall have greater thickness at attachment points and edges. Exposed sharp edges will not be permitted on any parts.

### **17.19.3 Resin**

Resin shall be of good commercial grade, thermosetting, polyester, phenolic, or acrylic material selected to meet the physical, flammability, smoke emission, and toxicity properties, and molding process requirements, as specified. The use of two different resins in the same matrix will not be allowed.

### **17.19.4 Reinforcement**

The fiberglass reinforcement shall be mat, fabric woven roving, continuous roving, chopped spun roving, or swirl mat as required to meet the physical properties below and the molding process requirements. The proposed glass content shall be confirmed through testing to ASTM D2584.

### **17.19.5 Gel Coat**

The gel coat shall have a minimum thickness of 0.016 in (0.40 mm) and a maximum thickness of 0.020 in (0.50 mm). The gel coat shall be resistant to scuffing, weather, water absorption, and cleaning agents.

If the surface of the FRP panel is to be painted then a primer gel coat shall be used and the part shall be painted in accordance with the Paints, Graphics, and Coatings section, above. If the FRP panel does not receive paint, then the gel coat shall be pigmented to match the color selected by Sound Transit.

### 17.19.6 Additives

Additives, fillers, monomers, catalysts, activators, pigments, fire retardants, and smoke inhibitors shall be added to the resin mixes to obtain finished products with the required physical characteristics below and other requirements of this document.

Mineral filler shall not exceed 28% of finished weight for any preformed matched die molding process.

### 17.19.7 Strength Requirements

Provide independent laboratory test reports confirming that the reinforced plastic material complies with the requirements of the standards listed below. Submit test results. (CDRL 17-14) Perform tests on test coupons that are trimmed from production parts. Test specimens shall be conditioned in accordance with ASTM D618.

FRP Strength Tests			
Mechanical Property	ASTM Test	Interior Panels	Exterior Panels
Tensile Strength	D638	10,000 lbf/in <sup>2</sup> (69 MPa)	18,000 lbf/in <sup>2</sup> (124 MPa)
Compressive Strength	D695	18,000 lbf/in <sup>2</sup> (124 MPa)	24,000 lbf/in <sup>2</sup> (165 MPa)
Flexural Strength	D790	15,000 lbf/in <sup>2</sup> (103 MPa)	30,000 lbf/in <sup>2</sup> (206 MPa)
Impact Strength	D256	10 ft-lb/in (5.3 J/cm) of notch	13 ft-lb/in (6.9 J/cm) of notch
Hardness		45 Barcol	45 Barcol

**17.20 Side Skin FRP – this section has been deleted from the Specifications.**

### 17.21 Thermoplastic Sheet

#### 17.21.1 General

Thermoplastic sheet shall withstand the environmental conditions in Section 2 without physical deformation or structural damage and shall be resistant to all recommended cleaning solutions. The thermoplastic sheet shall meet the relevant requirements in the Flammability, Smoke Emission, and Toxicity section, above. Test results shall be subject to Sound Transit review and approval. (CDRL 17-12)

Thermoplastic Sheet shall be used "as is" or pressure formed, or as approved by Sound Transit. The surface finish gloss level shall not vary by more than 5 points, as measured using a 60 glossometer. The surface texture shall not fade out at or near part contours.

**17.21.2 Product Requirements**

The thermoplastic sheet shall be homogeneous and extruded from virgin stock which shall not include any grind of vacuum formed parts. Cap sheet is not permitted.

The exposed surface of this material shall conform to the color, texture, and gloss specified in Section 15. Only UV stabilized pigments shall be used to create the specified color of the thermoplastic sheet. The color and surface finish of parts manufactured from this material shall be approved before the manufacture of any parts. Provide an anti-graffiti coating on exposed surfaces.

**17.21.3 Quality**

Finished parts shall be free of waves and quilting on both sides. Degraded polymer in the sheet shall not be allowed, and if present, shall be cause for rejection of the piece. Voids, lumps, and contamination shall also be cause for rejection of parts if the defects are larger than 0.010 in (0.25 mm), and the population of these defects is greater than one defect in 4 ft<sup>2</sup> (0.37 m<sup>2</sup>).

**17.21.4 Strength Requirements**

Independent laboratory test certificates shall be provided stating that the thermoplastic sheet complies with the requirements of the standards listed in the table below. Submit test results. (CDRL 17-15) Extruded sheet in the surface finish specified shall be used for testing.

<b>Thermoplastic Sheet Strength Requirements</b>		
<b>Mechanical Properties</b>	<b>ASTM Method</b>	<b>Value</b>
Specific Gravity	D792	1.20 to 1.45
Tensile Strength	D638	7,000 lbf/in <sup>2</sup> (48 MPa) minimum
Flexural Strength	D790	10,000 lbf/in <sup>2</sup> (69 MPa) minimum
Flexural Modulus	D790	3.3 x 10 <sup>5</sup> lbf/in <sup>2</sup> (2275 MPa)
Hardness Rockwell	D785	90 to 120 "R" Scale
Heat Shrinkage 15 min at 350°F (177°C)		10% maximum
Heat Deflection (annealed) @ 264 lbf/in <sup>2</sup> (1.8 MPa)	D648	190°F (88°C) min
Impact Strength, Fabricated Parts, Gardener Dart Drop 0.5 in (13 mm) dia. ball @ 73°F (23°C)	D5420	160 in-lb (18 J) min

## 17.22 Seat Materials

### 17.22.1 Seat Cushion Fill Material

#### 17.22.1.1 General

Seat cushion fill material shall be low-smoke flexible foam constructed of inherently fire-retardant materials. The thickness shall be approved during design review. The material shall have a polymerized or vulcanized homogeneous (free from foreign material), cellular structure with a porous surface and open cells. The cells shall be interconnecting and uniform in size.

Cellular material may be molded in one piece or may be assembled by laminating to achieve the required thickness. Laminated cushions shall be bonded together.

Cushion material shall be properly cured to prevent any objectionable odor.

#### 17.22.1.2 Physical Properties

Flexible foam shall meet the physical property criteria in the table below when tested without upholstery material. Submit test results. (CDRL 17-16):

<b>Flexible Foam Physical Property Criteria</b>		
<b>Mechanical Property</b>	<b>ASTM Test Method</b>	<b>Value</b>
Tensile Strength	D3574 Test E	5.0 lbf/in <sup>2</sup> (34.5 kPa) minimum
Elongation	D3574 Test E	70% minimum
Compression Set at 50%	D1055	15% maximum
Flex Fatigue	D1055	Thickness loss 5% maximum
Tear Strength	D3574	2.0 lbf/in <sup>2</sup> (13.8 kPa) minimum

### 17.22.2 Seat Upholstery Material

#### 17.22.2.1 General

Fabrics used for seat upholstery shall be made of woven, transportation grade fabrics to be approved by Sound Transit. The maximum fabric shrinkage shall be 2% in either the warp or fill direction.

#### 17.22.2.2 Physical Properties

Seat upholstery material shall be subjected to the physical tests of textile products required by the following ASTM methods, and the results shall not be less than the values in the table below. Submit test results. (CDRL 17-16)

<b>Seat Upholstery Material Physical Tests</b>		
<b>Description</b>	<b>ASTM Test Method</b>	<b>Criteria</b>
Fabric Weight	D3776/ D3376M	15.7 oz/yd <sup>2</sup> (372 g/m <sup>2</sup> ) without back coating
Fabric Count	D3775	Warp - (ends) 88 epi Fill - (picks) 40 to 72 ppi
Breaking Strength and Elongation	D5034	Warp - 200 lbf (896 N) Fill - 200 lbf (896 N)
Tear Strength (Tongue)	D2261	Warp - 20 lbf ( 89N) Fill - 20 lbf (89 N)
Seam Strength	D1683/ D1683M	8 to 10 stitches/in (3-4 stitches/cm) Warp - 100 lbf (444 N) Fill - 100 lbf (444 N)
Yarn Slippage	D4034	Warp - 75 lbf (336 N) Fill - 65 lbf (291 N)
Color Fastness	D3597	Water - Class 4 min Solvent - Class 4 min Crocking - Class 4 min Light - Class 4 min
Martindale Abrasion Test	D4966	20,000 cycles - no breaks

Flame-resistant polyester seat upholstery material shall be subjected to the physical tests of textile products required by the following ASTM methods, and the results shall not be less than the values in the table below. Submit test results. (CDRL 17-16).

<b>Flame-Resistant Polyester Physical Tests</b>		
<b>Description</b>	<b>ASTM Test Method</b>	<b>Criteria</b>
Fabric Weight	D3776/ D3776M	15.7 oz./yd <sup>2</sup> (372 g/m <sup>2</sup> ) without back coating
Fabric Count	D3775	Warp - (ends) 88 epi Fill - (picks) 40 to 72 ppi
Breaking Strength and Elongation	D5034	Warp - 270 lbf (1210 N) Fill - 200 lbf (896 N)
Tear Strength (Tongue)	D2261	Warp - 20 lbf ( 89 N) Fill - 20 lbf (89 N)
Yarn Slippage	D4034	Warp - 75 lbf (336 N) Fill - 65 lbf (291 N)
Color Fastness	D3597	Water - Class 4 min Solvent - Class 4 min Crocking - Class 4 min Light - Class 4 min
Martindale Abrasion Test	D4966	20,000 cycles - no breaks

## 17.23 Wire and Cable

### 17.23.1 General

Limit the number of wire types and sizes used in the vehicle to the extent possible.

Wire and cable installed on the vehicle shall comply with the flammability, smoke emission, and toxicity requirements of this Section, AAR RP-585, and NFPA 130, and shall be suitable for the application.

Vehicle wiring shall be designed, rated, and selected to last the life of the vehicle.

Submit a Wire and Cable design package (CDRL 17-17).

### 17.23.2 Wire and Cable Type Requirements

#### 17.23.2.1 Conductors

Conductors shall be one of the following:

- Soft, annealed tinned copper conforming to ASTM B33 for conductors rated 150 °C or less;
- Soft, annealed silver-plated copper conforming to ASTM B298 for conductors rated 250 °C or less; or

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- Soft, annealed nickel-plated copper conforming to ASTM B355 for conductors rated 450 °C or less.

Provide stranding suitable for the application. Provide extra-fine wire stranding for applications subject to repetitive motion.

### **17.23.2.2 Insulation**

Insulation shall meet the requirements and comply with the standards listed below.

Flexibility: For wire sizes No. 6 AWG and larger, the insulation material shall be formulated for extra flexibility.

Voltage Rating:

- Nominal voltages 300 V or less: Insulation shall be rated minimum 600 V, ac and dc.
- Nominal voltages greater than 300 V: Insulation shall be rated minimum 2000 V, ac and dc.

General Vehicle-Body Wiring:

- Sizes No. 12 to No. 28 AWG: Teflon®, mineral-filled, abrasion-resistant insulation; or
- All sizes: Flame retardant, flexible, irradiated cross-linked polyolefin complying with ICEA S-95-658, having a continuous temperature rating of 110 °C or 125 °C, as appropriate for the application.
- Flame, Smoke, and Toxicity Standards:
  - NFPA 130
  - 49 CFR 238
  - ASTM E662 in flaming and non-flaming modes
  - Bombardier SMP 800-C
  - IEEE 1202
  - UL 1685

High Temperature Applications:

- All wire sizes: Abrasion resistant Teflon® polytetrafluorethylene (PTFE) complying with SAE AS 22759/6 or Tetrafluorethylene (TFE) complying with SAE AS 22759/10.
- Wire sizes No. 16 AWG and larger only: Silicone rubber complying with AAR RP-587 and suitable for the application.

Within Equipment: Wiring within replacement modular units, electronic apparatus such as cards and card racks, and other equipment, as approved, shall be one of the following:

- Tefzel® ethylene tetrafluoroethylene (ETFE) per ASTM D3159 (material standard) and insulation construction per SAE AS 22759/16;
- Teflon® polytetrafluoroethylene (PTFE) type EE per NEMA HP 3;

- Cross-linked polyolefin insulated wire, as described for general vehicle-body wiring, above.

Crowded Locations (Cab Console or similar locations): Tefzel® ETFE per ASTM D3159 and insulation construction per SAE AS 22759/16.

### 17.23.2.3 Multi-Conductor Cable – General Applications

Where multi-conductor cable is approved, comply with the following:

- Conductors and insulation: As described above; color coded or otherwise permanently identified as approved.
- Fillers: Where required to obtain a circular cross-section, fillers shall be made of non-hygroscopic materials compatible with the wire insulation and jacket, and shall be of the same or of a higher temperature rating than the wire insulation.
- Binder Tape: Non-hygroscopic, of the same (or better) temperature class as the wire insulation, and of a compatible material. Apply if needed to assist in cable manufacture, or as required to permit the cable to function as intended in its application.
- Shield (if required):
  - Copper braid or concentrically-served copper, tin-plated per ASTM B33 or silver-coated per ASTM B298, minimum 85% shield coverage; or
  - Aluminum/polyester tape with a drain wire and minimum 10% overlap of the tape for complete coverage, as appropriate for the application. Tape shields shall not be used in applications where the cable is subject to continued flexing, such as for trucks or couplers.
- Overall jacket: Flame-retardant, irradiated cross-linked, modified polyolefin, Tefzel® (ETFE), or Teflon® (PTFE), fully compatible with the wire insulation and application. The nominal jacket thickness shall be as shown in the table below, with the minimum wall not less than 80% of the nominal value.

<b>Multi-Conductor Cable - Nominal Jacket Wall/Thickness</b>					
<b>Cable Diameter Under Sheath</b>		<b>Modified Polyolefin Jacket</b>		<b>Teflon or Tefzel Jacket</b>	
<b>Inch</b>	<b>mm</b>	<b>Inch</b>	<b>mm</b>	<b>Inch</b>	<b>mm</b>
0.000 – 0.250	0.00 – 6.36	0.045	1.14	0.010	0.25
0.251 – 0.500	6.37 – 12.71	0.045	1.14	0.015	0.38
0.501 – 0.750	12.72 – 19.06	0.060	1.52	0.021	0.53
0.751 – 1.000	19.07 – 25.40	0.080	2.03	0.021	0.53
1.001 – 1.500	25.41 – 38.10	0.080	2.03	0.025	0.64
1.501 – 2.000	38.11 – 50.80	0.110	2.79	NA	NA
2.001 – 2.500	50.81 – 63.50	0.125	3.18	NA	NA
2.501 – 3.000	63.51 – 76.20	0.140	3.56	NA	NA

### 17.23.2.4 Multi-Conductor Cable – Coupler

If multi-conductor cable is used for the coupler, the jacket shall meet the following minimum requirements:

- Low temperature arctic-grade, heavy-duty neoprene with a wall thickness suitable for 600 V.
- Extruded and vulcanized over the cabled conductors, well centered, with a smooth appearance and no objectionable roughness or irregularities, consistent with good industry practice.
- The nominal jacket thickness shall be as shown in the table below, with the minimum wall not less than 80% of the nominal value.

<b>Coupler Cable - Nominal Sheath Wall/Thickness</b>			
<b>Cable Diameter Under Sheath</b>		<b>Neoprene Jacket</b>	
<b>Inch</b>	<b>mm</b>	<b>Inch</b>	<b>mm</b>
0.000 – 0.250	0.00 – 6.36	0.072	1.83
0.251 – 0.500	6.37 – 12.71	0.087	2.21
0.501 – 0.750	12.72 – 19.06	0.100	2.54
0.751 – 1.000	19.07 – 25.40	0.100	2.54
1.001 – 1.500	25.41 – 38.10	0.115	2.92
1.501 – 2.000	38.11 – 50.80	0.135	3.43
2.001 – 2.500	50.81 – 63.50	0.152	3.86
2.501 – 3.000	63.51 – 76.20	0.195	4.95

### 17.23.2.5 Ethernet Cable

For network cabling provide industrial-grade Ethernet cable designed for reliable performance in a transit environment:

- Conductors: Tinned copper, solid or stranded as required for the application and specified performance.
- Shielding: Provide if required to obtain specified performance.
- Jacket: Abrasion-resistant.
- Construction:
  - Suitable for the intended installation method.
  - In compliance with flammability, smoke emission, and toxicity requirements of this Section.

- Minimum IP65 rated in accordance with IEC 60529 when mated with specified connectors.

## **17.24 Wire and Cable Application and Installation Requirements**

### **17.24.1 General**

Wire and cable shall be applied and installed as specified in NFPA 70, Chapter 3, Wiring Methods and Materials, APTA PR-E-RP-002-98, NFPA 130, and IEEE Std 16, except where otherwise specified, and except that wire shall be as specified in this document.

### **17.24.2 Circuit Overcurrent Protection**

Vehicle wiring shall have circuit protection conforming to NFPA 70, Article 240, Overcurrent Protection, except as modified by these Specifications.

Each and every low-voltage dc circuit and ac circuit shall be protected by an individual circuit breaker unless specified otherwise. Separate circuit breakers shall be provided for major assemblies or functions. No circuit breaker shall protect more than one circuit, nor shall any one circuit be protected by more than one circuit breaker.

Circuit breakers shall be sized by current rating and tripping time to protect both the associated equipment and the smallest wire size used in the circuit. Circuit breakers shall be sized to interrupt the maximum circuit fault current and shall be guaranteed by the manufacturer to successfully interrupt those, and all lower currents.

Local circuit protection shall be coordinated with main source protection such that faults or overloads downstream of the local protection shall trip the local protection, and not trip the main source protection. Local protection trip settings shall be lower than the main source power or current limit settings.

Fuses are not permitted in ac and low-voltage dc applications except where specified or approved.

### **17.24.3 Wire Sizes**

Wiring shall be sized for the intended load, voltage drop, application, and installation method.

Wire and cable ampacity shall comply with NFPA 70, Section 310.15, Ampacities for Conductors Rated 0-2000 Volts. Where the temperature rating of the approved wire or cable is not included in Section 310.15 tables, manufacturer's ratings may be used, provided that the rating method is consistent with NFPA 70 Section 310.15.

Regardless of load, minimum wire sizes shall be as follows:

- Wire pulled through conduit: No. 14 AWG
- Wire within control compartments: No. 22 AWG.
- Multi-conductor cables where current is not a factor in wire size selection: No. 22 AWG.

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- Wire on electronic units, cards, and card racks: No. 22 AWG
- Wire laid in, rather than pulled through, wireways: No. 16 AWG

Wires sizes other than the above shall be only as approved.

Trainline wiring, and all associated connections, shall be sized for operation of six-car trains. The voltage drop permitted between the battery or LVPS and any load in the vehicle shall be maximum 2 V. Voltage drop measurements shall include both the supply and return leads, as well as intervening circuit breakers and switches.

### **17.24.4 Insulation and Jacketing Levels**

Wiring within enclosures shall be insulated for the highest voltage in the enclosure, unless approved otherwise.

Exposed wiring in areas of likely impact or abrasion shall have additional protection in the form of additional jacketing or armor.

### **17.24.5 High Temperature Wire Installation**

If used for interconnecting pieces of apparatus, high-temperature wire shall be in bundles with a high-temperature rated protective covering.

High temperature insulated wire shall not be used in conduit or raceways without specific approval.

### **17.24.6 Circuit Separation**

Circuits shall be physically separated to reduce the possibility of unsafe conditions, interference, or equipment damage.

The following major circuit groups shall not be harnessed or bundled together, shall not run in the same conduit, and shall be physically separated and secured in enclosures, wire ducts, junction boxes, or other wire routing devices:

- High-voltage circuits
- AC circuits
- Communication circuits
- Battery-voltage-level circuits
- Semiconductor-voltage-level circuits

Wiring operating at potentials differing by 50 V or more shall be separated as follows:

- Shall not be harnessed or cabled together.
- Shall not be run in conduit together.
- In wireway, junction boxes, or other wire routing devices separate by a rigid physical barrier.
- Within equipment enclosures, separate, route, and secure so contact between wiring is not possible.

Provide separation and/or electromagnetic shielding between the conductors of high-current switching or transient-generating equipment and the wiring of semiconductor, logic, TWC, or communication circuits such that interference does not occur between circuits.

#### **17.24.7 Spare Wires**

Provide a minimum of 10% spare wires in each group of wires between equipment enclosures, but no fewer than two spares for each wire size smaller than No. 10 AWG. Unless specifically approved by Sound Transit, no spare wiring shall be used by the Contractor. Install spares in connectors on terminal boards or other means as approved by Sound Transit.

#### **17.24.8 Wire Handling**

Wiring shall be installed by qualified, experienced wiring personnel using appropriate tools for stripping insulation, cutting, tinning, soldering, attaching terminals, etc. Use wiring tools and equipment as recommended by the tool and equipment manufacturer.

Wire shall be protected from damage during all phases of equipment manufacture. Wire shall not be walked on, dragged across sharp or abrasive objects, kinked or twisted, or otherwise mishandled. The ends of wire shall not be permitted to lay on wet floors or other damp areas where moisture may be absorbed into the conductors.

When removing insulation, wire strands shall not be nicked or broken.

#### **17.24.9 Wiring Location Requirements**

Wiring shall be located such that heat sources, maintenance access, and the Sound Transit environment do not damage or reduce the life of the wiring. Wiring shall not pass through or over the battery compartment, or over heat-generating equipment such as acceleration and braking resistors.

#### **17.24.10 Wiring Methods**

##### **17.24.10.1 General**

Wiring shall be secured and protected against movement, chafing, and contact with conductive, sharp, or abrasive objects and surfaces such that normal equipment motion does not damage or reduce the life of the wiring. No wiring shall be secured directly to the vehicle structure, equipment enclosures, or any metallic surface.

Exposed wiring and multi-conductor cabling shall be kept to a minimum and shall be subject to Sound Transit review and approval.

##### **17.24.10.2 Specific Requirements for Wiring Method**

- Wire smaller than No. 6 AWG shall be installed in conduit or wireway unless it is an integral part of equipment or is contained within an enclosure.
- Wiring to resiliently mounted or moving equipment shall be by flexible conduit.

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- Wire No. 6 AWG or larger may be cleated in place without conduit or wireway.
- Wire ties may be used only to secure or bundle wire and cable within wireway, where exiting wireway or entering equipment enclosures, and within equipment enclosures.
- Multi-conductor cable shall not be exposed with the following exceptions:
  - Coupler cables with additional jacketing or armor; and
  - Wiring to standard small devices, such as speed sensors, that cannot accept conduit fittings.
- Undercar and roof wiring shall be waterproof, including entrance and exit points from equipment enclosures or wiring devices.

### **17.24.10.3 Wire and Cable Installation in Conduit**

Install wire and cable in conduit without using power equipment and without exceeding the manufacturer's allowed wire or cable pulling tension or sidewall tension.

Comply with the following requirements:

- Clean the conduit just before installation of wire or cable by pulling a brush or swab through.
- Install all cables to be placed in one duct simultaneously.
- Use extreme care in installing wire and cables so as to avoid twisting, kinking, scraping, or injuring the outer sheath.
- Wiring within conduit shall not be bundled or secured.
- Pulling compound, if used, shall be non-conductive, non-hygroscopic, non-odorous and shall not attract vermin.

### **17.24.10.4 Wire and Cable Installation in Wireway**

The installation of wire and cable in wireway shall comply with the requirements for NFPA 70 Article 376, Metal Wireways, or Article 378, Nonmetallic Wireways, including but not limited to the size of conductors, number of conductors, and ampacity of conductors based on wireway fill.

Comply with the following requirements:

- Wire and cable shall be laid into wireway. If pulling is required, prepare a pulling plan documenting the wire or cable manufacturer's minimum acceptable bend radius and maximum tension during pulling.
- To the extent possible, install all wire and cable in a wireway at the same time, unless physical separation barriers are provided.
- Wire and cable shall be installed neatly and fastened securely at least every 18 in (0.5 m) to eliminate movement and chafing.

- When wire and cable is in its final position, inspect to ensure that it has sufficient bend radius, and that there is no sagging, pinching, or possibility of chafing that could cause damage over time.

#### **17.24.10.5 Wire and Cable Installation by Cleating**

Cleating shall be by split-block cleats of fire retardant neoprene rubber with a durometer of 50 to 60. The neoprene blocks shall be clamped together with no fewer than two bolts with a rigid stiffener on each side of the cleat. The stiffeners shall ensure that clamping pressure is evenly distributed over the full length of the cleat.

Each cleat opening shall be sized only for the intended wire size and shall firmly grip the wire without insulation damage or cold flow. Shimming of oversized openings is not permitted. Cleat openings shall be molded into the material by an experienced manufacturer. Cutting, drilling, or modification of cleat openings during vehicle construction is prohibited.

Cleated wiring shall be routed and supported such that each individual run of wiring cannot contact other wiring or any other part of the vehicle under any circumstances. Intervals between adjacent cleats shall not exceed 18 in (0.5 m).

Provide a drip loop on exposed wiring to prevent fluid runoff into connected equipment.

#### **17.24.11 Enclosure Wiring**

##### **17.24.11.1 Wiring to Enclosures**

Wiring entry into enclosures shall be through the top or upper half of the sides for underfloor equipment and through the sides for roof mounted equipment. Wiring entry into the bottom of enclosures is prohibited except for wiring entering into interior enclosures through the floor.

Wiring entering or exiting enclosures shall be secured at or within 6 in (15 cm) of the transition point. The securing device and wiring slack shall ensure that there is no strain on the wiring at the transition point.

Wiring shall be removable from enclosures without removal of wire terminals or connectors.

##### **17.24.11.2 Wiring Within Enclosures**

Wiring within enclosures shall be attached to wire supports rigidly fastened to the enclosure structure. Wiring shall be clear from edges, bolt heads, and similar areas, and shall not interfere with or contact enclosure covers.

Wiring shall be located on the top or sides of the enclosure. Wiring shall be a minimum of 1 in (25 mm) above the bottom of the box, including wiring that must connect to the bottom of apparatus.

Wiring entering a removable enclosure shall be harnessed and secured to facilitate removal of the box. Wires from different wire runs shall not be harnessed together or with internal wiring.

## *Materials and Workmanship*

Wiring shall be secured such that there is no strain on wire terminals, multi-pin connector pins, or other wire termination hardware.

Wire dress shall allow for sufficient slack at terminals to provide for shock and vibration induced movements, equipment shifting, alignment, cover removal, and component replacement. Provide additional wire length for re-termination of wires without excess tension or splicing as follows:

- AWG 10 and smaller: Four reterminations
- AWG 8 and larger: Three reterminations

### **17.24.12 Identification**

Devise a wire and terminal designation system that will coordinate each electrical circuit in the vehicle into a unified system:

- The system shall identify wiring, including circuit return wiring, and terminals according to their respective circuit function(s), and shall accurately correlate with the vehicle schematics.
- Common designations for return circuits are not permitted.
- Alternative designations may be used with Sound Transit approval in small standard assemblies, such as PA amplifiers.

Clearly identify each terminal and identify each wire with both its circuit designation, and, if attached to a terminal, its terminal designation.

- Mark wires within 3 in (75 mm) of the end of the wire.
- Provide white or yellow permanent markers with black printing or continuous wire marking printed on the wire.
  - Markers shall be oil and grease resistant and shall withstand the worst case combinations of ambient and equipment temperatures.
  - Printing shall be done by machine with permanent ink that will not rub off. Wire markers shall meet the adherence and solvent resistance requirements specified by SAE AS 81531. Hand printing is prohibited.
- Color coded wires are permitted as an alternative in small standard assemblies such as PA amplifiers.

### **17.24.13 Wire Ties, Anchors, and Clamps**

Wire ties and anchors shall be nylon formulated for resistance to ozone and ultraviolet light, rated for outdoor service, and shall last for the life of the vehicle.

Comply with the following for wire ties:

- Select width for intended wiring load and minimum insulation indentation.

## *Materials and Workmanship*

- Install with tools with automatic tensioning devices, as supplied by the wire tie manufacturer.
- Install with sufficient tension to restrain the wiring but without indenting the wire insulation.
- Install with cut ends flush with the locking mechanism.

If used, wire tie anchors shall be riveted or screwed to rigid structure. Adhesive-based wire tie anchors are not permitted.

Wire clamps shall be nylon formulated for resistance to ozone and ultraviolet light, rated for outdoor service, or stainless steel covered with neoprene or silicon rubber such as Adel clamps as manufactured by Adel Wiggins. Wire clamps shall last for the life of the vehicle. Fasten clamps with bolts and elastic stop nuts.

### **17.25 Wiring Terminations**

#### **17.25.1 General**

Vehicle wiring shall be connected via terminals and terminal boards and/or multi-pin connectors. Wire splicing is not permitted. Inline connectors and splice packs are prohibited. Junction boxes or equipment enclosures shall be used for all wire terminations or circuit branches.

Wiring terminations and connections shall be subject to Sound Transit review and approval. (CDRL 17-18)

#### **17.25.2 Terminal Boards**

As used in this document, the term "terminal board" refers to devices commonly called terminal blocks, terminal strips, terminal studs, or similar, to which wires are connected. Terminal boards shall be of a series service proven in rail transit.

The conducting portion of terminal boards shall be plated copper. The insulating portion shall be a strong, high temperature rated, tracking resistant material that is not brittle. The material shall be either a filled reinforced thermosetting material or a thermoplastic material. Use of general purpose phenolic is prohibited.

Clamps, screws, or other hardware may be plated steel. Jumpers between adjacent terminals shall be plated brass or copper.

Terminal boards for power circuits, or for wire sizes greater than No. 8 AWG, shall be stud type, with barriers between terminals. Stud-type terminal boards shall be in accordance with SAE AS 27212 and shall have plated brass or steel studs. Wiring shall be fastened with flat washers over the wire terminals, plated spring type lock washers and hex nuts of the same materials as the stud. Wiring connected to threaded studs shall have a minimum of 2-1/2 threads exposed beyond the nuts.

Terminal boards for control circuits shall be either screw-compression clamp, or push-on tab (FASTON, for example) with barriers between terminals.

Each terminal board shall have a minimum of 10%, but no fewer than one unused terminals. For terminal boards with more than 100 terminals, the minimum number of unused terminals shall be 10 plus 2 for every 50 additional terminals above 100.

A maximum of four terminals shall be connected to any single terminal stud, provided that there is no interference between terminal barrels and sufficient threads protrude beyond the nut. Arrange the wiring so that no more than two terminals are connected to a stud, from each side of the terminal board. On screw compression-clamp terminal boards, connect a maximum of two terminals to each binding terminal. For other terminations, only one wire per terminal is permitted.

Provide adequate space to permit connecting wire terminals with standard tools.

### **17.25.3 Wire Terminals**

Wire terminals used throughout the vehicle shall be mechanical crimp type such as AMP PIDG as manufactured by TE Connectivity, or other approved manufacturer with a comprehensive line of terminals, connector pins, and application tools available. Terminals shall comply with SAE AS 25036.

Terminals used with compression clamp terminal blocks shall have insulating collars and shall be of a series approved by the terminal board manufacturer for use with the selected terminal boards.

"FASTON" type terminals shall be of a type which permits at least 100 cycles of removal and re-attachment without losing proper grip, such as AMP PIDG terminals, by TE Connectivity.

All other wiring shall use terminals complying with the following requirements:

- Ring type terminals; hook type terminations are not permitted. With specific approval, spade type terminals may be used in applications such as relays or other devices with captive screw fasteners.
- Conductor sizes No. 10 AWG or smaller: Insulated terminals with metal strain relief device under the insulation that is crimped onto and grips the wire insulation simultaneously with the terminal. The insulation material shall be rated for the expected worst case temperature.
- Plated copper.

Attach wire terminals to the wiring with crimping tools and dies as recommended by the manufacturer and approved by Sound Transit:

- Maximum of one wire in each terminal.
- Crimping tools shall be ratcheting types that ensure a complete compression.
- Maintain these tools in proper calibration and ensure that personnel using them are properly trained.

#### **17.25.4 Power Wiring Terminals**

Terminate power wiring with bolted compression terminals as manufactured by TE Connectivity (AMP brand), Thomas & Betts, or approved equal using tools and procedures recommended by the terminal manufacturer. Crimping tools shall be ratcheting types that ensure a complete compression.

Use double-bolted terminals at locations where rotation of a single bolted terminal would result in contact or unacceptable clearance with other conductors or the enclosure.

#### **17.25.5 Multi-Pin Cable Connectors**

##### **17.25.5.1 General**

Provide cable connectors with removable crimp contacts. Select contacts for the intended wire size and as recommended by the manufacturer.

The connector contact area shall be plated with a minimum of 0.000100 in (2.5 µm) of silver for general purpose applications and plated with a minimum of 0.000030 in (0.8 µm) of gold over a minimum of 0.000050 in (1.3 µm) of low stress nickel for general purpose and low level dry circuit applications.

Adjacent connectors shall use either different inserts or different insert orientations to prevent erroneous connections.

Cables shall be clamped where the force by displacement is greatest. Clamping on cable wires is prohibited.

Use extension bodies where necessary to ensure that there is sufficient room to terminate cable wires while providing the seal and clamp on the cable jacket.

##### **17.25.5.2 Waterproof Cable Connectors**

Waterproof cable connectors shall be used for under-vehicle and exposed locations; they may also be used at other locations. Connectors shall be circular or rectangular, as described below.

- Circular connectors shall be one-quarter to one-third turn, with three bayonet couplings, quick disconnect, as manufactured by ITT-VEAM, CIR series, or approved equal.
- Rectangular connectors shall be metal-shelled, positive-locking, heavy-duty multi-pole as manufactured by Harting and ILME and shall conform to DIN EN 61984 and DIN EN 175301-801.

Waterproof cable connectors shall have the following features:

- Watertight as defined in NFPA 70 under the environmental conditions specified in Section 2.
- Furnished with gaskets on the front mating surface and on the back at the cable entry.
- Give audible, visual and tactile indications of full coupling.
- Rated for a minimum life of 2,000 couplings before failure.

Speed sensor connectors only may be multi-turn, fine thread, metal shelled, waterproof connectors, Cannon or approved equal.

Seal unused connector pin positions with either connector contacts or plastic sealing plugs designed for that purpose.

### **17.25.5.3 Non-Waterproof Cable Connectors**

Non-waterproof cable connectors may be used in weatherproof interior locations. Connectors shall be AMP Circular Plastic Connectors or Circular Metal Shell by TE Connectivity, or approved equal.

### **17.25.6 Ethernet Cable Connectors**

Connectors shall be industrial Ethernet M12 type, complying with IEC 61076-2-101, with the following features:

- Gold plated contacts
- Rated for minimum 500 mating cycles
- Connectors and the cable-to-connector attachment IP65 rated per IEC 60529.

## **17.26 Grounding**

### **17.26.1 Ground Wire**

Ground wires to resiliently mounted equipment, from the car body to truck frame, or in other locations with relative movement, shall be tinned braided copper ground cables fitted with flared terminal barrels designed for strain relief.

Grounding wires to fixed equipment may be standard vehicle wiring.

Ground wires shall be sized to limit voltage rise to less than 50 V under worst case fault currents.

### **17.26.2 Grounding Connections**

Provide grounding pads for grounding connections to the vehicle body, truck frame, and other vehicle structures. Grounding pads shall be tinned or silver electro-plated copper and shall be silver soldered or brazed to both the vehicle body and the grounded item.

Ground connections shall use bolted terminals or shall be welded stainless steel. For bolted terminals, ground pads shall be through-drilled and the terminal fastened with a bolt, flat washer, and locknut. The flat washer shall bear on the ground wire terminal.

The grounding connection method employed shall have maximum dc resistance of 0.0025 ohms, or 0.025 ohms at 150 kHz for any applied ac voltage.

Fixed equipment that is held by screws, bolts, or metallic clamps may be considered to be grounded by its mounting hardware.

## **17.27 Conduit**

### **17.27.1 General**

Conduit installed on the exterior of the vehicle shall be assembled such that it is watertight under the environmental conditions specified in Section 2 and shall use watertight terminations where entering boxes, enclosures, or enclosed wireway. Submit a design package (CDRL 17-19).

### **17.27.2 Permitted Conduit Types**

Conduit shall be rigid aluminum alloy, galvanized rigid steel, or non-metallic or liquidtight flexible metal conduit as described below.

#### **17.27.2.1 Aluminum Rigid Metal Conduit**

Use: May be used where flexibility is not required.

Conduit, elbows, nipples: Aluminum alloy, UL listed, complying with ANSI C80.5.

Couplings and terminations: The same aluminum alloy as the conduit, threaded type.

Bushings: Nylon insulated, the same aluminum alloy as the conduit.

Fittings to secure conduit: Two-hole, heavy-duty galvanized steel straps, manufactured for the size of conduit they are used to secure.

#### **17.27.2.2 Steel Rigid Metal Conduit**

Use: May be used where flexibility is not required.

Conduit, elbows, and nipples: Steel, hot-dip galvanized inside and out after threading, UL listed, complying with ANSI C80.1.

Couplings and terminations: Steel, galvanized, threaded type.

Bushings: Nylon insulated, metallic.

Fittings to secure conduit: Two-hole, heavy-duty galvanized steel straps, manufactured for the size of conduit they are used to secure.

#### **17.27.2.3 Flexible Non-Metallic Conduit**

Use: May be used where flexibility is required but not where subject to physical damage:

## *Materials and Workmanship*

Conduit: Material meeting the flammability, smoke emission, and toxicity requirements of this Section. For interior use, rated IP 64 with fittings; for exterior locations, conduit shall be UV resistant and rated IP66 with fittings.

Terminations: Manufactured by the conduit manufacturer for the conduit selected and suitable for the application.

Fittings to secure conduit:

- For corrugated-exterior-wall type: Clips manufactured for the purpose by the conduit manufacturer and designed to restrain longitudinal motion.
- For smooth-exterior-wall type: Two-hole, heavy-duty galvanized steel straps, manufactured for the size of conduit they are used to secure.

### **17.27.2.4 Liquidtight Flexible Metal Conduit**

Use: May be used where flexibility is required but not where subject to physical damage or accidental impact damage, such as under the vehicle ends.

Core: Flexible galvanized steel with a continuous copper bonding conductor spiral wound between the convolutions.

Jacket: Waterproof, abrasion resistant covering containing no polyurethane or PVC, meeting the flammability, smoke emission, and toxicity requirements of this Section; moisture- and oil-proof. If used in exterior locations, jacket shall be UV resistant and rated IP66 with fittings.

Terminations: Zinc-coated steel, as supplied or recommended by the manufacturer.

Fitting to secure conduit: Two-hole, heavy-duty galvanized steel straps, manufactured for the size of conduit they are used to secure.

### **17.27.3 Conduit Fill**

Conduit fill shall not exceed the maximum fill permitted by NFPA 70, Chapter 9, Table 1, Percent of Cross Section of Conduit and Tubing for Conductors and Cables, including Notes to Tables.

### **17.27.4 Conduit Installation**

#### **17.27.4.1 General**

Install conduit to prevent moisture traps and arrange to gravity-drain toward control boxes or an open end.

Install conduit such that wire and cable may be installed after conduit installation without using power equipment and without exceeding the allowed wire or cable pulling tension or sidewall tension.

Install a bushing on each conduit terminated at a junction box, enclosure, or wireway.

Metallic conduit shall be safety grounded to the vehicle structure as specified in Section 9.

#### **17.27.4.2 Aluminum and Steel Rigid Metal Conduit**

Install conduit in accordance with NFPA 70, Article 344, Rigid Metal Conduit, including but not limited to how bends are made, the number of bends in one run, bend radii, reaming and threading, securing and supporting conduit, and use of bushings. Field bending and threading shall also be in accordance with the manufacturer's recommendations.

After threading, clean to remove threading oil. Protect threads of aluminum conduit from corrosion with oxidation-inhibiting compound and steel conduit with minimum two coats of brushed on cold galvanizing compound.

If conduit is terminated at floor level, extend minimum 1 in (25 mm) about the floor to prevent entrance of liquid.

Conduit runs shall be made electrically continuous by the use of conductive joint compound. Conductive joint compound shall be subject to Sound Transit review and approval. (CDRL 17-19)

Clean conduit after installation by pulling through a brush or swab.

#### **17.27.4.3 Flexible Non-Metallic Conduit:**

Install conduit in accordance with the requirements of NFPA 70, Article 356, Liquidtight Flexible Nonmetallic Conduit, including but not limited to the number of bends in one run, bend radii, and securing and supporting conduit.

#### **17.27.4.4 Liquidtight Flexible Metal Conduit:**

Install conduit in accordance with the requirements of NFPA 70, Article 350, Liquidtight Flexible Metal Conduit, including but not limited to the number of bends in one run, bend radii, and securing and supporting conduit.

### **17.28 Wireway**

#### **17.28.1 General**

Wireway shall be as defined in NFPA 70 Article 376, Metal Wireways or Article 378, Nonmetallic Wireways. It includes wire duct, trough, channel, or other means, not including conduit, used to contain electrical wire, electrical cable, or communications cable. It is approved for use only where it will remain permanently accessible, such as where installed in electrical lockers or behind removable panels.

Wireway shall be designed and installed to ensure that wire and cable can be installed without damage. Provide for proper wire management that will allow wire and cable to be securely fastened within wireways to prevent movement and chafing, but allow changes to be made throughout the lifetime of the vehicle.

If used for conductors of different voltages, provide circuit separation as specified in this Section.

Surfaces and edges of wireway shall be designed to prevent damage to wire and cable insulation. At wire entry and exit points, provide additional wire protection and support.

Wireway that penetrates the roof shall be terminated in a waterproof entrance box or with a waterproof fitting.

### **17.28.2 Permitted Wireway Types**

Wireway shall be metallic or non-metallic. Wireway shall be subject to Sound Transit review and approval. (CDRL 17-19)

#### **17.28.2.1 Metallic Wireway**

Metallic wireway may be used on the interior or exterior of the vehicle. It shall be fabricated from galvanized mild steel or stainless steel unless otherwise approved by Sound Transit.

Steel wireway and covers shall be galvanized after all welding, cutting and drilling operations are complete. The inside steel shall be primed and painted with white paint. Exteriors and covers shall be painted according to the approved color scheme. Seals shall not be painted.

If not made with perforated material, provide drains to prevent accumulation of water.

Wireway shall incorporate wire support hardware sufficient to support wiring every 18 in (0.5 m) or less.

Provide removable covers:

- Undercar, roof, and other exterior wireway covers shall be waterproof with resilient seals. The seals shall retain their resilience and watertightness for no less than 10 years. The covers shall be stiffened such that the seals are compressed evenly over the seal length when fastened. Undercar duct covers shall be on the bottom of the duct.
- Interior wire duct covers need not be sealed.

#### **17.28.2.2 Non-Metallic Wireway**

Non-metallic wireway may be used only on the interior of the vehicle where not subject to physical damage, such as within electrical lockers.

For non-metallic wireway, comply with the following:

- Material shall be low-smoke, halogen-free, complying with requirements for flammability, smoke emission, and toxicity in this Section.
- Wireway shall be designed for the intended purpose and may be solid or slotted.
- Provide a removable cover.

### **17.28.3 Wireway Fill**

For power wiring, the sum of the cross-sectional areas of all conductors contained at any cross-section of a wire duct shall not exceed 50% of the interior cross-sectional area of the wire duct. In wireway with control wiring only, the cross-sectional area limit does not apply, but wiring shall be installed such that no wiring touches the cover.

### **17.28.4 Wireway Installation**

#### **17.28.4.1 Metallic Wireway**

Attach securely to the vehicle structure using specified fasteners. Secure at intervals complying with NFPA 70, Article 376, Metal Wireways, as a minimum.

Metallic wireway shall be safety grounded to the vehicle structure as specified in Section 9.

#### **17.28.4.2 Non-Metallic Wireway**

Attach securely to the vehicle structure using specified fasteners; adhesive fasteners are not permitted. Secure at intervals complying with NFPA 70, Article 378, Nonmetallic Wireways.

### **17.29 Junction Boxes**

#### **17.29.1 General**

Junction boxes are enclosures that are part of the conduit and wireway system, and include both pull boxes and boxes for electrical connections or terminations; they do not contain electrical equipment. Refer to Section 15 for Equipment Enclosures.

Junction boxes for vehicle wiring shall be as manufactured by the Contractor or by a regular supplier of electrical junction boxes.

#### **17.29.2 Material and Construction**

Junction boxes shall be fabricated of HSLA or galvanized mild steel with a minimum wall thickness of 14 gauge.

Exterior junction boxes shall be constructed to NEMA 250 Type 4, and interior junction boxes to Type 12.

Junction box cover openings shall have a NEMA-type formed lip which provides a bearing surface for the cover seal. The portion of the lip bearing on the seal shall be flat and no less than 0.125 in (3.2 mm) wide.

Junction box walls of large boxes shall be stiffened with the stiffeners welded in place. Stiffening criteria shall conform to high quality commercial practice.

Junction boxes larger than 12 in (300 mm) in any dimension shall have depressed bottoms such that water accumulates in the center. The central point shall have a 0.25 in (6 mm) drainage hole fitted

with a 0.125 in (3.2 mm) cotter pin with the tangs facing into the box. Alternative drainage schemes may be proposed. Drain holes provisions specified in this Section do not alleviate the water test requirements in Section 16.

### **17.29.3 Covers**

Covers shall be fabricated of the same material as the box. All cover hardware shall be stainless steel. The cover shall have folded edges that overlap the box opening lip by at least 0.375 in (10 mm) with the cover fully secured. The folded edges shall be completely welded at the corners. The cover edge may also serve as the clamp bearing surface. Covers of large boxes shall be stiffened with the stiffeners welded in place.

Seals shall be closed cell neoprene foam at least 0.375 in (10 mm) thick and shall remain resilient and watertight for at least 10 years. Seals shall be attached and retained in a channel near the perimeter of the cover. The seal shall be compressed no more than 50% with the cover securely fastened. The sealing system shall pass the water test in Section 16.

Covers shall be fastened by NEMA-type clamps welded to the box structure. Clamp fasteners shall be hex or Phillips head captive screws. Clamp location and cover stiffness shall ensure even compression of the seal. Clamp fasteners shall be sized to go solid when tightened and shall not rely on seal resilience for tightness. The edge of the cover shall not bear on the enclosure before the clamp goes solid.

Provide retaining devices that prevent the cover from falling when unfastened and permit the cover to swing fully open. On boxes larger than 12 in (300 mm) in any dimension, the retaining devices shall permit the cover to be removed without tools. Chains or cables will not be permitted. Covers that open upward shall incorporate a holding device.

### **17.29.4 Terminal Board Mounting and Wire Fill**

Terminal boards shall mount to rails, brackets or standoffs fastened to the enclosure, not directly to the enclosure. No equipment shall be mounted to the enclosure bottom or within 1 in (25 mm) of the bottom.

The number of conductors in each junction box shall not exceed the limit in NFPA 70 Article 314, Outlet, Device, Pull, and Junction Boxes; Conduit Bodies; Fittings; and Handhole Enclosures.

### **17.29.5 Finish**

The interior of junction boxes and covers shall be primed and painted with white paint. Exteriors shall be painted according to the approved color scheme. Seals and cover hardware shall not be painted.

## **17.30 Electrical Devices and Hardware**

### **17.30.1 General**

Electrical devices shall be transit industry proven. Electrical connections shall use either captive screws or captive nuts, with crimp terminals.

### **17.30.2 Contactors and Relays**

Comply with the following requirements:

- Contactors and relays shall meet or exceed the requirements of MIL-PRF-6106 and MIL-R-5757 respectively, or shall have a documented successful history of operation in rail transit control applications.
- The coils of all devices shall be suppressed, except where performance may be affected. Unsuppressed coils are permitted only with the explicit approval of Sound Transit.
- Contact current ratings shall be based on continuous, inrush, or interrupting requirements, whichever is worse and then derated by at least a factor of four. Contact materials shall be selected for the actual loads, and not solely on the device rating. Silver bifurcated contacts and gold alloy bifurcated cross bar contacts shall be used on low level and dry circuits, respectively.
- Contacts connected in series shall not be operated in circuits where the voltages and currents exceed the single derated contact ratings. Contacts shall not be connected in parallel.
- Contact ratings shall be for the worst condition of reduced surface contact which may result from tip misalignment during normal operation of the device.
- Relays and contactors shall be constructed so that the contacts make and break with a wiping motion.
- Contactor arc chute spray shall be directed away from grounded items and any other electrical device.
- Contactor tip replacement shall be by bolted connection and shall not require removing the contactor or any other equipment, except the arc chute.
- Contactors shall be built with series fed arc blowout coils, unless approved otherwise.
- Time delay relays shall be of the R-C or solid state type. Mechanical or pneumatic time delay devices are not permitted.
- Relays and contactors shall be identified with the appropriate circuit designation. The label shall not be obscured by wiring or other equipment and shall not be mounted on relay covers, arc chutes, or other removable items.
- Plug-in relays shall be provided with a retainer that is captive to the relay socket. The retainer shall be arranged such that, when released, contact cannot be made with energized adjacent circuitry.

## *Materials and Workmanship*

- Contactors shall have a mechanical service life of at least one million switching operations, except as approved where infrequent operation is expected.
- Relays shall have a guaranteed mechanical service life of at least five million switching operations. Contact electrical life shall be no less than 500,000 operations, or 10 years, whichever is greater.
- There shall be a maximum of two wire terminations on any relay or contactor terminal.
- Relays and contactors shall be mounted and oriented as recommended by the Supplier.

### **17.30.3 Switches**

Switches shall be oil-tight, industrial grade switches suitable for NEMA Type 4 applications for exterior use and Type 13 applications for interior use.

Toggle and push-button switches shall be per MIL-DTL-3950, MIL-PRF-8805, Specification Sheet /1, MIL-DTL-83731, or equal, as approved by Sound Transit.

Contacts shall not be operated at voltages or currents in excess of the manufacturer's recommendations. Contact current ratings shall be de-rated by at least a factor of four for all applications. Contacts connected in series shall not be operated in circuits where the voltages and currents exceed the single derated contact ratings. Contacts shall not be connected in parallel.

Switches shall not directly control highly inductive or high inrush loads. Switch contacts shall be silver, double break. Switch mechanisms shall provide a wiping motion when contacts make or break.

Switch bodies shall be keyed to prevent rotation. Mounting hardware, including the body portion extending through the panel, shall be metal.

There shall be a maximum of two wires connected to each switch terminal.

Switches shall be individually replaceable without disconnecting or removing anything other than the mounting fasteners and electrical connections of the switch to be replaced.

In addition to the above requirements, all switches and pushbuttons shall meet the following requirements:

- Contact resistance shall be less than 0.1 ohm at 3 Vdc and a 10 mA load;
- Open circuit resistance shall be 50 megohms minimum; and
- Resistance to case shall be 1000 megohms minimum at 500 Vdc.

Control switches that are subject to water splash shall be environmentally sealed. "Subject to water splash" is defined as equipment mounted near windows or doors, or mounted on the Operator's control console.

## **17.30.4 Circuit Breakers**

### **17.30.4.1 General**

Circuit breakers of the same rating shall be of the same manufacture and model throughout the vehicle.

The ON, OFF, and TRIPPED positions of all circuit breakers shall be permanently marked on the handle or the case of the circuit breaker. The circuit breaker, when tripped, shall assume a distinct position between the ON and OFF positions to indicate the tripped condition.

Electrical connections to circuit breakers shall either be threaded to accept machine screws or use a threaded stud.

Each circuit breaker pole shall be equipped with an arc chute and other devices for arc extinguishment.

The continuous current rating of thermal-magnetic trip circuit breakers shall be selected in accordance with NFPA 70 for the load and type of service specified. Circuit breaker current rating shall be clearly and permanently marked.

Thermal-magnetic trip circuit breakers shall conform to the requirements of UL 489.

Electrically-operated circuit breakers shall be operated from the low-voltage dc supply.

### **17.30.4.2 High-Voltage Circuit Breakers**

The use of distribution-type, high-voltage dc circuit breakers is prohibited.

See Section 9 for high-speed circuit breaker requirements.

### **17.30.4.3 Low-Voltage Circuit Breakers**

Low-voltage circuit breakers shall be either one-, two-, or three-pole devices depending on the intended function. Trip elements shall be thermal-magnetic, or magnetic, as is appropriate for the application.

Provide low-voltage circuit breakers suitable for their intended use:

- General Use: Westinghouse Series C, Quicklag C frame, or Heinemann Series AM or approved equal with center trip position, front connection or approved access arrangement, and approved labeling.
- Fast Operation: Airpax type IMLK, dust sealed, magnetic breaker, or Airpax type UP, hermetically sealed, magnetic breaker, or an approved equal.

## **17.30.5 Circuit Breaker Installation**

All circuit breakers shall be mounted in the vertical direction with the ON position up.

## *Materials and Workmanship*

Circuit breakers shall be individually replaceable without disconnecting or removing anything other than the mounting fasteners and electrical connections of the breaker to be replaced.

Circuit breaker terminals shall not be used as junction points.

Wires to circuit breakers shall use ring terminals.

Circuit breaker current rating shall be clearly and permanently marked and shall be completely visible after installation.

See Section 9 for mounting location of circuit breakers.

### **17.30.6 Fuses**

Fuses will not be permitted except where specified or approved. Comply with the following where approved for use:

- Fuses shall be permanently identified adjacent to the fuse and the rating of each fuse shall be permanently and clearly marked on each fuse.
- Fuses shall be readily accessible. Fuses mounted in equipment boxes outside of the car shall be accessible from the side of the vehicle.
- Fuse holders shall contain fuse retention devices at both ends.
- High-voltage fuses shall be mounted in totally enclosed, dead front fuseholders with no exposed high-voltage connections. The fuse shall be extracted from the circuit when the fuse holder is opened and the exposed fuse shall be safely isolated from any circuit connection.
- Air gap and creepage distances shall be as approved. Fuses and fuse holders used in nominal 1500 V circuits shall be rated for no less than 2000 V.
- Where circuits use multiple fuses or fuses and circuit breakers, the coordination between the protective devices shall be discussed in the Program Review Meetings. The Contractor shall submit a report on circuit protection coordination. This report shall be subject to Sound Transit review and approval. (CDRL 17-20)

### **17.30.7 Bus Bars**

Bus bars shall be fabricated from OFE (Oxygen Free Electronic CDA C10100) or ETP (Electrolytic Tough Pitch CDA C11000) copper. The bus bar conductivity shall be 100% IACS. All bus bars shall be silver or tin plated.

Current densities, other than at joints, shall not exceed 1750 A/in<sup>2</sup> (2.71 A/mm<sup>2</sup>), and in any case shall not exceed a value which would cause a bus bar temperature rise greater than 86°F (30°C). Current densities in joints shall not exceed 650 A/in<sup>2</sup> (1 A/mm<sup>2</sup>).

Bus bars shall be properly brazed together at joints unless bolted connections are found to be absolutely necessary for maintenance purposes and are approved. The overlap at bus bar joints shall be no less than 10 times the thickness of the bus material. Bus bar connection bolts shall be torqued

to obtain a uniform bus bar connection pressure of 200 lbf/in<sup>2</sup> (1,379 kPa). Bolting hardware shall be plated steel with Belleville washers to maintain connection pressure.

### **17.30.8 Capacitors and Resistors**

Provide hermetically sealed, dry tantalum capacitors in metal cases, except for very high values that are not commercially practical or available. If dry tantalum capacitors cannot be used, provide long life grade aluminum electrolytic capacitors (for circuits with nominal voltages up to 100 V), oil, or gas impregnated metalized polypropylene capacitors. Long life grade aluminum electrolytic capacitors may be used in circuits with nominal voltage levels above 100 V only with Sound Transit approval.

Commutating capacitors shall be a paper or plastic film type and incorporate a non-toxic impregnant, and shall be chosen to give a service life of at least 30 years. Filter capacitors shall have high ripple current rating for long life.

Capacitors shall be derated 20% for voltage based on the nominal supply voltage and maximum case temperature. If filter capacitors are exposed to low ripple voltages, lesser values of derating may be accepted if it can be shown that reduced operating temperatures can be achieved due to lower dissipation; however, the sum of the dc and ac ripple voltages shall always be less than the capacitor's voltage rating at a maximum case temperature of 185°F (85°C).

Except for braking and motoring resistors, all resistors shall be derated 50% for power dissipation.

### **17.30.9 Transformers and Inductors**

Transformers and inductors shall be derated 10% for current. Transformers shall have the following characteristics:

- Vacuum-pressure impregnated (VPI) windings;
- Withstand rating at least twice the maximum peak-to-peak voltage that they will be subjected to in operation;
- Maximum audible noise of 60 dB referenced to 20 µPa at a distance of 2 ft (0.6 m) while operating at rated voltage and load. (This applies only to units located within the vehicle interior.);
- Designed to minimize radiated and induced EMI; and

The location, orientation, mounting, cable connections and cable routing shall be in accordance with the overall EMI/EMC control plan for the vehicle.

### **17.30.10 Switch, Breaker, and Fuse Panels**

Switch and breaker panels shall be dead-front type. Live portions of the protected circuitry shall be completely concealed so that no danger of electrocution or shock exists from touching the panel or any of its appurtenances or devices.

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Mount each switch and circuit panel in the specified equipment enclosures and arrange for ease of operation and access to connections.

Identify switches, breakers, fuses, and indicating lights with a nameplate of raised or recessed letters. The panel shall conform to NFPA 70, Article 408, Switchboards, Switchgear, and Panelboards. The dead front shall be moisture-proof, electrically insulating laminated phenolic or fiberglass, or grounded metal, of approved quality suitable for switchboards. Asbestos shall not be used.

A wiring gutter shall be provided along the top, sides and bottom for routing high-voltage leads to their designated circuit breakers.

The panel shall be secured by approved, captive fasteners and shall be configured for easy removal so that maintenance and repair action is not impeded.

Power distribution to circuit breakers and switches shall be from a bus bar or bus circuit. Distributing power by successive or daisy-chained connections between device terminals will not be permitted.

### **17.30.11 Battery Backup Circuits**

Where individual electronic circuits require their own battery, the following conditions apply:

- The batteries shall be rechargeable nickel-cadmium with a built-in charger or non-rechargeable lithium, unless otherwise approved by Sound Transit. (CDRL 17-21)
- If a nickel-cadmium battery is used, the charge time vs. discharge time must be approved for the specific application. In no case shall the battery life span be less than five years.
- If a lithium battery is used, the calculated life span and the assumptions for that calculation must be approved for the specific application. In no case shall the life span be less than five years.
- In order to properly assess the impact of distributed battery backup systems, the Contractor shall provide a complete list of battery locations, battery type, estimated lifespan, discharge time, and the impact of battery discharge failure. Approval of items above may be affected by this total vehicle evaluation. Distributed battery backup systems shall be subject to Sound Transit review and approval. (CDRL 17-21)

### **17.31 Reliability Standards**

All electrical and electronic control systems shall be designed, and components shall be selected, using MIL-HDBK-338, as a guide. All devices shall be derated to operate within the "Acceptable" region for electrical stress versus temperature for "Airborne Applications". If there is a conflict between guidelines given elsewhere in this Specification and MIL-HDBK-338, the more restrictive condition shall govern. Other service-proven electrical and electronic control system devices may be submitted for Sound Transit review and approval. (CDRL 17-22)

### **17.32 Ability to Repair Electrical and Electronic Devices**

The Contractor shall supply information to Sound Transit to permit the repair of printed circuit boards, relays, contactors and filters. (CDRL 17-23) The information shall be sufficiently complete to allow Sound Transit or an independent contractor to perform repairs. This information shall include circuit diagrams, bills of material, manuals, catalog data and other documentation appropriate to the device and necessary to perform repair.

Units shall not be sealed, potted or constructed to prohibit repair by Sound Transit. Units that must be potted or sealed by design shall have a minimum 10-year warranty, except for power semiconductor modules, if they are replaceable at the module level.

### **17.33 Semi-Conductor Standards**

#### **17.33.1 General**

Semiconductors shall be selected to withstand all continuous and transient voltage and power demands present in the circuit application without damage or reduction in life. Circuit designs shall provide for the presence of high current switching equipment on the vehicle and the resultant induced voltages and currents in electrical equipment.

Discrete semiconductors shall have the following minimum voltage breakdown ratings:

- Semiconductors, except diodes (see below), operated from the battery supply, or those connected to trainlines, shall have minimum breakdown ratings of four times the maximum achievable circuit voltage. Suppression devices shall be provided as necessary to protect the devices and limit the circuit voltage.
- Diodes operated from the battery supply, used as suppression devices, or connected to trainlines shall have a minimum breakdown rating (PIV) of 1000 V. Diodes with less than 1000 V PIV rating may be used if adequate circuit transient protection is also provided.
- Discrete semiconductors operated from inverters or other isolating devices shall have a minimum breakdown rating of two times the maximum circuit voltage, except where specifically detailed otherwise. Suppression devices shall be provided as necessary to protect the devices and limit the circuit voltage.

Semiconductor junction temperatures shall be limited to 300°F (150°C) (or to the maximum rated temperature for the device, whichever is less) or less at maximum ambient temperature and at maximum rated output power.

Semiconductors shall be operated at less than 50% of the maximum continuous current rating or 50% of the maximum continuous power rating, whichever is more restrictive. High power/current devices may be exempt from this requirement with prior Sound Transit approval, on a case-by-case basis. The Contractor shall submit complete device information, including all manufacturer's application recommendations, and calculated current and power demands with all waiver requests. If approved, such waivers will not reduce other requirements, including reliability. (CDRL 17-24)

Integrated circuits operated from the battery supply through inverters or other isolating devices shall be operated within the voltage and current ratings specified by the manufacturer, derated to less than 50% of the maximum stress level at the maximum operating temperature of the device as specified by the manufacturer.

Where the supplies to integrated circuits are regulated and surge protected, the voltage rating shall be 15% below the manufacturer's recommended maximum. In addition, the maximum power shall be limited to 50% of the manufacturer's specified maximum at the maximum operating temperature.

Silicon semiconductors shall be hermetically sealed and rated for operation over the temperature range of -40°C to +85°C. IGBT modules will not be required to be hermetically sealed. Non-hermetic devices will be considered, subject to Sound Transit review and approval, provided comparable reliability can be documented during the design review process.

Gallium Arsenide and similar optical semi-conductors shall be rated for operation over the temperature range of -40°F (-40°C) to +185°F (85°C).

### **17.33.2 Availability of Semiconductors**

Semiconductors shall be available from at least two manufacturers and available from U.S. distributors. Single source devices, such as high-voltage power devices, microprocessors, ASICs, and related support chips may be used only if approved by Sound Transit during the design review process. Such devices shall be essential to the proposed equipment, shall meet the service requirements, and shall be supplied by veteran manufacturers likely to support the device.

Each device shall be labeled to identify both the manufacturer and the complete part number. Operational characteristics of the device shall be published and available to Sound Transit.

### **17.33.3 Environmental Stress Screening**

All printed circuit boards or electronic assemblies shall undergo Environmental Stress Screening (ESS). The temperature cycling regimen shall be in accordance with "Reliability Toolkit: Commercial Practices Edition," Table 7.6.1-2, Baseline Temperature Cycling Regimen for Organizations Lacking ESS Experience, from the Reliability Analysis Center, except as indicated below. The temperature extremes may be limited to -13°F (25°C) to 158°F (+70°C), at the discretion of the Supplier.

The ESS shall be performed with the equipment operational, powered, and oriented as per the ultimate application. Input signals and output loads to simulate the maximum power dissipating condition in the equipment shall be applied during the rising temperature and maximum temperature portions of the temperature cycle. The equipment shall be given a full functional test before and after the ESS, and monitored for failure throughout the ESS. In the event of equipment failure, the repaired equipment shall be given another complete ESS test. Alternatives to this Baseline ESS may be acceptable at the discretion of Sound Transit, provided service-proven components, with quantifiable reliability, are used. (CDRL 17-25)

#### **17.33.4 Other Prohibitions**

Electronic equipment shall use stock components and shall function properly with the component manufacturer's full range of tolerances, such that after-purchase screening or testing of components shall not be required.

Matching of components shall be permitted only if the components are normally available from the manufacturer in matched sets.

Germanium semiconductors shall not be used.

#### **17.34 Printed Circuit Board Standards**

Printed circuit boards shall be designed, constructed and inspected to IPC-2221 and IPC-2222, except where more stringent requirements are noted here. Within IPC-2221, printed circuit board classes are designated. Printed circuit boards supplied under this Specification shall be Class 2, minimum. Class 3 requirements shall apply to all vital equipment.

Circuit board material shall be NEMA LI 1 Type FR-4 for boards with no components with power dissipation greater than 2 watts and which are not mounted adjacent to components dissipating greater than 2 watts. Otherwise, circuit board material shall be NEMA LI 1 Type FR-5.

Printed circuit boards shall have base material minimum 1/16 in (1.6 mm) thick. Conductor material shall be copper, shall be firmly attached to the board, and shall be resistant to blistering and peeling when heated with a soldering iron.

All printed circuits boards shall be designed for ease of testability per IPC-2221, "Example of a Testability Design Checklist".

Traces shall be made as wide as practical, with the minimum width being based on a 50°F (10°C) temperature rise.

Components with pins shall be mounted only on one side. Connections shall be made to the other side or internal layers via plated through holes. SMT devices may be mounted on both sides if part of an approved existing design.

Circuit boards shall be inherently stiff or shall be reinforced to prevent damage due to vibration or handling. Circuit boards larger than 100 in<sup>2</sup> (64,520 mm<sup>2</sup>) shall be centrally stiffened unless otherwise approved.

All printed circuit boards with the same function shall be interchangeable between equipment groups without additional adjustment.

Printed circuit boards shall be of the "plug-in" type, with positive support against vibration. Single board applications of a "non-plug-in" type shall be subject to Sound Transit review and approval. (CDRL 17-26)

Printed circuit boards shall be designed for insertion and removal with power applied, except where power is removed by a switch adjacent to the card rack and except where the mechanical construction would generally prohibit removal and insertion with power applied. Where a switch is used, it shall be labeled with a warning regarding its proper use.

#### **17.34.1 Marking**

The component and wiring sides of the board shall each be marked to indicate capacitor and diode polarity, and at least two leads or one lead and a graphic symbol indicating orientation of all transistors and thyristors. Alternative schemes for component identification on circuit boards may be submitted for Sound Transit approval during design review.

Integrated circuits and other multi-terminal devices shall have an index mark on the component side of the board, visible with the component inserted, to indicate proper keying and insertion; the first pin on all IC packages shall be identified on the wiring side of the board.

#### **17.34.2 Component Mounting**

Components shall be fastened to the board in such a manner as to withstand repeated exposure to shock and vibration. Large components shall be supported in addition to the solder connections. Power resistors shall be mounted on standoffs so that the resistor bodies do not contact the board, and shall be spaced far enough away from the board so that resistor-produced heat will not discolor or damage the board.

#### **17.34.3 IC and Device Sockets**

IC and device sockets are prohibited, except for components that must be removed for reprogramming or initial calibration procedures or devices that are available only for mounting in sockets. Socket applications shall be subject to Sound Transit review and approval during design review. All other components shall be soldered in place.

Where approved, IC sockets shall comply with MIL-DTL-83502 and MIL-DTL-83734, as is applicable for the device, and shall be made of the following materials:

- The bodies shall be molded from diallyl phthalate, PTFE Teflon, or approved equal.
- The contacts shall be fabricated from beryllium copper and shall be plated with a minimum of 0.000030 in (0.8  $\mu\text{m}$ ) of gold over a minimum of 0.000050 in (1.3  $\mu\text{m}$ ) of low stress nickel in the area of contact with IC pins. Sockets with tin-plated contacts may be used only where gold-plated sockets are not commercially available, and only with approval of Sound Transit.

#### **17.34.4 Conformal Coating**

Both sides of assembled printed circuit boards shall be coated with a clear insulating and protective coating material conforming to IPC-CC-830, Class 2 or better, except that all coatings shall include fluorescent indicators.

All IC sockets, connectors, and test points shall be masked when the coating is applied.

#### **17.34.5 Keying and Interlocks**

Circuit boards shall be keyed to prevent insertion into the wrong location.

Circuit boards in safety related control systems including ATS, propulsion, friction brakes, or any other systems which can cause unsafe train operation with a card removed, shall be interlocked through a safety circuit to disable the vehicle if a circuit board is removed.

#### **17.34.6 Circuit Board Connectors**

Printed circuit board connectors shall be heavy duty, high reliability, two-part type with a history of successful service in rail applications and shall be approved by Sound Transit during design review prior to commencing design.

Connectors that comply with MIL-DTL-55302, and which have plated contacts as described below, will be considered to comply with requirements of this document.

The connector contact area shall be plated with a minimum of 0.000030 in (0.8  $\mu$ m) of gold over a minimum of 0.000050 in (1.3  $\mu$ m) of low stress nickel.

Card edge connectors are prohibited.

#### **17.34.7 Enclosures and Circuit Board Hardware**

Rack-mounted circuit boards shall plug into racks containing the mating half of the circuit board connector (see Circuit Board Connectors section, above). The circuit board rack shall mount in an enclosure conforming to these Specifications. The rack, circuit board, and circuit board hardware shall be designed as an integrated system.

The rack and enclosure shall provide environmental and EMI shielding as required to meet the requirements of these Specifications.

Printed circuit boards shall be positively retained by means of keeper bars or other approved method. The enclosure or rack cover shall not be used to retain the circuit boards.

Each circuit board shall be fitted with an ejector or hand grip to assist in board removal.

The rack and the edge of each board, or the card ejector, shall be labeled with corresponding numbers to identify board location within the enclosure.

#### **17.34.8 Testing**

Non-digital test points shall be provided in appropriate locations on modules. Battery negative return or local power supply common test points, as is appropriate, shall also be provided. The test points shall accept a U.S. standard 0.080 in (2 mm) diameter tip plug or shall be a turret lug similar to Cambion No. 160-1026-01-05-00, or approved equal, with sufficient clearance to permit

attachment of a standard oscilloscope probe clip. All test points shall be identified by appropriate markings.

## **17.35 Software and Microprocessor-Based Systems**

### **17.35.1 General**

All computer hardware and software to be provided under this Contract is subject to the requirements in this Section in addition to system specific requirements stated elsewhere in this specification. This shall include but not be limited to that which is

- Resident within a microprocessor-controlled intelligent subsystem
- Provided as part of test or interface equipment
- Provided for the purpose of post-download data analysis and processing
- Incorporated within training technology
- Bench Test Equipment (BTE)
- Electronic manuals

The functional requirements for software are detailed in other portions of the Specifications and the software must be treated as an integral part of the total system design. Common requirements pertaining to all software that is being provided under this Contract are presented in this Section. These requirements include both design requirements and documentation requirements for the software. Selected hardware requirements are also included within this Section. Refer to IEC 60571 for related electronic equipment requirements.

### **17.35.2 Design Process**

The major goals for this Design Process Section are to assure that the systems are complete, reliable, require few, if any, changes late in the development cycle, are provided on schedule, and are changeable, if necessary, in the future without compromising design integrity.

The Contractor shall be responsible for the overall design, allocation of requirements to the subsystems, and integration of the subsystems into the complete system. The overall System Functional Description shall define the partitioning of the system and the allocation of requirements (including derived requirements) to the subsystems.

Since software is part of a total system design, it will be reviewed as part of each design review.

#### **17.35.2.1 Systems Engineering**

System Functional Descriptions are required to be developed as a result of a rigorous systems engineering approach. The SFDs shall be subject to Sound Transit review and approval. (CDRL 17-27)

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The Contractor is responsible for providing an overall, vehicle-level System Functional Description (SFD) meeting the following requirements:

- Clearly define the subsystems which make up the overall system.
- Clearly describe and graphically depict the interfaces between the subsystems. Where the interfaces between subsystems are complex, the interface may be generally described in the SFD, but the details must be described in an Interface Control Document (ICD) which is appended to the SFD.
- Describe how the functional requirements of the Technical Specifications are allocated to the subsystems, including the possible decomposition of single requirements into multiple requirements which are allocated to multiple subsystems.
- Define an overall system architecture that minimizes detrimental interactions between systems where a problem with one system can affect other systems. In general the systems should be independent as much as possible.
- Define common terminology for all subsystems which is used by all Suppliers.
- Define the overall system's LRUs and LLRUs.

A System Functional Description (SFD) meeting the following requirements shall be provided for each subsystem. The SFD shall:

- Clearly describe and graphically depict the subsystem's external interfaces, its hardware and software components and the internal interfaces between these components.
- Describe the allocation of the Technical Specification requirements, which have been allocated to the subsystem, including derived requirements, among the subsystem components. Where the subsystem components are further divided into subcomponents, it shall describe the allocation of requirements to these components down to the level of the LLRU.
- Clearly describe the allocation of requirements to hardware and the allocation of requirements to software, including the allocation of requirements to all programmable logic devices used in the system.
- Provide a technical description of the hardware and of the software used to execute each function.
- Provide a technical description of all key algorithms used to implement allocated requirements.
- Contain a Software Configuration Item Summary Table (SCIST) which links each Software Configuration Item (SCI) to a specific subsystem component and to the specific processor in which the SCI runs. The table shall link each SCI to the section in the SFD which describes the software item and to its design documentation (Software Requirements Specification and Software Design Description) by document number. Each SCI shall be identified by assigned part number and each processor shall be identified by manufacturer's part number and descriptive name.

- Contain a table which identifies all programmable logic devices (PLD), including but not limited to CPLDs and FPGAs. The table shall identify the device by manufacturer's part number and shall identify, by part number, the data used to customize the device to the specific application. It shall also identify the means used to program each PLD, and the documentation, by document number, which shall be provided to describe the design of the PLD.
- Contain a description of each programmable logic device used in the subsystem, which includes a description of each function performed by the PLD.

### **17.35.3 Software and Microprocessor-Based Systems Functions and Features**

#### **17.35.3.1 Hardware Platform**

Carborne and custom computer hardware shall be designed and constructed in accordance with the general electronic design principles of Section 17.

The microprocessor-based systems shall be based on an established family of microprocessors in wide use in the control system industry.

The use of commercially-available computer boards must be specifically approved by Sound Transit on a case-by-case basis. Such approval will be based upon a technical review of the product, product documentation, and a commercial assessment of product availability. (CDRL 17-28)

All software and hardware provided under this procurement, whether acting separately or in combination, must properly process all times and dates within the required span of years from 2015 to 2075 inclusive. This includes but is not limited to all carborne software as well as all PTUs, development systems, operating systems, and workstations.

Requirements for proper time and date processing must be included in the System Functional Descriptions for all systems or subsystems that use times and dates.

Since setting the time and date is required as part of normal operation of the cars and is required for system validation testing, the design must allow for setting of the time for the whole system or for any part of the system, forward or back, to any time in the required span of years, without incorrect operation or loss of data.

The control system shall be powered by dedicated transformer-isolated power supplies driven from the vehicle battery circuit.

All processor system input and output signals shall be through isolation buffers. High-voltage inputs and outputs shall be isolated external to the microcomputer card rack. Low-voltage (battery and logic voltage level) inputs and outputs shall be isolated via buffer cards in or external to the microcomputer card rack. The isolation buffers shall:

- Protect and isolate the control system from damage due to over-voltage, under-voltage, transients, shorts, and opens;

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- Perform necessary voltage translations;
- Remove noise and undesired signals;
- Limit, pre-process, discriminate, and format those signals that would otherwise require excessive processor time; and
- Consist of optical isolators, transformer isolators, and other circuits appropriate to the application. Voltage divider circuits are not allowed.

Program code and fixed data shall be stored in reprogrammable non-volatile memory. Flash PROM circuitry shall be configured so that reprogramming is accomplished using a password-protected PTU laptop along with appropriate passwords and menus. After the software design has stabilized in revenue service, flash PROM reprogramming shall be disabled such that an approved hardware "key" is required for future reprogramming.

Other than the main car battery, the use of batteries shall require Sound Transit approval. (CDRL 17-29) Refer to the Battery Backup Circuits section, below. Rechargeable batteries shall be sized to retain data for at least six months without charging and shall be located such that leakage cannot damage control system components. Battery life shall be minimum five years, regardless of type. The system shall announce the need for battery replacement such that the battery continues to perform its function until it can be replaced at the next periodic maintenance. Batteries shall not be connected by soldering. Upon detection of the loss of input power to non-battery backed systems, the processor system shall store all necessary RAM control data to non-volatile memory and take other actions, as necessary, to shut down safely.

The hardware shall be designed to allow program expansion without hardware modification. The memory needs of the installed software shall not use more than 60% of the installed memory. This requirement applies individually to each type of memory installed, whether Flash PROM, RAM, or other type. Peak processing time demands shall not be greater than 50% of the available processor time, except as indicated below. Since the peak demand may occur during some executions of a fixed interval computation cycle, the execution time for such cycles must be measured by the software and evaluated for compliance. The Contractor may petition for relief from the 50% requirement, based on product maturity and the lack of potential for expansion or modification. In no case may more than 75% of the peak processor time be used, and, generally, more margin will be required. The hardware shall include spare input and output channels of each type used within the system, except for major output drivers, the quantity of which is fixed by the overall system design (e.g., traction motor semi-conductors and sign character drivers). In addition, the architecture and assembly construction shall allow for the installation of additional I/O hardware. Simple singular functions performed by dedicated embedded processors may use up to 75% of the available processor time and do not have to provide spare I/O capability.

The Contractor shall provide for Sound Transit's approval a plan for carry-out software upgrade campaigns fleet-wide on an expedited basis. The plan shall incorporate provisions in individual systems, in the PTUs, and/or in on-board networks, that will permit individual technicians to upload new software to multiple processors simultaneously.

### **17.35.3.2 Operating Systems and Languages**

The language, and its implementation for the selected microprocessor system, shall be commercially available in English. No proprietary languages are allowed. All languages and operating systems must have an acceptable installed base (widespread use) and be approved by Sound Transit. Operating systems to be used in the product shall be described as commercially-available Software Configuration Items (SCIs) in the System Functional Descriptions. Only operating systems with documented and demonstrated actual real-time capabilities are allowed for use with software items performing real-time functions.

The Contractor and its suppliers shall use the current versions of all software and of all operating systems available at the time of the Third Program Review. Obsolete operating systems shall not be used. In the event that an operating system becomes obsolete (defined as no longer supported by its manufacturer) during the life of the Contract, the Contractor shall supply to Sound Transit a migration plan to a current operating system, which describes the consequences to all affected hardware and software.

Compilers and other software development tools shall be commercially available and shall be most recent versions fully supported by the tool manufacturer. Proprietary compilers shall not be used.

The use of proprietary communications protocols must be approved by Sound Transit. Proprietary protocols shall only be permitted if they are fully described in an Interface Control Document (ICD) and if Sound Transit is granted full rights to the use of the protocol.

### **17.35.3.3 General Features**

Software shall perform the following basic functions:

- Implement the desired control scheme such that the specified performance is achieved;
- Monitor all inputs for unsafe, erroneous, unusual, or unknown conditions or combinations of conditions. This includes network inputs that must be verified to be only of the types and content specified in the system design. Invalid messages must trigger a fault;
- Sample all input conditions at rates sufficient to detect and remedy all unsafe or damaging conditions in the shortest possible time. Sampling rates and program execution times shall be such that the control system is not the limiting factor in response to unsafe or damaging conditions. Software shall be designed to ensure that the timing requirements for safety-related tasks are always met;
- Limit all output commands to safe levels regardless of any combination of input conditions;
- Perform self-diagnostic routines and respond promptly, safely, and predictably to detected faults. The self-diagnostics shall include tests for program corruption and integrity in read/write memories;
- Respond safely and predictably when powering up or recovering from power interruptions. All power interruptions likely to have corrupted temporary storage shall be detected and

cause the system to re-initialize all affected routines and temporary data. Detection of power interruptions may be by hardware; and

- Permit thorough interrogation of all input, output, and internal conditions by external diagnostic equipment.

Programs shall be modular with separation of Operating/Executive Software from Application Software.

Software version numbers shall be included within the code and shall be accessible to the Monitoring and Diagnostic Systems. Programs stored in sets of memory devices must self-test to assure that the correct complement of devices is installed. Software shall have verifiable version control based on a cyclic redundancy check (CRC-32) polynomial published in the system documentation and verifiable using an approved utility. This utility shall be included in the PTUs, and the Monitoring and Diagnostics System. When requested by these systems, the software shall calculate the CRC-32 value and report it along with the version ID. The value can then be compared to the value for that version as documented in the Software Version Description (SVD).

System parameters shall be adjustable via PTU. Appropriate parameters shall be suggested by Suppliers, in design review, for Sound Transit review and approval. Parameters and allowed ranges shall be specified in the Software Requirements Specifications and the software shall restrict setting of parameters to these ranges. Attempts to set values outside the allowed ranges shall trigger a fault.

In the event that vital functions are performed in processor-based systems, functionality shall be verified in accordance with IEEE 1483. Such verification shall be subject to Sound Transit review and approval. (CDRL 17-30)

#### **17.35.3.4 Testability**

All system or subsystem-level features and functions of software systems shall be testable on a systems level. Specific approval by Sound Transit is necessary for any feature which is not testable on a systems level. (CDRL 17-31) For features which are only testable with special equipment, all such equipment shall be supplied by the Contractor as test equipment, and become the property of Sound Transit. This equipment shall provide the logic, sequencing, and emulation necessary to verify that the software functions as intended. In lieu of separate equipment, appropriate test functions may be provided within the Portable Test Equipment.

Type tests of processor systems shall verify the proper operation of all software features, including diagnostics. The type tests shall demonstrate that the system under test can successfully recognize and report all faults or events reported to the Monitoring and Diagnostic System. Fault criteria for triggering faults and system response, including number of cycles to equipment lockout, shall be evaluated based upon the Specifications and the system design documentation, including Interface Control Documents. Where such tests may result in damage to the system hardware, the fault or event may be simulated to avoid damage to the hardware. Such testing shall be performed any time the software is changed prior to putting it into service.

Software validation (testing) shall be part of the total project testing process. Test procedures, testing and test reports shall be subject to the review, witnessing and documentation process

required. Software testing shall be a prerequisite to higher level testing, such as system level and vehicle level tests. Software validation test procedures must be approved by the Sound Transit prior to the execution of the tests.

#### **17.35.4 Portable Test Unit (PTU) and Bench Test Equipment (BTE) Software**

For custom software that is resident in test computers, Sound Transit shall be given a license for unlimited use of the software for the approved purposes of this Contract. Licenses shall not be linked to specific hardware serial numbers. In addition, furnish PTU and BTE equipment software documentation, compliant with this Section. PTU and BTE software shall be subject to the approved Configuration Control Plan of this Section. The operating system and hardware employed for the PTU shall be the last, user-friendly system available at the time of system design and development. While it is anticipated that the system will be Microsoft Windows based, advances in technology may preclude this from being the best choice. Accordingly, identification of the system to be used will be made by Sound Transit at the time of design review.

#### **17.35.5 Communication and Control System Security**

Vehicle communication and control systems shall be secured against unauthorized access and attack, both from the vehicle itself and from the wayside. Security requirements shall apply both when the vehicle is in revenue service and when the vehicle is out-of-service for maintenance or storage. Security measures shall be consistent with industry best practices at the time of design.

To demonstrate compliance, the Contractor shall prepare and submit for approval a Vehicle Communication and Control System Vulnerability Assessment identifying all potential system vulnerabilities; associated risk (including exploit likelihood and consequences); countermeasures applied; and resulting mitigated risk. The report format shall be similar to that of a hazard analysis; a representative sample of the proposed report format shall be submitted for approval as part of the software documentation methodology required in this Section.

Exploits to be considered shall include, but are not necessarily limited to, the following, as appropriate:

- Vandalism;
- Eavesdropping;
- Device/user impersonation;
- Dictionary attacks;
- Message modification;
- Session hijacking;
- Buffer overflow;
- Denial of service;
- Jamming (physical layer denial of service);
- Virus/worm infection;
- Unauthorized software installation; and
- Unauthorized root/administrator access.

Security measures shall include, but are not limited to, the following, as appropriate:

- Restricting physical access to communication and control system components to all but authorized personnel;
- Use of Access Control Lists (ACL);
- Use of device and/or user authentication;
- Use of encryption;
- Use of hardware keys in conjunction with passwords/passphrases;
- Access logs;
- Intrusion detection/prevention;
- Antivirus;
- Proper isolation, including network isolation, of security critical system functions from other functions;
- Application of secure coding practices; and
- Use of secure operating systems.

Security measures shall be designed and implemented such that any negative effect on reliability, availability and basic system operation is minimized.

#### **17.35.6 Delivery of Software**

Each software release shall be provided to Sound Transit on flash memory or CD-ROM, and shall include executables, updated software documentation, updated user documentation, a Software Version Description Document and a SVVR. If source code will not be placed into escrow, source code must be included.

With the exception of source code covered under an escrow agreement, an initial release of software executables for carborne systems shall be supplied to Sound Transit within 180 days of the Conditional Acceptance of the first vehicle. The initial release shall include Portable Test Unit (PTU) executables.

With the exception of source code covered under an escrow agreement, an initial release of non-carborne software shall be supplied to Sound Transit within 180 days of Conditional Acceptance of the related system.

When half of the total number of cars has been delivered, the Contractor will deliver to Sound Transit all software executables and source code for carborne systems, with the exception of source code covered under an escrow agreement.

Within 180 days after the delivery of the final car, the Contractor shall deliver final versions of all software with the exception of source code covered under an escrow agreement.

After the delivery of the final software versions through the end of the warranty period, software changes shall be accompanied by a delivery of the updated software, excluding source code covered by an escrow agreement.

Escrowed source code shall be provided to the designated escrow agent and updated in accordance with the applicable escrow agreement. There shall be an initial release 180 days after the Conditional Acceptance of the first vehicle or related system, and updated when half of the total number of cars has been delivered and within 180 days after delivery of the final car.

## **17.36 Software Documentation**

### **17.36.1 General**

For non-commercially available software, thorough and accurate software documentation, including source code, shall be submitted by the Contractor for Sound Transit's approval. (CDRL 17-32) Documentation shall be sufficient for Sound Transit to monitor the Contractor's and suppliers' progress, as well as to fully comprehend and analyze the operation of the equipment in which the software is to be installed; and to enable Sound Transit to maintain and modify the software to correct problems, adapt it to changing requirements, add features, and port it to a new hardware platform. The documentation shall describe how all requirements, including those of this Section, will be met. Software documentation training shall be included within the formal Training Program.

### **17.36.2 Documentation Requirements**

The software documentation shall conform to IEEE Std 1558-2004 for a Type 5 procurement. Each Contractor and supplier software document must conform to IEEE Std 1558-2004, including the additional IEEE Standards as cited in Section 5 of IEEE Std 1558-2004.

The Contractor shall define a single software documentation methodology for the project and require all suppliers to comply with it. The methodology shall be submitted for Sound Transit's approval. If CASE tools are used which automatically generate documentation, they shall be consistent with the Contractor's documentation methodology. The Contractor shall provide descriptions to enable Sound Transit's design reviewers to understand the documentation methodology. Software documentation training for specialized CASE tools shall be included within the formal Training Program.

Documentation for non-commercially available software shall be divided into two categories, as follows:

- Category A: Application-specific software, developed or adapted specifically for this Contract, including open source items that have been customized, and
- Category B: Application-independent software, that is, fixed system software that is used in multiple applications (e.g., operating systems), or software that is encapsulated in a replaceable component (e.g., intelligent power modules) and in either case was not developed or adapted specifically for this Contract.
- Documentation for software in Category A shall meet all requirements of this Specification. Documentation for software in Category B may be exempt from certain Specification requirements, as approved by Sound Transit.
- Classification of software as Category A or B shall be subject to Sound Transit's approval. In any case, Category B software must be of an existing, service-proven design. New

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software first developed or software adapted under this Contract that is intended for use on other applications as well shall be considered as Category A regardless of the supplier's intended use of the software in the future.

The placing of software design documentation details, such as proprietary source code or compilers, in an escrow account, in lieu of submittal to Sound Transit, is permitted, subject to Sound Transit's approval, provided that sufficient software information is provided (submitted and/or shown to an approved reviewer) to enable Sound Transit to evaluate overall system performance. In any case, delivered documentation shall be sufficient to allow Sound Transit to operate and change the software including, but not limited to, source code changes, parameter adjustment, and troubleshooting of software issues.

- The escrowed software design, documentation details, source code, etc., shall be made available to Sound Transit for its own use for any of the below-listed reasons:
  - If the Contractor or its supplier is no longer in business, or no longer supports the product and has not transferred the rights to the design to another entity.
  - If, based on an independent third party assessment, the Contractor or its supplier no longer supports the product at a reasonable cost.

The Contractor shall submit the following documents for approval:

- System Functional Description (SFD) at the vehicle level;
- Interface Control Documents (ICD) between systems/subsystems at the vehicle level;
- Software Project Management Plan (SPMP);
- Software Quality Assurance Plan (SQAP);
- Software Configuration Management Plan (SCMP);
- Software Verification and Validation Plan (SVVP); and
- Software Verification and Validation Report (SVVR).

The Contractor's SVVP and SVVR, listed above, shall reflect the verification and validation related to integration of systems at the vehicle level.

Each supplier shall submit the following documents for approval:

- System Functional Description for each system they provide;
- Software Project Management Plan including a schedule showing the tasks and dates leading to the submittal of all deliverables;
- Software Quality Assurance Plan; and
- Software Configuration Management Plan.

Each supplier shall identify in the SFD each Software Configuration Item by assigned part number. The SFD shall identify all software used by the system including Category A, Category B, and

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Commercially Available Software. The SFD shall also identify separately all software tools needed to produce the system software.

Each supplier shall submit for approval the following documents for each SCI of Category A or of Category B in the supplier's system:

- Software Requirements Specification (SRS);
- Software Design Description (SDD);
- Software Test Plan (STP);
- Software Test Procedure (STPr);
- Software Test Report (STR);
- Software Requirements Traceability Matrix (SRTM);
- Software Verification and Validation Plan (SVVP);
- Software Verification and Validation Report (SVVR);
- Software Version Description (SVD); and
- Software User's Manual (SUM).

Certain document submittal requirements may be waived, as approved by Sound Transit, for software classified as Category B, as defined above.

An SVD shall accompany each release of software including the first release. The SVD shall contain a description of problems addressed, known problems yet to be addressed, features added, requirements added or changed, design changes, changes to related software documents and evidence of document review, test plan changes, and test results. A revised SVVR shall accompany each SVD.

Software User's Manuals (SUM) shall comply with IEEE Std 1063. In addition, for software requiring installation and removal by the user (PTU or BTE software), the SUM must include installation and removal instructions for the software. The SUM for all software having a Graphical User Interface (GUI) shall provide a navigation path to every screen, and the available methods for exiting a screen, both with and without applying permanent changes. The SUM for all software with a GUI shall describe all icons, controls and indications on each screen to the extent that the intended use is clear, including allowable ranges for inputs and outputs. All warning and error screens must be described.

### **17.36.3 Commercially Available Software**

Some software supplied under this procurement may be commercially available to a wide variety of users. Examples include operating systems supplied by chip manufacturers and database software for wayside fault analysis. The Contractor shall submit a list of software which is commercially available to the general public. Sound Transit shall determine which software will be classified as Commercially Available Software.

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For Commercially Available Software, software documentation requirements are limited to the following:

- The original data storage/transfer media (CD-ROM) functional and usage details;
- All provider manuals; and
- All licenses required for Sound Transit's site use.
- Descriptions of any configuration or customization such as the selection of options or features or the setting of parameters.

The Contractor shall incorporate training on how the software is to be used in the specific situation for which it was provided as part of the Training Program described.

### **17.36.4 Configuration Control**

The Contractor is responsible for the operability and compatibility of hardware and software revisions through the entire duration of the contract.

The Contractor shall develop a Software Configuration Control Plan (CCP) for tracking software changes to individual cars on Sound Transit's property until Acceptance of the entire fleet. The CCP shall also control software on non-car equipment such as PTUs, BTEs and the like, and shall include a mechanism to ensure continuing compatibility between car software and non-car software. This plan shall be submitted for approval by Sound Transit. It shall be consistent with the Contractor's approach to configuration control of hardware and require similar approvals and tests.

All software shall be identified by a name and a unique version number and date. The name shall identify the equipment into which the software is installed. Every change to software shall be reflected in an update to the version number and date.

The Contractor shall maintain a database of the software version of every software item on each car and in each piece of non-car equipment. The database shall be kept current by the Contractor at all times and made available upon request. The software version status of every software item on the car shall be provided by the Contractor at the time of Conditional Acceptance/Acceptance of each car. The software version status of every software item on each piece of non-car equipment shall be provided by the Contractor at the time of Conditional Acceptance/ Acceptance of that piece of equipment.

A utility shall be provided with all PTUs, BTEs and Software Workstations by which a unique Version ID value can be calculated using CRC-32 on the executable file for each Software Configuration Item. The calculated Version ID shall be included in the SVD of each software release.

### **17.36.5 Additional Requirements for Documents**

The Software Requirements Specifications shall include unique requirements identifiers for all requirements to facilitate tracing through the other documents. They shall also include timing

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requirements for all functions including the required intervals for fixed cycle processing requirements.

The Software Requirements Traceability Matrix (SRTM) shall provide cross-referencing between the requirements of the SRSs and the corresponding sections of the SFD, SDD, and the Software Test Plans. It shall include one table for each Software Configuration Item (SCI) and within each table there shall be a row for each SRS requirement. The first column shall be the unique identifier for the individual requirement defined in the SRS. Columns 2 to 6 shall be, in order, a short description of the requirement, the reference to the corresponding SFD section, the reference to the SRS section, the reference to the SDD section or sections, and last, the reference or references to the Software Test Plan (STP)/Software Test Procedure (STPr). Since the references are dependent on the version of the documents referenced, the specific version IDs of all referenced documents must be stated for each table. All references to documents shall specify the location of the pertinent text to a sufficiently specific degree so that the reader easily and unambiguously understands the intention.

All documents shall be submitted as separate documents, not as internal to other submittals. All documentation shall use names and acronyms consistent with those in the Specifications and as defined in the Contractor overall system definition.

The Contractor shall assure that the documentation produced provides for the straightforward traceability of requirements of the Specifications throughout the design documentation and including the final tests.

All documents submitted shall use revision bars in the margin and/or underline/strike through to highlight changes from one revision to the next.

### 17.36.6 Design Reviews and Document Submittals

The correspondence between design reviews and software submittals shall be as shown below. Deliverables must be completed within the development phases given in the table and shall be subject to Sound Transit review and approval.

<b>Review Type</b>	<b>Software Related Documentation</b>
Within 60 days after NTP: (CDRL 17-33)	Software Project Management Plan (SPMP) for Contractor Software Quality Assurance Plan (SQAP) for Contractor Preliminary Software Configuration Management Plan (SCMP) for Contractor Preliminary Software Configuration Control Plan (SCCP) for Contractor Conceptual Overall (vehicle-level) System Functional Description (SFD)

Review Type	Software Related Documentation
<p>Within 120 days after NTP: (CDRL 17-34)</p>	<p>Software Project Management Plan (SPMP) for Suppliers                      Software Quality Assurance Plans (SQAP) for Suppliers                      Software Configuration Management Plan (SCMP) for Suppliers                      Preliminary System Functional Descriptions (SFD) for Contractor and Suppliers                      Preliminary Software Requirements Specifications (SRS) for Suppliers                      Preliminary Software Verification and Validation Plan (SVVP) for Contractor and Suppliers</p> <p>Identification of languages, compilers, Computer Aided Software Engineering (CASE) tools, and operating systems to be used for Contractor and Suppliers                      Identification of degree of software transportability for Contractor and Suppliers</p>
<p>Preliminary Design Review: (CDRL 17-35)</p>	<p>System Functional Descriptions (SFD)                      Software Requirements Specifications (SRS)                      Software Test Plan (STP)                      Preliminary Software Test Procedures (STPr)                      Preliminary Software Design Descriptions (SDD)                      Software Requirements Traceability Matrix (SRTM)                      Interim Software Verification and Validation Reports (SVVR)                      Revisions to other documents for changes or updates</p>
<p>Final Design Review: (CDRL 17-36)</p>	<p>Updated System Functional Descriptions (SFD)                      Updated Software Requirements Specifications (SRS)                      Updated Software Test Plan (STP)                      Software Test Procedures (STPr)                      Software Design Descriptions (SDD)                      Source Code Files and related Software Tools                      Software Configuration Management Plan (SCMP) for Contractor and Suppliers                      Software Verification and Validation Plans (SVVP) for Contractor and Suppliers                      Software Verification and Validation Reports (SVVR) for Contractor and Suppliers                      Revisions to other documents for changes or updates</p>

After original approval, changes to the software shall be formally submitted for review and approval by Sound Transit, prior to implementation of the changes in the source code. The software documentation shall be revised concurrently with software changes. Each version of software must be accompanied by revised, reviewed, and released software documentation as well as Software Version Descriptions.

### **17.37 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail below or at the referenced location. Refer to Section 19 for CDRL requirements.

- 17-1 Recommended cleaning agents (Section 17.1.5)
- 17-2 Certification of No Prohibited Materials (Section 17.1.6)
- 17-3 Proposed materials not covered by specification or standard (Section 17.1.8)
- 17-4 Safety Data Sheets (SDS) (Section 17.1.8)
- 17-5 Fasteners Design Package: (Section 17.4.1.1)
  - 1. Matrix listing each type of fastener used on the vehicle. Manufacturer's data for each type of fastener, with sufficient information to demonstrate compliance with the Specifications.
  - 2. Plating type used for high strength fasteners.
  - 3. For structural threaded fasteners, furnish sufficient information to demonstrate compliance with the requirement for coordination of nut strength with bolt strength to prevent undetected internal thread stripping, including calculations if required.
  - 4. For safety-related fasteners, proposed sample quantities to be used for production lot testing.
- 17-6 Metals Testing and Inspection
  - 1. Production lot fastener test reports (Section 17.4.4.2)
  - 2. Test and inspection plan for stainless steel in welded applications (Section 17.5.4)
  - 3. Structural steel test and inspection plan (Section 17.6.2)
  - 4. Structural casting qualification test reports (Section 17.7.2)
  - 5. Structural castings test and inspection reports (Section 17.7.3)
  - 6. Radiographic inspection sampling frequency (Section 17.7.3.2)
  - 7. Aluminum sheet, extrusions and forgings test reports (Section 17.8.1)
- 17-7 Welding, Brazing, and Torch Soldering Design Package
  - 1. Proposed nondestructive inspection rate for welds (Section 17.9.5)
  - 2. Proposed sampling plan for volumetric inspection of full penetration production welds (Section 17.9.5)
  - 3. Proposed sampling plan for metallographic weld inspection (Section 17.9.5)
  - 4. Welding specifications, procedures and documents (Section 17.9.7)
  - 5. Specifications for welding electrodes, welding wires, and cover gases (Section 17.9.7)
  - 6. Special welding procedures for stainless steel to HSLA or other combinations of metals (Section 17.9.8)
  - 7. Resistance welding procedures (Section 17.9.9)

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8. Spot weld records and test reports (Section 17.9.9)
  9. Torch soldering test samples (Section 17.9.13)
- 17-8 Elastomers Design Package
1. Resilient, natural rubber and elastomeric truck suspension component test reports (Section 17.11.2)
  2. Applications, bonding procedures and bonding agents for elastomers (Section 17.11.5)
- 17-9 Rubber floor covering color and marbling samples (Section 17.13.2.6)
- 17-10 Pressure vessel test reports (Section 17.14.6)
- 17-11 Paint
1. Paint sample and finish binders (Section 17.16.3.1)
  2. Color samples and tri-stimulus values (Section 17.16.3.3)
  3. Type test of first vehicle (Section 17.16.4.6)
  4. Tubular beams corrosion protection test report (Section 17.16.4.3)
  5. Truck paint selection (Section 17.16.5)
  6. Accelerated testing of durability of powder coating system (Section 17.16.8)
  7. Paint coating and application document (Section 17.16.11)
- 17-12 Flammability, smoke emission, and toxicity
1. Flammability, smoke emission, and toxicity test results (Section 17.17.1)
  2. Flammability and smoke emission matrix (Section 17.17.2)
  3. Request for waiver of smoke and flammability requirements, if requested (Section 17.17.2)
  4. Materials toxicity test reports (Section 17.17.3)
  5. Combustible content heat release rate report (Section 17.17.4)
  6. Floor assembly fire test procedure (Section 17.17.5)
  7. Floor assembly fire test report (Section 17.17.5)
  8. Roof assembly fire test procedure (Section 17.17.6)
  9. Roof assembly fire test report (Section 17.17.6)
  10. Lumber flammability, smoke emission, and toxicity test reports (Section 17.18.1)
  11. Honeycomb panel flammability, smoke emission, and toxicity test reports (Section 17.18.4)
  12. Melamine faced aluminum panel flammability, smoke emission, and toxicity test reports (Section 17.18.5)
  13. Melamine panel flammability, smoke emission, and toxicity test reports (Section 17.18.6)
  14. Fiberglass reinforced plastic flammability, smoke emission, and toxicity test reports (Section 17.19.1)
  15. Thermoplastic sheet flammability, smoke emission, and toxicity test reports (Section 17.21.1)

17-13 Panel Design Package

1. Honeycomb panel structural strength test reports (Section 17.18.4)
2. Phenolic composite floor panel test reports (Section 17.18.7)

17-14 Fiber Reinforced Plastic

1. Reinforced plastic test certificates (Section 17.19.7)

17-15 Thermoplastic sheet strength test certificates (Section 17.21.4)

17-16 Seat Materials Design Package

1. Flexible foam physical property test reports (Section 17.22.1.2)
2. Seat upholstery physical property test reports (Section 17.22.2.2)
3. Polyester seat upholstery physical property test reports (Section 17.22.2.2)

17-17 Wire and Cable Design Package (Section 17.23.1)

1. Wire and cable samples, specifications, compliance with referenced standards, and intended application for each type (Sections 17.23.2.2, 17.23.2.3, 17.23.2.4, 17.23.2.5)
2. Wire ampacity rating tables or other methods used for calculating ampacity for each type wire and cable (Section 17.24.3)
3. Request for approval for exposed wiring and cabling (Section 17.24.10.1)
4. Wiring and terminal designation system (Section 17.24.12)
5. Label and label printer manufacturer's data (Section 17.24.12)

17-18 Wiring Terminations Design Package

1. Terminal boards design data (Section 17.25.2)
2. Wire terminal product line and installation tools (Sections 17.25.3, 17.25.4)
3. Multi-pin cable connector manufacturer's data and intended application for each type (Section 17.25.5)
4. Ethernet cable connectors (Section 17.25.6)

17-19 Conduit and Wireway Design Package

1. Manufacturer's data and intended use for each type conduit (Section 17.27.2)
2. Conduit conductive joint compound (Section 17.27.4.2)
3. Manufacturer's data and intended use for each type wireway (Section 17.28.2)

17-20 Coordination between protective devices (Section 17.30.6)

17-21 Battery backup circuit documentation and battery type (Section 17.30.11)

17-22 Request to use other service-proven electrical and electronic control system devices (Section 17.31)

- 17-23 Electrical and electronic device repair information (Section 17.32)
- 17-24 Semiconductor current and power demand waivers, if proposed (Section 17.33.1)
- 17-25 Alternatives to Baseline ESS, if proposed (Section 17.33.3)
- 17-26 Non-plug-in single board applications, if proposed (Section 17.34)
- 17-27 System Functional Descriptions (Section 17.35.2.1)
- 17-28 Use of commercially-available computer boards (Section 17.35.3.1)
- 17-29 Use of batteries in microprocessor-controlled systems (Section 17.35.3.1)
- 17-30 Verification of vital functions (Section 17.35.3.3)
- 17-31 Features not testable on a systems level (Section 17.35.3.4)
- 17-32 Software documentation and source code -all software documentation as required by IEEE 1558-2004 whether as part of the following packages or individually at a time defined by the Contractor.
- 17-33 Conceptual Design documents (Section 17.36.6)
- 17-34 First Program Review documents (Section 17.36.6)
- 17-35 Second Program Review documents (Section 17.36.6)
- 17-36 Third Program review documents (Section 17.36.6)

## **17.1 Cited References**

The following standards or references were cited in this Section at the referenced location:

- |            |  |
|------------|--|
| AAR M-201  | (AAR MSRP, Section S) Steel Castings (Sections 17.7.1, 17.7.3)   |
| AAR M-618  | (AAR MSRP, Section E) Hose, Air, Wire-Reinforced (Section 17.14.3)                                     |
| AAR M-927  | (AAR MSRP, Section E) Hose Fittings and Hose Assemblies, Air, Wire-Reinforced (Section 17.14.3)        |
| AAR RP-585 | (AAR MSRP, Section M) Wiring and Cable Specification (Section 17.23.1)                                 |
| AAR RP-587 | (AAR MSRP, Section M) Wire and Cable Insulating Material—Silicone Rubber Insulated (Section 17.23.2.2) |

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AAR S-400	(AAR MSRP, Section E) Brake Equipment—Installation Specifications (Section 17.14.3)
AC 43.13-1B	FAA Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair (Section 17.4.6.2)
ALCOA Tech Rpt No. 524	“Specification Covering Use of Aluminum in Passenger Carrying Railway Vehicles” (Sections 17.3.3, 17.8.3)
The Aluminum Association	“Aluminum Standards and Data” (Section 17.8.1)
The Aluminum Association	“Aluminum Design Manual” (Section 17.18.2)
ANSI C80.1	Electrical Rigid Steel Conduit (ERSC) (Section 17.27.2.2)
ANSI C80.5	Electrical Rigid Aluminum Conduit (ERAC) (Section 17.27.2.1)
ANSI Z26.1	Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways (Sections 17.12.1, 17.12.2.8, 17.12.2.9, 17.12.3)
APTA PR-CS-S-004-98	Standard for Austenitic Stainless Steel for Railroad Passenger Equipment (Sections 17.5.2, 17.5.4)
APTA PR-E-RP-002-98	Recommended Practice for Wiring of Passenger Equipment (Section 17.24.1)
ASME B4.1	Preferred Limits and Fits for Cylindrical Parts (Section 17.2.6)
ASME B16.18	Cast Copper Alloy Solder Joint Pressure Fittings (Section 17.14.3)
ASME B16.22	Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings (Section 17.14.3)
ASME B31.1	Power Piping (Section 17.14.1)
ASME BPVC	Boiler and Pressure Vessel Code (Sections 17.9.2, 17.14.6)
ASTM A6/A6M	Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling (Section 17.6.1)
ASTM A36/A36M	Standard Specification for Carbon Structural Steel (Section 17.6.1)
ASTM A53/A53M	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless (Section 17.14.3)

ASTM A176	Standard Specification for Stainless and Heat-Resisting Chromium Steel Plate, Sheet, and Strip (Section 17.5.3)
ASTM A262	Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels (Sections 17.5.2, 17.5.4)
ASTM A449	Standard Specification for Hex Cap Screws, Bolts and Studs, Steel, Heat Treated, 120/105/90 ksi Minimum Tensile Strength, General Use (Section 17.4.3.2)
ASTM A480/A480M	Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip (Section 17.5.3)
ASTM A488/A488M	Standard Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel (Sections 17.9.2, 17.9.4)
ASTM A502	Specification for Rivets, Steel, Structural (Section 17.4.8.2)
ASTM A568/A568M	Standard Specification for Steel, Sheet, Carbon, and High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, General Requirements for (Section 17.6.1)
ASTM A588/A588M	Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance (Section 17.6.1)
ASTM A606/A606M	Standard Specification for Steel, Sheet and Strip, High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, with Improved Atmospheric Corrosion Resistance (Section (17.6.1)
ASTM A666	Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate and Flat Bar (Sections 17.5.2, 17.5.4)
ASTM A710/A710M	Standard Specification for Precipitation-Strengthened Low-Carbon Nickel-Copper-Chromium-Molybdenum-Columbium Alloy Structural Steel Plates (Section 17.6.1)
ASTM A763	Standard Practices for Detecting Susceptibility to Intergranular Attack in Ferritic Stainless Steels (Sections 17.5.3, 17.5.4)
ASTM B26/B26M	Standard Specification for Aluminum-Alloy Sand Castings (Section 17.8.1)
ASTM B33	Specification for Tin-Coated Soft or Annealed Copper Wire for Electrical Purposes (Sections 17.23.2.1, 17.23.2.3)

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ASTM B85/B85M	Standard Specification for Aluminum-Alloy Die Castings (Section 17.8.1)
ASTM B88	Standard Specification for Seamless Copper Water Tube (Sections 17.14.3, 17.14.4)
ASTM B108/B108M	Standard Specification for Aluminum-Alloy Permanent Mold Castings (Section 17.8.1)
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus (Section 17.4.5)
ASTM B247	Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings (Section 17.8.1)
ASTM B280	Standard Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service (Section 17.14.4)
ASTM B298	Standard Specification for Silver-Coated Soft or Annealed Copper Wire (Section 17.23.2.1, 17.23.2.3)
ASTM B355	Standard Specification for Nickel-Coated Soft or Annealed Copper Wire (Section 17.23.2.1)
ASTM B633	Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel (Section 17.4.1.4)
ASTM C542	Standard Specification for Lock-Strip Gaskets (Section 17.11.6)
ASTM D256	Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics (Section 17.19.7)
ASTM D412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension (Section 17.11.2)
ASTM D573	Standard Test Method for Rubber—Deterioration in an Air Oven (Section 17.11.2)
ASTM D618	Standard Practice for Conditioning Plastics for Testing (Section 17.19.7)
ASTM D638	Standard Test Method for Tensile Properties of Plastics (Sections 17.18.5, 17.19.7, 17.21.4)

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ASTM D648	Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position (Section 17.21.4)
ASTM D695	Standard Test Method for Compressive Properties of Rigid Plastics (Section 17.19.7)
ASTM D785	Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials (Section 17.21.4)
ASTM D790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials (Sections 17.18.5, 17.19.7, 17.21.4)
ASTM D792	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement (Section 17.21.4)
ASTM D952	Standard Test Method for Bond or Cohesive Strength of Sheet Plastics and Electrical Insulating Materials (Section 17.18.5)
ASTM D1055	Specification for Flexible Cellular Materials Latex Foam (Section 17.22.1.2)
ASTM D1149	Standard Test Methods for Rubber Deterioration–Cracking in an Ozone Controlled Environment (Section 17.11.2)
ASTM D1683/D1683M	Standard Test Method for Failure in Sewn Seams of Woven Apparel Fabrics (Section 17.22.2.2)
ASTM D2261	Standard Test Method for Tearing Strength of Fabrics by the Tongue (Single Rip) Procedure (Constant-Rate-of-Extension Tensile Testing Machine) (Section 17.22.2.2)
ASTM D2584	Standard Test Method for Ignition Loss of Cured Reinforced Resins (Section 17.19.4)
ASTM D3159	Standard Specification for Modified ETFE–Fluoropolymer Molding and Extrusion Materials (Section 17.23.2.2)
ASTM D3182	Standard Practice for Rubber–Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets (Section 17.11.2)
ASTM D3183	Standard Practice for Rubber–Preparation of Pieces for Test Purposes from Products (Section 17.11.2)

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ASTM D3190	Standard Test Method for Rubber—Evaluation of Chloroprene Rubber (CR) (Section 17.11.2)
ASTM D3363	Standard Test Method for Film Hardness by Pencil Test (Section 17.16.4.6.1)
ASTM D3574	Standard Test Methods for Flexible Cellular Materials—Slab, Bonded, and Molded Urethane Foams (Sections 17.22.1.2)
ASTM D3597	Standard Performance Specification for Woven Upholstery Fabrics—Plain, Tufted, or Flocked (Section 17.22.2.2)
ASTM D3775	Standard Test Method for Warp (End) and Filling (Pick) Count of Woven Fabrics (Section 17.22.2.2)
ASTM D3776/D3776M	Standard Test Methods for Mass Per Unit Area (Weight) of Fabric (Section 17.22.2.2)
ASTM D4034	Standard Test Method for Resistance to Yarn Slippage at the Sewn Seam in Woven Upholstery Fabrics (Section 17.22.2.2)
ASTM D4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers (Section 17.16.4.6.2)
ASTM D4966	Standard Test Method for Abrasion Resistance of Textile Fabrics (Martindale Abrasion Tester Method) (Section 17.22.2.2)
ASTM D5034	Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test) (Section 17.22.2.2)
ASTM D5402	Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs (Section 17.16.4.6.4)
ASTM D5420	Standard Test Method for Impact Resistance of Flat, Rigid Plastic Specimen by Means of a Striker Impacted by a Falling Weight (Gardner Impact) (Section 17.21.4)
ASTM E94	Standard Guide for Radiographic Examination (Sections 17.7.2, 17.10.3)
ASTM E119	Standard Test Methods for Fire Tests of Building Construction and Materials (Sections 17.17.5, 17.17.6)
ASTM E165/E165M	Standard Practice for Liquid Penetrant Examination for General Industry (Section 17.10.1)

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ASTM E446	Standard Reference Radiographs for Steel Castings up to 2 in. (50.8 mm) in Thickness (Sections 17.7.3, 17.10.3)
ASTM E662	Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials (Section 17.23.2.2)
ASTM E709	Standard Guide for Magnetic Particle Testing (Section 17.10.1)
ASTM E1354	Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter (Section 17.17.4)
ASTM F519	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments (Section 17.4.4.3)
ASTM F606	Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets (Section 17.4.4.3)
ASTM F1344	Standard Specification for Rubber Floor Tile (Section 17.13.1)
ASTM G85, Annex 5	Standard Practice for Modified Salt Spray (Fog) Testing, Annex A5, Dilute electrolyte cyclic fog dry test (17.16.4.3)
AWS Welding Handbook	(Sections 17.9.2, 17.9.12, 17.9.13)
AWS B 2.2/B2.2M	Standard for Brazing Procedure and Performance Qualification (Section 17.9.12)
AWS D 1.1/D1.1M	Structural Welding Code—Steel (Sections 17.9.2, 17.9.5)
AWS D 1.2/D1.2M	Structural Welding Code—Aluminum (Section 17.9.2)
AWS D 1.3/D1.3M	Structural Welding Code—Sheet Steel (Section 17.9.2)
AWS D 1.6/D1.6M	Structural Welding Code—Stainless Steel (Section 17.9.2)
AWS D17.2/D17.2M	Specification for Resistance Welding for Aerospace Applications (Section 17.9.2, 17.9.9)
Bombardier SMP 800-C	Toxic Gas Generation (Section 17.17.3, 17.23.2.2)
29 CFR 1910.119	Process safety management of highly hazardous chemicals (Section 17.1.6)
29 CFR 1910.1200	Hazard Communication (Section 17.1.8)

49 CFR 223	Safety Glazing Standards–Locomotives, Passenger Cars and Caboose (Section 17.12.1)
49 CFR 238	Passenger Equipment Safety Standards (Section 17.23.2.2)
DIN EN 61984	Connectors – Safety Requirements and Tests (Section 17.25.5.2)
DIN EN 175301-801	Detail Specification - High Density Rectangular Connectors, Round Removable Crimp Contacts (Section 17.25.5.2)
ICEA S-95-658	Power Cables Rated 2000 V or Less for the Distribution of Electrical Energy (17.23.2.2)
IEC 60529	Degrees of Protection Provided by Enclosures (IP Code) (Section 17.23.2.5, 17.25.6)
IEC 60571	Railway Applications - Electronic Equipment Used on Rail Vehicles (Section 17.34)
IEC 61076-2-101	Connectors for electronic equipment - Product requirements - Part 2-101: Circular connectors - Detail specification for M12 connectors with screw-locking (Section 17.25.6)
IEEE Std. 16	IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles (Section 17.24.1)
IEEE 1202	IEEE Standard for Flame-Propagation Testing of Wire and Cable (Section 17.23.2.2)
IEEE 1483	Verification of Vital functions in Processor-Based Systems Used in Rail Transit Control (Section 17.34.3.3)
IEEE Std 1558-2004	IEEE Standard for Software Documentation for Rail Equipment and Systems (Section 17.36.2)
IFI	Industrial Fasteners Institute (IFI) Inch Fastener Standards Book (Section 17.4.6.3)
IFI	IFI ISO Standards Handbook (Section 17.4.6.3)
IFI	Torque Book for Fasteners (Section 17.4.7)
IFI 143	Test For Evaluating The Torque-tension Relationship On Both Externally And Internally Threaded Fasteners (Section 17.4.5)
IIW	International Institute of Welding Collection of Reference Radiographs of Welds Section (17.7.4)

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IPC-2221	Generic Standard on Printed Board Design (Section 17.33)
IPC-2222	Sectional Design Standard for Rigid Organic Printed Boards (Section 17.33)
IPC-CC-830	Qualification and Performance of Electrical Insulating Compound for Printed Wiring Assemblies (Section 17.33.4)
ISO 273	Fasteners – Clearance holes for bolts and screws (Section 17.4.2.5)
ISO 898-1	Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread (Section 17.4.3.2)
ISO 898-2	Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with specified property classes – Coarse thread and fine pitch thread (Section 17.4.3.2)
MIL-DTL-25427	Detail Specification: Coupling Assembly, Hydraulic, Self-Sealing, Quick Disconnect (Section 17.4.2)
MIL-DTL-3950	Detail Specification: Switches, Toggle, Environmentally Sealed, General Specification for (Section 17.30.3)
MIL-DTL-55302	Connectors, Printed Circuit Subassembly and Accessories (Section 17.33.6)
MIL-DTL-83502	Sockets, Plug in Electronic Components, Round Style, General Specification for (Section 17.33.3)
MIL-DTL-83731	Detail Specification: Switches, Toggle, Unsealed and Sealed, General Specification for (Section 17.30.3)
MIL-DTL-83734	Sockets, Plug-in Electronic Components, Dual-in-Line (DIPs) and Single-in-Line Packages (SIPs), General Specification for (Section 17.33.3)
MIL-HDBK-132	Protective Finishes for Metal and Wood Surfaces (Section 17.9.1)
MIL-HDBK-338	Electronic Reliability Design Handbook (Section 17.30)
MIL-P-23469	Pin-Rivet, Grooved and Collar, Grooved Pin-Rivet, Swage-Locked (Lockpin), General Specification for (Section 17.4.8.2)

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MIL-PRF-6106	Performance Specification: Relays, Electromagnetic, General Specification for (Section 17.30.2)
MIL-PRF-8805	Performance Specification: Switches and Switch Assemblies, Sensitive, Snap Action (Basic, Limit, Push Button and Toggle Switches) General Specification for (Section 17.30.3)
MIL-R-5757	Relays, Electromagnetic, General Specification for (Section 17.30.2)
MMM-A-181	Federal Specification: Adhesives, Phenol, Resorcinol or Melamine Base (Section 17.18.3)
NAS 410	Certification and Qualification of Nondestructive Test Personnel (Section 17.10.1)
NASM21044	Nut, Self-Locking, Hexagonal, Regular Height, 250 Deg, F, 125 ksi Ft <sub>u</sub> and 60 ksi Ft <sub>u</sub> (Section 17.4.6.1)
NEMA HP 3	Electrical and Electronic Polytetrafluoroethylene (PTFE) Insulated High-Temperature Hook-up Wire; Types ET (250 V), E (600 Volt), and EE (1000 Volt) (Section 17.23.2.2)
NEMA LD 3	High-Pressure Decorative Laminates (HPDL) (Sections 17.18.5, 17.18.6)
NEMA LI 1	Industrial Laminated Thermosetting Products (Section 17.33)
NEMA 250	Enclosures for Electrical Equipment (1000 Volts Maximum) (Section 17.29.2)
NFPA 70	National Electrical Code (Sections 17.24.1, 17.24.2, 17.24.9.4, 17.25.5.2, 17.27.3, 17.27.4.2, 17.27.4.3, 17.27.4.4, 17.28.1, 17.28.4.1, 17.28.4.2, 17.29.4, 17.30.4.1, 17.30.10)
NFPA 130	Standard for Fixed Guideway Transit and Passenger Rail Systems (Sections 17.17.2, 17.17.5, 17.17.6, 17.23.1, 17.23.2.2)
NIST PS 1	Structural Plywood (Section 17.18.3)
QQ-B-654	Federal Specification: Brazing Alloys, Silver (Section 17.14.5)
Reliability Toolkit	Reliability Toolkit: Commercial Practices Edition, Reliability Analysis Center (Section 17.32.3)
SAE AMSSTD 401	Sandwich Constructions and Core Materials – General Test Methods (Section 17.18.4)

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SAE AMS 5567	Steel, Corrosion Resistant, Seamless or Welded Hydraulic Tubing, 19Cr - 10Ni (SAE 30304), Solution Heat Treated (Section 17.14.2)
SAE AMSST 6845	Tubing, Steel, Corrosion-Resistant (S30400), Aerospace Vehicle Hydraulic System 1/8 Hard Condition (Section 17.14.2)
SAE AMSC 7438	Core Material, Aluminum, for Sandwich Construction (Section 17.18.4)
SAE AS 22759/6	Wire, Electrical, Fluorocarbon-Insulated, Abrasion Resistant Extruded PTFE, Nickel-Coated Copper Conductor, 600 Volt (Section 17.23.2.2)
SAE AS 22759/10	Wire, Electrical, Fluoropolymer-Insulated, Extruded TFE, Nickel-Coated Copper Conductor, 1000 Volt (Section 17.23.2.2)
SAE AS 22759/16	Wire, Electric, Fluoropolymer-Insulated, Extruded ETFE, Medium Weight, Tin-Coated Copper Conductor, 600-Volt, 150 °C (Section 17.23.2.2)
SAE AS 25036	Terminal, Lug, Crimp Style, Copper, Insulated, Ring Tongue, Bell-Mouthed, Type II, Class 1 (For 105 °C Total Conductor Temperature) (Section 17.25.3)
SAE AS 27212	Terminal Board Assembly, Molded-In-Stud, Electric (Section 17.25.2)
SAE AS 81531	Marking of Electrical Insulating Materials (Section 17.24.11)
SAE J343	Test and Test Procedures for SAE 100R Series Hydraulic Hose and Hose Assemblies (Section 17.14.2)
SAE J429	Mechanical and Material Requirements for Externally Threaded Fasteners (Section 17.4.3.2)
SAE J516	Hydraulic Hose Fittings (Section 17.14.2)
SAE J517	Hydraulic Hose (Section 17.14.2)
SAE J533	Flares for Tubing (Section 17.14.2)
SAE J673	Automotive Safety Glasses (Section 17.12.1)
SAE J995	Mechanical and Material Requirements for Steel Nuts (Section 17.4.3.2)

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SAE J1273	Recommended Practices for Hydraulic Hose Assemblies (Section 17.14.2)
SAE J1405	Optional Test Procedures for Hydraulic Hose Assemblies (Section 17.14.2)
SAE USCAR 7	De-embrittlement Verification Test (Section 17.4.4.3)
UL 489	Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures (Section 17.30.4.1)
UL 1685	Standard for Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables (Section 17.23.2.2)

**END OF SECTION 17**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 18  
SYSTEM SUPPORT**

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**SECTION 18: SYSTEM SUPPORT**

**18.1 Manuals and Catalogs**

The Contractor shall furnish manuals for use by vehicle operators and maintenance personnel in accordance with the requirements of this Section. Manuals to be supplied as part of this Contract are as follows:

Operator's Instruction Manuals:	150 copies
Train Operator Quick Reference Guide:	150 copies
Maintenance, and Servicing, and Heavy Repair Manuals:	5 copies
Parts Catalogs:	5 copies
Training Manuals:	5copies
Special Test Equipment Manuals:	5 copies

The Contractor shall supply electronic copies of each of the above listed manuals to Sound Transit in PDF format compatible with ISO 32000-1.

Within 180 days after Notice to Proceed, the Contractor shall submit a sample of Tables of Contents and sample formats for each type of manual and for the parts catalog. (CDRL 18-1)

The intent of this deliverable is to establish scope, organization, and format early on in the process as a prerequisite for effective document development. Delivery of 10 sets of drafts of the manuals and catalogs shall occur in accordance with the following schedule:

<b>Manual Type</b>	<b>Delivery of First Draft (CDRL)</b>	<b>Delivery of Final Draft (CDRL)</b>
Operator's Instruction Manual	24 months after NTP (18-2)	40 months after NTP (18-3)
Train Operator Quick Reference Guide	24 months after NTP (18-4)	40 months after NTP (18-5)
Maintenance and Servicing Manual	24 months after NTP (18-6)	40 months after NTP (18-7)
Heavy Repair Manual	24 months after NTP (18-8)	40 months after NTP (18-9)
Parts Catalog	24 months after NTP (18-10)	40 months after NTP (18-11)
Training Manual	180 days before start of training (18-12)	90 days before start of training (18-13)
Special Test Equipment Manual	24 months after NTP (18-14)	40 months after NTP (18-15)

Each manual shall be conspicuously marked on each page where metric threaded fasteners are used within a unit.

The final approved hardcopy manuals shall be delivered no later than 60 days after approval of Final Draft, except final hardcopy of Training Manual that shall be delivered 60 days prior to starting the first training course. (CDRL 18-16)

### 18.1.1 Operator's Instructional Manual

The Operator's Instructional Manual shall contain all information needed for the optimum operation of the vehicle. It shall include general vehicle familiarization material, such as:

- Safety instructions;
- Location, function, and operation of controls, gauges, indicators and switches;
- Discussion of the trucks, couplers, lights, environmental control, hydraulic brakes, and other features of the vehicle which the operator may not be in a position to control or adjust but of which the operator should have some basic knowledge;
- Emergency procedures;
- Trouble symptoms and diagnosis methods; and
- Train operator corrective action, if any.

The manual shall be logically organized with systems and elements considered in descending order of importance. Care shall be taken that all statements are clear, positive, and accurate, with no possibility of incorrect implications or inferences.

Additionally, the manual shall be provided as a Power Point presentation or alternate format, as approved by Sound Transit. (CDRL 18-17)

### **18.1.2 Train Operator Quick Reference Guide**

The Train Operator Quick Reference Guide is an abbreviated version of the Train Operator's Manual, and will be available in every cab.

### **18.1.3 Maintenance and Servicing Manual**

The electronic Maintenance and Servicing Manual shall enable the maintenance staff to have with them in convenient form, all information needed for preventive maintenance inspections, on-vehicle running maintenance and adjustment, and on-line trouble diagnosis of each system. It shall include such data as troubleshooting guides, equipment specifications and schematics for the vehicle and each of its systems.

The Maintenance and Servicing Manual shall also contain a detailed analysis of each component of the vehicle so that the maintenance staff can effectively service, inspect, maintain, adjust, troubleshoot, repair, replace, and overhaul.

An integrated set of schematics for all electrical and hydraulic systems and interfaces on the vehicle shall be supplied as a separate section. Schematics shall clearly show references to higher and lower levels of detail. All portions of the drawings shall be clearly legible when printed on 8.5 in by 11 in paper.

The lubrication and cleaning section shall list recommended products, including recommended cleaning agents for all materials exposed to normal cleaning operations, as specified in Section 17.

### **18.1.4 Heavy Repair Manuals**

The Heavy Repair Manuals shall contain a detailed analysis of each component of the vehicle so that the maintenance staff can effectively service, inspect, maintain, adjust, troubleshoot, repair, replace, and overhaul all components on the vehicle. The Heavy Repair Manuals shall include instructions for using Portable Test Units (PTU), bench testers, and shop test stands for maintenance, adjustment, test, and troubleshooting functions as they apply to overhaul.

There shall be a separate section for the Overhaul Process Manual Requirements as needed by electronics lab personnel. It shall include detailed electronic repair information with exploded views.

### **18.1.5 Parts Catalogs**

The Parts Catalogs shall enumerate and describe every component with its related parts for the vehicles, PTUs, bench test equipment and special tools, including the supplier's number, the commercial equivalents, and Sound Transit's stock number. The inclusion of Sound Transit's stock number will require prior submission of the parts catalogs to Sound Transit for coding.

Drawings showing cutaway, isometric and exploded views of subassemblies and components shall be used to permit identification of all parts down to the lowest level replaceable unit (LLRU). The LLRU is defined as the lowest level of component assembly which consists of a separate individually fabricated part. Parts common to different components - as, for example, bolts and nuts - shall bear the same Contractor's number for all components with a reference to the other components in which they are found. Each part or other component shall have identified the next higher assembly of which it is a part. Commercially available items such as common fastenings, fuses, lamps, fittings, bearings, and relays shall be identified by standard hardware nomenclature adequate to order these items through commercial channels, as well as the Contractor's number. A separate list of these items shall be provided in the catalog with adequate information to order these items through commercial channels.

An important aspect of the parts catalog shall be the complete itemization of all consumable parts and servicing materials (oils, paints, special compounds, greases, etc.) required on the cars and the component requiring their use. In addition to the normal cross referencing noted above, at least three supply sources shall be provided for each required consumable and servicing material. Suppliers and materials shall be specified by trade name and type. Of the three required sources, at least two shall be located in the United States. Any consumable for which three suppliers are not listed shall be justified separately by the Contractor and subject to Sound Transit approval, and specifications suitable for the manufacture of the item shall be provided. (CDRL 18-18) The justification for use shall be submitted prior to the use of the material on the first vehicle.

#### **18.1.6 Training Manuals**

The Training Manual shall contain sufficient material to aid the Contractor in performing the requirements of the User Education section, below. Training Manuals shall be separate and distinct from the operations and maintenance manuals described above. They shall contain a step-by-step introduction to each systems function and operation. The material shall describe those features and equipment peculiar to the systems supplied to Sound Transit. Separate Training Manuals shall be provided for maintenance personnel and for operators.

#### **18.1.7 Special Tools and Test Equipment Manuals**

Operations and maintenance manuals for each special device identified in the Diagnostic Test Equipment and the Gauges and Special Tools sections, below, shall be presented in the same format as required for all other manuals. Each of these manuals shall be submitted with its respective special device according to the schedule identified for the device.

Besides the requirements in the section for the special device, the manuals shall include setup and testing procedures for each test device. They shall also include, in a separate section, all information needed for periodic inspection and servicing requirements, including lubrication, inspection and adjustment of all apparatus.

#### **18.1.8 Format and Content**

The organization of the manuals and catalogs shall treat the vehicle as an integrated system and not as a grouping of disassociated parts. The manuals shall highlight the precautions to be taken

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by operating and service personnel to ensure their safety while operating vehicles and performing maintenance and servicing operations.

Manuals furnished under this Contract shall be complete, modern, thoroughly organized, and authentic with no extraneous or irrelevant information.

The material in the maintenance manuals and parts catalogs shall be similarly organized and indexed, with a standard numbering system. Each section of the maintenance manuals is to be subdivided, to the extent required by the subject matter, into the following topics:

- General subsystems description and operation;
- Block diagrams;
- Signal flow diagrams;
- Integrated schematics;
- Functional wiring and/or piping diagrams;
- Troubleshooting techniques;
- Lubrication and cleaning, including frequency, methods and trade identifications of recommended materials, component location and description;
- Inspection and maintenance standards including wear limits, settings, and tolerances;
- Installation and removal; and
- Test and evaluation procedures.

The format of all data contained in the manuals shall be consistent from section to section.

Following the issue of each publication, the Contractor shall provide revised pages covering any changes, whether required by change of design, or procedures, or due to error. All submittals of revised pages shall be accompanied by an updated revision record for each manual documenting date revised, page number, effective date of the revision, a description of the change, and the reason for the change. Manual and catalog revisions both hard copy and electronic shall be supplied to Sound Transit before, or coincident, with the arrival of the altered parts or components.

These revisions shall be kept current (revised every 6 months or less) during the warranty period. After the warranty period, revisions shall be supplied to Sound Transit every 6, 9 or 12 months for a period of 5 additional years. Sound Transit will establish a definite time for submittal after acceptance of the first 10 vehicles. Changes affecting safety, safe maintenance or operation shall be supplied as soon as they are discovered

All publications shall be in loose leaf form, and use 60 or 70 pound offset paper. They shall be in seven general categories and sized as follows:

- Operator's Instruction Manual: Pocket Sized

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- Train Operator Quick Reference Guide: Pocket Sized
- Maintenance and Servicing Manual: Standard Sized
- Heavy Repair Manual: Standard Sized
- Parts Catalog: Standard Sized
- Training Manuals: Standard Sized
- Special Test Equipment Manual: Standard Sized

Pocket sized manuals shall be 4-1/4 in wide, 7 in high, and not more than 1-1/4 in thick. They shall be bound along the 4-1/4 in dimension and have pages as large as can be accommodated without damage. Punch holes shall be on 9/16 in centers.

Standard sized manuals shall be reproduced on pages that are 8-1/2 x 11 in. The binder cover shall be 10 in to 10-1/2 in wide (depending on ring size) and 11-1/2 in to 12 in high. The binders shall not exceed 3 in overall thickness. Punched holes shall be on 3/4 in centers. Folded pages will be permitted (11 x 17 in, "Z" - folded) where the information to be conveyed cannot be presented clearly on single pages. Manuals for 8-1/2 x 11 in pages may be divided into multiple volumes if the required material cannot be accommodated within the maximum binder thickness. Cross-references and a Table of Contents shall be provided in each volume.

All covers shall be approximately 1/16 in thick, resistant to oil, moisture, and wear, to a high degree commensurate with their intended uses. Final sets of manuals shall be serialized with numbers to be supplied by Sound Transit. The numbers shall be permanently marked on the spine of the cover.

Loose-leaf metal binder rings with locks shall be used to prevent undesired opening and to provide positive engagement when closed. Diagrams and illustrations shall not be loose or in pockets.

All printed material shall be clearly reproducible by dry copying machines. This precludes the use of halftone illustrations. Line drawings are required.

The Contractor shall supply master reproducible copies of all documents. The quality of the master shall be such that duplicates may be made of the same quality as the original, approved submittals.

All documents or drawings shall be in English language only. All dimensions given in metric units shall also state the English unit equivalents in parenthesis next to the metric dimensions.

### **18.1.9 Interactive Electronic Maintenance Manuals**

In addition to the PDF copy of the manuals, the Contractor shall provide interactive electronic versions of all manuals in a format alterable by Sound Transit. The Interactive Electronic Technical Manuals (IETM) shall be submitted for review and approval along with the draft and final release of the manuals as specified in this Section.

The interactive electronic technical manuals (IETM) shall be identical in format and content to the other manuals as specified above. The IETM shall be created in Adobe FrameMaker and published with a browser style front end in SGML or HTML format and be compatible with Sound Transit's existing online manuals. The front end shall link to tagged and searchable PDF files documents. All graphics shall be scalable vector format to a high resolution when zooming in on details.

The user shall be able to read and scroll through the text and illustrations on the screen just as in a paper manual. All references to other sections, figures, drawings, even if in "another manual" shall be hyperlinked to the actual location in the applicable document. The user shall be able to search a single index of all manuals and find any alphanumeric text string found in text, figures or drawings.

The Contractor shall update the IETM concurrent with the updates to the hardcopy and electronic copies as specified in this Section.

## **18.2 Diagnostic Test Equipment**

### **18.2.1 General**

The Contractor shall provide all equipment specified in this Section for comprehensive in-service testing of vehicles. All of the test equipment identified below shall be delivered not later than:

- 30 months after NTP for Portable Test Units (PTU) (CDRL 18-20);
- 40 months after NTP for Bench Test Units (BTU) (CDRL 18-21), and;
- 30 months after NTP for Vehicle Monitor System Data Management Work Station. (CDRL 18-22)

Sound Transit will use the Line Replaceable Unit (LRU) concept while maintaining the vehicle. LRU is a unit that can be replaced on a vehicle without removal of other vehicle components within Mean-Time-To-Repair (MTTR), defined in Section 2. Opening of covers to access the LRU is allowed. Sound Transit intends to detect a failed LRU on a vehicle with the MDS, Portable Test Units (PTU) or other means, and to manipulate the failed LRU status on Bench Test Units (BTU). The Contractor shall submit the LRU list for each system with the preliminary design documents and again with the final design documents for Sound Transit review and approval (refer to Section 19). The diagnostic test equipment is to be supplied in two levels, maintenance facility BTU and PTU. The BTUs shall allow definite confirmation of LRU failure, if possible a determination of the defective area on the failed LRU, failure of some standalone components (i.e. hydraulic valve), and LRU calibration. The PTU shall identify a failed LRU on the vehicle with a high degree of accuracy.

The Contractor shall make all modifications to the specified test equipment that is required because of changes and modifications made to the vehicle or any of its subsystems to meet the requirements of this Contract. The Contractor shall submit drawings of the proposed test equipment in accordance with the requirements of Section 19. (CDRL 18-23) All drawings of test equipment will be subject to the design review process required in the Specifications.

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Each piece of test apparatus shall be accompanied by an operations and maintenance manual as specified in the Special Tools and Test Equipment Manuals section, above. The manuals shall include the following:

- Complete diagrams, schematics, and maintenance and calibration instructions for the device itself; and
- Complete maintenance, calibration, and trouble-shooting procedures for the associated carborne system and its circuit boards, written around the use of the test equipment.

Acceptance of all test equipment shall occur subsequent to a Contractor demonstration that the test equipment performs its intended function.

### **18.2.2 Maintenance Facility Bench Test Devices**

Bench Test Units shall be supplied by the Contractor for the purpose of testing, troubleshooting, and calibrating all electrical, electronic, mechanical, and electro-mechanical components of each vehicle subsystem necessary and critical to the proper operation of that subsystem.

Test units shall be for use in maintenance and repair facilities. The Contractor shall coordinate with Sound Transit the unit's design to ensure compatibility with Sound Transit maintenance facilities.

Sound Transit maintenance personnel shall be able to use BTU(s) for rapid automatic LRU and LLRU testing to detect "Fault - No Fault" condition with high degree of accuracy; for calibration of the control equipment used in vehicle-mounted systems and components that need calibration for proper vehicle operation; and for rapid automatic testing of complete assemblies of assemblies which are removable from the vehicle to find defective LRU(s) and LLRU (s) with high degree of accuracy. BTU(s) shall produce all of the operating commands and other input signals necessary to fully exercise all bench- components, and to measure or indicate all of the signals, responses and outputs produced by a module by means of indicators such as lamps, meters, oscilloscopes, or gauges. Manual isolation of the faulty component within a module is permitted. Input signals shall be user-selectable and capable of being generated as a one-shot signal for a specified time period, an indefinitely held input to facilitate fault isolation, or a repeatable one-shot with hold on a faulted module output to identify intermittent faults. Each bench tester shall be supplied with an instructional manual that describes how to use the tester along with expected results and how to troubleshoot and repair the tester.

Testing of high speed data and address lines may be limited to verifying activity on the lines with a storage oscilloscope.

Shop supplied electric power will be available for bench tester use. Bench testers shall be designed to operate on 120 or 230 Vac, 60 Hz. Design of the tester shall be such that input signals or supplies can be varied over the full working range of the device. The bench test device, when used in accordance with instructions supplied by the Contractor, shall test and calibrate the vehicle equipment to a level equal in quality to that performed by the original supplier.

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Sound Transit has acquired several specialized bench test units and it is Sound Transit's desire to utilize this equipment to the extent possible for ST2 vehicles. To that end the Contractor shall submit detailed description of each proposed BTU (CDRL 18-24). The information shall provide complete description of functionality and capability of the test equipment, including a price breakdown of the main modules, assemblies and parts, so that Sound Transit can determine if its existing BTUs can be used on ST2 vehicles and systems.

It is also possible that an upgrade to the existing ST1 BTUs will allow their use on ST2 vehicles. To investigate this possibility, Sound Transit will supply functional and interface information for the existing ST1 BTUs, and make provisions to have ST1 BTUs available for Contractor inspection, so that the Contractor can determine feasibility of upgrading existing ST1 BTUs for use on ST2 vehicles, including testing, trouble shooting and repairing LRUs down to the component level.

### **18.2.3 Tablet Computers**

To facilitate management of the project during vehicle design and delivery, within 90 days of NTP the Contractor shall supply fifteen tablet computers for use by Sound Transit management and maintenance personnel (CDRL 18-19). The computers shall have the following minimum specifications:

- Diagonal screen size of 10 in to 12 in;
- 512 GB SSD storage;
- 8 GB RAM;
- Wireless connectivity complying to IEEE 802.11ac/802.11a/b/g/n;
- At least one USB 3.0 port;
- Bluetooth functionality to enable connection of peripheral devices.

The computers shall have the latest version of Windows operating system as of the date the first car is accepted and shall be preinstalled with the most-current version of Microsoft Office and a PDF copy of the ST2 vehicle Technical Specifications, Contract provisions, and a copy of the approved production schedule for the vehicles. All licenses for Microsoft Office and any other installed software shall be provided.

Folders shall be created in the file system of each tablet computer for:

- Test procedures;
- Test results;
- Forms;
- QA reports;
- Received Correspondence;

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- Sent Correspondence;
- Folders for each individual LRV, by number;
- Drawings;
- Maintenance Manuals.

The folders will not be pre-populated with content. Each tablet computer shall access a common file storage location to acquire documents and files not noted as preinstalled above.

Power charging apparatus, the original manufacturer operator or user guides, and protective cases for each tablet computer shall be supplied.

### **18.2.4 Portable Test Units**

#### **18.2.4.1 General**

Portable Test Units (PTUs) approved by Sound Transit shall be supplied for all on-board systems to aid the maintenance staff in maintaining, troubleshooting, software parameters modification, and calibration of the vehicle equipment. The PTU operating system software shall be of the latest version available at the time the first vehicle ships to the Sound Transit maintenance facility.

A design report describing the PTUs for each system, listing interfaces, hardware configuration, and operating instructions of the PTUs shall be submitted no later than 180 days after NTP. (CDRL 18-25)

Each PTU, including a laptop computer used as PTU, shall be supplied with an instructional manual that describes how to use the tester along with expected results and how to troubleshoot and repair the tester as specified in this Section. Complete parts lists and schematic diagrams of non-laptop computer PTUs are to be included. Ten sets of DVD-ROM or Memory Stick with software for each program installed in a PTU shall be provided to Sound Transit when the PTUs are delivered.

If laptop computers are used in the portable test equipment for several vehicle systems, their functions should be combined into one unit. The PTUs, laptop based and non-laptop based, shall be supplied with all necessary software installed, and with licensing agreements, for each PTU program, and these units shall be a “top-of-the-line” configuration at the time of supply as approved by Sound Transit.

The carborne equipment design shall make use of Ethernet connectors to establish all the connections required for utilization of the PTUs. Power required for operation of the PTUs shall be supplied by the carborne low-voltage power supply and the carborne auxiliary power supply, as is appropriate for the function. There shall be no high-voltage connections (1500 Vdc) allowed between the vehicle and any PTU. It shall not be necessary to remove, dislodge, dismount, or disconnect any component, card, wire, chassis, terminal, or cable in order to perform periodic calibration, or trouble diagnosis while using the PTUs.

The PTUs shall include all cables, connectors and associated equipment to interface with the test points.

#### **18.2.4.2 Functional Requirements**

When used according to the instructions supplied by the Contractor, each PTU shall enable the maintenance technician to fully check and calibrate the system or subsystem under test and to locate and replace any removable component which has failed. The function of the PTUs shall be to produce all of the operating commands and other input signals necessary to fully exercise all functions and components of the particular system or subsystem under test. The PTU shall measure actual values from transducers and indicate all signals, responses and outputs produced by a system. Any Portable Test Unit shall also operate in a passive monitoring mode, to permit observation of the functions of those systems while the vehicle is being operated at all normal vehicle operating speeds.

The Contractor shall develop a general PTU interface specification that is consistent with the details below and all relevant sections of the Specifications. This interface specification shall be used to ensure a common “look and feel” for all PTU applications regardless of supplier, and shall be submitted to Sound Transit. (CDRL 18-26)

The specification shall standardize details including, but not limited to the following:

- Graphical symbols used for common electrical, electronic, electro-mechanical and mechanical components such as contactors, relays, circuit-breakers, valves, motors, etc.
- Color codes for the status of the above items.
- Terminology for the status of the above items shall be consistent, and shall be in plain English language, not logical status. For example, valves are open or closed, contactors are on or off.
- Engineering units used for data presentation.
- System status and functional information shall be provided in a graphical format, superimposed over a system diagram or schematic. When a graphic presentation is not feasible, system status and functional information shall be provided in English language statements and relevant engineering units, and shall be formatted for easy readability. In no case shall the use of a PTU require “look-up” tables or other references to translate various codes into human comprehensible text.
- Laptop based PTU’s shall operate under the most current Microsoft Windows environment. All user interaction with the software shall be consistent with established Windows conventions.
- PTU software manipulation shall be adequately protected against inadvertent parameter changes that affect vehicle operation in general and vehicle safety functions in particular.

### **18.2.4.3 Physical Requirements**

The test equipment shall perform under the environmental conditions imposed by the activities of the vehicle inspection and repair shop with temperatures ranging from 20°F (-7°C) to 115°F (46°C) in the test areas. The test equipment shall be completely portable and suitable for rough handling during use on the shop floor, pit locations, and use in the yard. The test equipment shall be self-protected in the event of an overload or short circuit condition.

Response and output indicators and input signal generators shall be of an industrial grade. Each PTU shall be housed in an aluminum or fiberglass suitcase-type enclosure with a removable cover suitable for use in a shop environment and as manufactured by Zero Manufacturing Co., Skydyne, or approved equal. (Include in CDRL 18-25) All meters supplied as part of the PTUs shall be of a variety capable of withstanding industrial service. The weight for any PTU shall not exceed 10 pounds (13.6 kg) without the prior approval of Sound Transit. (Include in CDRL 18-25)

If a supplier of equipment has developed an acceptable PTU for use with similar equipment on a previous contract, and the supplier plans to utilize the same design for this contract, and the weight of the unit is not more than 20% above the specified weight limitation, the Contractor may seek Sound Transit approval to utilize the existing PTU design. (Include in CDRL 18-25)

### **18.2.4.4 Interface Connections**

Connection of the PTU to the equipment shall be through an Ethernet connector. The same connector shall be connected to common vehicle wide PTU Ethernet network in normal operation.

### **18.2.4.5 Cables and Hoses**

The Contractor shall not require connection of external apparatus to the PTUs without the prior written approval of Sound Transit. (CDRL 18-27) In such cases, terminals shall be provided to allow connection of the required apparatus to the PTUs. However, such apparatus shall be considered part of the PTUs and shall be supplied with it on a one-to-one basis.

## **18.2.5 Vehicle Monitor System Data Management Work Station**

A workstation shall be provided at each maintenance facility for the storage and analysis of data collected from the Monitoring and Diagnostics System.

The workstation shall be capable of performing the following tasks:

- Retrieve data from vehicles in the maintenance facility and storage yard via wireless LAN;
- Retrieve data from various PTU computers used to download car data;
- Retrieve data directly from a vehicle;
- Provide data storage for both statistical and fault data;

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- Sort and store all data using Windows-compatible data storage formats;
- Provide custom reports including multiple variable sorting on time, car, number, specific fault, failed system, and other relevant parameters; and
- Provide procedures for archiving and retrieving older data.

### **18.3 Replacement Parts**

#### **18.3.1 Recommended Spare Parts**

In addition to the capital spare parts being purchased as part of the Contract, the Contractor shall furnish a list of recommended spare parts for use during the first two years of revenue service. (CDRL 18-28)

The Contractor shall supply the recommended spare parts list after design development is completed and within 24 months of NTP. The list of recommended spare parts shall be predicated on the Contractor and subcontractor experience with the equipment in service on other properties and the maintenance requirements expected for Sound Transit. Consumption rate data and data on lead time for procurement of replacement parts shall be made available to Sound Transit in support of these spare parts recommendations.

The recommended spare parts list shall include the parts description, part number, quantity recommended.

#### **18.3.2 Spare Parts for Warranty Repairs**

The spare parts ordered by Sound Transit for support of revenue operations shall not be utilized by the Contractor or its subcontractors for warranty repairs and warranty parts replacements. Parts required for use by the Contractor and its subcontractors to provide warranty support are considered the responsibility of the Contractor and its subcontractors. Sound Transit shall not be responsible for receiving or storing any parts for warranty support.

At the end of the warranty period, Sound Transit will consider a negotiated price for purchase of all parts stocked by the Contractor for warranty support.

#### **18.3.3 Availability of Replacement Parts**

The Contractor and its subcontractors shall guarantee parts availability for the vehicle and all systems for a period of 10 years from Contract award. The Contractor shall provide a list of detailed drawings (CDRL 18-29) to Sound Transit at the beginning of the warranty period and the detailed drawings (CDRL 18-30) at the end of the 10 year period. Sound Transit may waive the drawing requirements for “off-the-shelf” items, but not the list, if the Contractor shows that the drawings are not available from the component supplier.

#### **18.3.4 Gauges and Special Tools**

Each special tool required shall be supplied by the Contractor. Special tools include but are not limited to jigs, fixtures, equipment, hand tools, power tools, or other tools and equipment

necessary to maintain, repair, overhaul, assemble, and disassemble the vehicle or subsystems, other than the PTUs and bench testers, that are not commonly available from commercial tool suppliers. Operations and Maintenance manuals shall be supplied with each special tool, as specified in the Special Tools and Test Equipment Manuals section, above. The manuals shall explain the use of the gauge or tool, and its care and maintenance. Drawings showing all dimensions and materials and part lists must also be supplied.

All special tools shall be provided as per the Commercial Provisions.

#### **18.3.4.1 Tire Pressing Device**

If a Tire Pressing Device is required to install tires on the wheels the Contractor shall provide and install the device in the Sound Transit maintenance shop. (CDRL 18-31) The Contractor shall coordinate the installation of the device with the Design Build Contractor.

#### **18.3.4.2 Rerailing Equipment**

The Contractor shall provide a set of Lucas, Railquip, or approved equal rerailing equipment to Sound Transit. (CDRL 18-32) It shall be suitable for lifting, shifting sideways, and rerailing a vehicle with any combination of wheels off the track. The equipment shall be suitable for use in both open and paved track, in open areas and in confined spaces such as against station platforms and in tunnels.

The equipment shall include as a minimum:

- Aluminum alloy lifting jacks;
- Lateral move equipment;
- Gasoline powered hydraulic pump unit;
- Hand pump;
- Control desk; and
- Color coded hydraulic hose lines.

The Contractor shall demonstrate the proper operation of the equipment by derailing each truck on a vehicle, by lifting it off the track, and then by rerailing the vehicle.

#### **18.3.4.3 Jack Socket Adapters**

The Contractor shall supply two complete sets of Jack Socket Adapters (four or six jack socket adapters per side, as required by the vehicle design) to Sound Transit. (CDRL 18-33)

#### **18.3.4.4 Center Truck Dollies**

The Contractor shall supply two center truck dollies to enable moving a car off-line which has a failed center truck. (CDRL 18-34)

### **18.3.5 Tooling Rights**

The Contractor shall not destroy castings, patterns, forming, or extrusion dies for fifteen years and without first offering Sound Transit the opportunity to purchase same.

## **18.4 User Education**

### **18.4.1 General**

User education shall consist of the two major categories listed below:

- Operator education (basic vehicle operation including how to detect and resolve in-service problems and emergencies); and
- Maintenance education (including preventive, corrective, and overhaul of components and/or assemblies).

The Contractor shall, within 180 days after NTP, submit an educational program outline (CDRL 18-35) and a schedule (CDRL 18-36). The training outline shall identify each module of instruction, the general topics to be taught, and indicate the order in which modules will be presented. The schedule shall identify milestones for submitting the course outlines, lesson plans, instructor and student guides, audio and visual aids, simulators, coordinated access to vehicles and spares, written and practical tests, and conducting classes.

The program shall be conducted at Sound Transit facilities in Seattle, Washington, and include classroom and hands-on instruction for a selected group of instructors, supervisors, mechanics, technicians, and train operators.

Prior to the initiation of classroom instruction, all instructors to be utilized by the Contractor shall attend a one-day orientation at Sound Transit to become familiar with Sound Transit safety regulations and facilities, and to be advised of student qualifications and expectations.

The Contractor shall provide an adequate supply of high quality, professionally prepared material on paper, and such other training aids as detailed in this Section to impart the essential knowledge to the people involved and leave them with authoritative and up-to-date reference material. The manuals shall be accurate, complete, and of professional quality.

All training materials and lesson plans shall become the property of Sound Transit at the completion of the training program. (CDRL 18-37) The Contractor shall be responsible for the condition of these materials for the duration of the training program, and shall replace all damaged materials unless the damage resulted from neglect by Sound Transit. Lesson plans shall be updated as required during the course of instruction.

All maintenance and operations courses shall include a combination of classroom and hands-on instruction. Written and practical tests shall be designed and given at suitable points in each course to determine the extent to which students have learned and can apply the information.

Sound Transit reserves the right to videotape any or all training activities. The Contractor may request copies of any such recordings.

### **18.4.1.1 Training Materials**

Training Aids shall include any Power Point presentations or alternate format as approved by Sound Transit (CDRL 18-38), slides, posters, annotated enlargements of schematics, videos, working models, cutaway diagrams, cutaway views or sectioned sample hardware, custom simulators, computer-based training modules, interactive video or other appropriate technology-based training. The presentations shall include computer animation to illustrate concepts, such as airflow, current flow, etc. The Contractor shall provide three-dimensional drawings/renderings of car arrangement and major equipment in electronic format, as approved by Sound Transit. (CDRL 18-39)

Where an actual set of equipment is planned for use as a training aid, an additional set, specifically for the purpose of training, shall be added to the number required for delivery at Contractor cost. (CDRL 18-40) Contract spares will not be used for training.

The Contractor shall create videos of the following for use during the training program.

- Contractor's manufacturing production line (CDRL 18-41); and
- Car Maintainability Demonstration (CDRL 18-42).

To ensure the safety of maintenance personnel, operating personnel, and passengers, the Contractor shall supply five copies of DVD or Memory Stick that cover the procedure for preparation of a train for service, operation of a train under normal operation, and emergency procedures for moving trains under fault conditions. Drafts of the DVD or Memory Stick must be delivered before the first Unit(s) arrives on Sound Transit property with continual updates to the DVD or Memory Stick as deemed necessary by Sound Transit. (CDRL 18-43) The final DVD or Memory Stick shall be delivered three months after the delivery of the first production car. (CDRL 18-44)

### **18.4.2 Operator Education**

The Contractor shall train one group of ten Sound Transit trainees not later than 60 days after arrival of the first vehicle on Sound Transit property. The vehicle must be fully operational; however, Sound Transit recognizes that the vehicle may not be accepted at this time.

Within thirty days of conditional acceptance of the first vehicle, the Contractor shall instruct seven groups of ten representatives each from Sound Transit's Transportation Department, one of which will be the previously-trained trainee group, during separate two-day training sessions. Vehicles supplied for this purpose shall be accepted and shall have all applicable systems properly operating.

The subject matter for the operator education shall be approved by Sound Transit at least 60 days prior to the delivery of the first vehicle. (CDRL 18-45) The Operator's Instructional Manual shall be used as a guideline.

Prior to shipment of the first vehicle, the Contractor shall conduct a one or two day training class at the factory for a small number of experienced Sound Transit operators and mechanics. The

class shall focus on hands-on training to familiarize the personnel with the vehicle, controls, and operational functionality. The purpose of this class is to have individuals authorized to perform vehicle moves when the first vehicle(s) arrive on Sound Transit property. This will allow Sound Transit to support the Contractor's onsite commissioning activities while the other training required by this section takes place.

### **18.4.3 Maintenance Education**

Sound Transit employees shall be exposed to the depth of detail that is necessary for the performance of preventive, corrective, and overhaul maintenance operations for all systems and sub-systems supplied under the Specifications. Students shall be afforded the opportunity to perform the more complex maintenance functions on the vehicle and in the shop, in addition to troubleshooting systems with faults artificially introduced in the equipment, while using the appropriate subsystem test devices.

Classroom instruction for maintenance courses shall include not only the details and functioning of parts under discussion, but the essentials of their routine care, including lubrication schedules, materials, Contractor's recommendations for test frequency, tolerance limits, and methods for testing, including instruments required, when applicable. When methods of access, removal, dismantling, or application are not self-evident, the instruction shall cover these matters. Overhaul procedures shall be included.

Field instruction for maintenance courses shall include both on-vehicle demonstrations and demonstrations of basic overhaul procedures using equipment in the Sound Transit facility.

The subject matter for the maintenance education shall be approved by Sound Transit at least 90 days prior to the delivery of the first vehicle. (CDRL 18-46)

Within 90 days after the delivery of the first vehicle the Contractor shall have completed instruction for 4 groups of up to 15 representatives of Sound Transit's Maintenance department during separate 4-week training sessions. The first group of 15 representatives shall receive 3 additional weeks of training for a total of 7 weeks.

To make the required overhaul training relevant it shall be deferred until the equipment is scheduled to be overhauled in accordance with the manufacturer's recommendation. The training courses shall be provided for up to 10 representatives from Sound Transit's maintenance department.

#### **18.4.3.1 Instruction Requirements**

Instruction shall include, at a minimum, the following:

- Introduction to the equipment, including terminology, identification of major components, location on the car;
- Detailed theory of operation;
- Routine care, including lubrication schedules, adjustments, limits, and inspection criteria;

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- Problem symptoms, troubleshooting techniques, and repair procedures;
- Removal and replacement from the LRV;
- Disassembly and reassembly for the purpose of component familiarity and any special processes;
- Instruction in the use of all special tools and processes; and
- Use of manuals.

### **18.4.3.2 Required Topics**

The maintenance education shall, at a minimum, include in-depth instruction covering the following subjects:

- Air conditioning and heating systems, including their controls;
- Auxiliary power supply system, including battery, battery charger, inverter, and controls;
- Monitoring and Diagnostic System;
- Braking system, including controls, hydraulic pressure unit, and disc and track brakes;
- Coupler and coupler controls;
- Lighting controls;
- Propulsion system, including traction motors and controls;
- Trucks, including bearings, bearing surfaces, gear units, frame, suspensions, and shock absorbers;
- Door operators and controls;
- Vehicle Communications and Passenger Information System;
- Closed Circuit Television equipment;
- Automatic Passenger Counting System;
- Cab Signal;
- Train-to-Wayside Communication; and
- Removal, replacement, and adjustment of car body materials and equipment, such as glazing, seats, doors, windshield wipers, heaters, circuit breakers, switches, light fixtures, underfloor equipment, and trucks.

The Contractor shall provide a detailed schedule for proposed courses. (CDRL 18-47) This information shall be grouped by course and separately indicated for each individual course proposed.

### **18.4.3.1 Equipment to be Furnished**

As part of special tooling and test equipment supply, the Contractor shall deliver at least one complete set of all special tools and all test equipment (such as jigs, fixture, meters, gauges, vacuum pumps, temperature sensing devices) necessary to service, maintain, and overhaul each system for use in the training program. At the completion of the training program these special tools, test equipment, and training aids shall be turned over to Sound Transit, in proper working order, by the Contractor.

### **18.5 Deliverables**

The Contract Deliverables Requirement List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to Section 19 for CDRL requirements.

- 18-1 Manual and Parts Catalog format samples and tables of content samples. (Section 18.1)
- 18-2 Operator's Instruction Manual, first draft (Section 18.1)
- 18-3 Operator's Instruction Manual, final draft (Section 18.1)
- 18-4 Train Operator Quick Reference Guide, first draft (Section 18.1)
- 18-5 Train Operator Quick Reference Guide, final draft (Section 18.1)
- 18-6 Maintenance and Servicing Manuals, first draft (Section 18.1)
- 18-7 Maintenance and Servicing Manuals, final draft (Section 18.1)
- 18-8 Heavy Repair Manual, first draft (Section 18.1)
- 18-9 Heavy Repair Manual, final draft (Section 18.1)
- 18-10 Parts Catalog, first draft (Section 18.1)
- 18-11 Parts Catalog, final draft (Section 18.1)
- 18-12 Training Manuals, first draft (Section 18.1)
- 18-13 Training Manuals, final draft (Section 18.1)
- 18-14 Special Test Equipment Manuals, first draft (Section 18.1)
- 18-15 Special Test Equipment Manuals, final draft (Section 18.1)
- 18-16 Final approved hardcopy and electronic media manuals and catalog (Section 18.1)
- 18-17 PowerPoint version of Operator's Instructional Manual (Section 18.1.1)

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- 18-18 Documentation on consumables with less than three suppliers (Section 18.1.5)
- 18-19 Delivery of tablet computers (Section 18.2.3)
- 18-20 Delivery of PTU packages (Section 18.2.1)
- 18-21 Delivery of BTU packages (Section 18.2.1)
- 18-22 Delivery of vehicle monitor system data management work station (Section 18.2.1)
- 18-23 Diagnostic test equipment drawings. (Section 18.2.1)
- 18-24 BTU Detailed Description (Section 18.2.2)
- 18-25 PTU design report (Section 18.2.4.1)
- 18-26 PTU interface specification (Section 18.2.4.2)
- 18-27 External apparatus connection to the PTUs (Section 18.2.4.5)
- 18-28 Recommended spare parts list (Section 18.3.1)
- 18-29 List of detailed drawings for warranty replacement parts (Section 18.3.3)
- 18-30 Detailed drawings for replacement parts (Section 18.3.3)
- 18-31 Tire Pressing device (Section 18.3.4.1)
- 18-32 Rerailing equipment (Section 18.3.4.2)
- 18-33 Jack socket adapters (Section 18.3.4.3)
- 18-34 Center truck dollies (Section 18.3.4.4)
- 18-35 Educational program outline (Section 18.4.1)
- 18-36 Education program schedule (Section 18.4.1)
- 18-37 Manuals and Training Materials for Use During Training (Section 18.4.1)
- 18-38 Training aid software alternate format (other than PowerPoint) (Section 18.4.1.1)
- 18-39 Training aid drawing/renderings electronic format (Section 18.4.1.1)
- 18-40 Actual equipment used for training aids (Section 18.4.1.1)
- 18-41 Video recordings of manufacturing production line (Section 18.4.1.1)
- 18-42 Video recordings of maintainability demonstration (Section 18.4.1.1)

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18-43 DVDs of Operations procedures, draft (Section 18.4.1.1)

18-44 DVDs of Operations procedures, final (Section 18.4.1.1)

18-45 Subject matter for operator education (Section 18.4.2)

18-46 Subject matter for maintenance education (Section 18.4.3)

18-47 Maintenance education schedule for individual courses (Section 18.4.3.2)

**18.6 Cited Standards**

The following standards or references were cited in this Section at the referenced location:

ISO 32000-1                      Document management – Portable document format – Part 1: PDF  
(Section 18.1)

**END OF SECTION 18**

**SOUND TRANSIT  
REQUEST FOR PROPOSAL  
FOR LOW FLOOR LIGHT RAIL VEHICLES**

**SECTION 19  
PROGRAM CONTROL AND QUALITY ASSURANCE**

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## **SECTION 19: PROGRAM CONTROL AND QUALITY ASSURANCE**

### **19.1 General**

The design and production of the LRVs shall be controlled by the Contractor to ensure that a high quality product suitable for long and trouble free life is produced and that the requirements of this document are met.

Sound Transit may, at its option, monitor any or all Contractor activities, review any or all designs, and inspect or test any or all equipment. The Contractor shall not hinder or limit such activities.

All business is to be conducted in the English language, including all meetings, correspondence and any other documents that are submitted to Sound Transit.

### **19.2 Project Management Plan**

The Contractor shall confirm the proposed project manager in a submittal within 10 days of NTP, for Sound Transit approval (CDRL 19-1). The project manager shall be full-time on this Contract and shall have no other responsibilities within the Contractor's organization except for this Contract.

A project management plan shall be submitted for Sound Transit approval within 90 days of NTP. (CDRL 19-2)

The project management plan shall include, but not be limited to:

- An organization chart for the Contractor's staff, including primary personnel involved in this Contract from senior executive positions to professional personnel such as design engineers, manufacturing engineers, test engineers, and managers of material procurement, subcontractor administration, manufacturing and quality assurance as a minimum. The organization chart must include a vehicle integration engineer whose responsibilities shall include, but not be limited to, propulsion-brake interface; propulsion-, brake-cab signal interfaces; vehicle-TWC interface; EMI interface; vehicle mechanical parameters-wayside interfaces; vehicle systems-data monitoring system interfaces; and vehicle mechanical-electrical parameters to shop facility interfaces.
- A management chart which clearly depicts the design, manufacturing, and testing responsibilities of the Contractor and each subcontractor or supplier for all systems and major components described in the Specifications. The company name, affiliation, principal contact and position, and the location at which the work will be performed shall be included.
- A progress schedule, with critical paths indicated, showing all major work tasks, including subcontractor contributions and all submittals, inspections, tests, and Sound Transit approvals as may be required by the Specifications and the Contract Deliverables Requirements List (see last bullet below). The progress schedule shall be updated at least

every month and resubmitted to Sound Transit with the monthly report. All schedules shall be current within two weeks of the time of receipt at Sound Transit.

- A Project Quality Management Plan that describes the methods, correspondence control, and communications to be employed to monitor, oversee, and control the progress schedule, technical performance, program changes, subcontracts, material procurement, configuration management, manufacturing controls, hold point inspections, source inspections, design reviews, FAI coordination, in-service support, warranty, and tests (see this Section).
- An Inspection and Test Plan (ITP), which shall include references to all formal inspection and test procedures. The ITP shall identify all witness and hold point inspections and shall be submitted to Sound Transit for approval prior to implementation. A work flow diagram representing the major levels of assembly and the hold point inspections shall be included within the ITP.
- A Contract Deliverables Requirements List (CDRL), which shall contain a consolidated listing of all submittals and hardware required by the Specifications such as data, test reports, material samples, and drawings. The CDRL shall be arranged as a vertical listing, and shall include an item number, submittal title, submittal description, and the section number of the Specifications requiring the submittal, required submittal date, and the Contractor's projected submittal date. For each item it shall be indicated whether it must be reviewed and approved early in the program as a key conceptual design submittal, prior to the start of procurement, prior to the start of manufacturing, prior to first article inspection, prior to the start of vehicle testing, prior to the delivery of the first unit, may be deferred to some point after delivery of the first unit or as an as-built submittal, or for information only.

### **19.3 Interface with Subcontractors, Designers, Suppliers, and Wayside Construction Contractors**

#### **19.3.1 Interface with Subcontractors, Designers, and Suppliers**

The Contractor shall ensure that all designers, suppliers, and subcontractors are informed of all specified requirements and that appropriate engineering management tools are used to coordinate and provide communication between the designers of interrelated systems.

All applications of material, or equipment, by the Contractor shall be with the full concurrence of the suppliers that the application is suitable and within the recommended limits of operation of the material, or equipment.

The Contractor shall have all designers, subcontractors, and suppliers available when required for meetings, production problems, testing, resolution of design deficiencies, and all other similar situations. During all phases of this project, Sound Transit shall have access to all designers, subcontractors, and suppliers.

### **19.3.2 Interface with Wayside Construction Contractors**

The Contractor shall coordinate and cooperate with Sound Transit wayside construction contractors on administrative, civil, and systems interface issues. The Contractor shall provide the necessary documents and information to Sound Transit and the wayside construction contractors within the time limits specified elsewhere in the Specifications. The Contractor shall provide the following vehicle information to Sound Transit and concurrently to the wayside construction contractors within 120 days of vehicle contract NTP:

- Preliminary dynamic and static envelope (CDRL 19-3);
- Jacking points and load distribution (CDRL 19-4);
- Accelerating and braking performance (CDRL 19-5);
- EMI data and ongoing coordination (CDRL 19-6);
- Mounting locations for communications, cab signal, and TWC antennae (CDRL 19-7);
- Pantograph mounting location, with wire tracking data and forces data (CDRL 19-8); and
- Vehicle electrical load data for both propulsion and auxiliary systems, with vehicle at rest, accelerating, and at balancing speed (CDRL 19-9).

Sound Transit and the Contractor shall discuss and mutually agree on other aspects and/or information required from the Contractor at the first Project Meeting.

## **19.4 Meetings**

### **19.4.1 Kick-off Meeting**

A kick-off meeting, the first Project Meeting, shall be held 10 days after NTP at a time and location designated by Sound Transit. At this meeting, the Contractor shall present key personnel to Sound Transit.

### **19.4.2 Specification Review Meeting**

The Contractor shall conduct a Specification Review Meeting (SRM) no later than 30 calendar days after NTP. During this meeting the Contractor's Project Manager and technical specialists, major subcontractors and suppliers, and Sound Transit will populate the Specification Compliance Matrix, specified below in the Specification Compliance Matrix section.

### **19.4.3 Project Meetings**

#### **19.4.3.1 General**

Meetings shall be held between the Contractor and Sound Transit on a monthly basis for the purpose of reviewing program progress and other program activities that cannot be readily resolved by correspondence. These meetings are intended to serve as a forum to discuss design problems and issues; to answer questions raised by Sound Transit, the Contractor or its

subcontractors; to discuss contractual matters; to review schedule and payment issues; to witness tests and discuss their results; and to review design, fabrication and assembly status. The Contractor shall ensure that persons knowledgeable in the topics to be discussed are present as required at these meetings, including appropriate subcontractors and suppliers.

As directed by Sound Transit, project meetings will be held at either the Contractor's or Sound Transit's facilities, at other locations relevant to the main topic of interest, or in conference calls or web meetings.

The Contractor shall submit electronic copies of the agenda and a data package covering information to be addressed in each meeting 10 days prior to the meeting, or as approved by Sound Transit. (CDRL 19-10)

#### **19.4.3.2 Design Review Meetings**

Design review meetings will typically be of one to three days duration, and shall address multiple subjects or more than one system or subsystem where possible. During these meetings, action items will be identified, with each action item assigned to an individual for disposition by a pre-determined response date. An action item log will be maintained by the Contractor.

At a minimum, the following systems shall be subject to both a preliminary and final design review:

- Car Structure
- Electrical Distribution
- Trucks (including suspension)
- Lighting
- Propulsion
- Communications
- Friction Brakes
- Doors
- Coupler
- Seats
- Pantograph
- HVAC
- Event Recorder
- Monitoring and Diagnostic
- Close Circuit Television
- Cab Signaling
- Interior appointments
- Roof equipment arrangement
- Cab layout

Thirty days, or unless otherwise agreed, prior to each preliminary and final design review, design review packages shall be submitted for Sound Transit review. The design review packages shall, at minimum include the following items:

- Table of contents of the package
- Agenda
- Presentation material
- System Functional Description
- Component List
- Drawing List
- Design Drawings
- Software Documents
- Reliability
- Maintainability
- Test Plan
- Diagnostic Equipment
- Design Schedule

#### **19.4.3.3 Minutes of Meetings**

Meeting minutes shall be taken at all meetings. Minutes shall include a summary of all topics discussed and a listing of all understandings and agreements reached, including action items. Unless otherwise agreed, the Contractor shall be responsible for taking all meeting minutes. (CDRL 19-11) Whenever possible, the language and status of action items shall be discussed and agreed to prior to closing the meeting. The format for the meeting minutes shall be submitted to Sound Transit as part of the Project Management Plan. (CDRL 19-2)

The meeting minutes shall be submitted for Sound Transit review and approval.

#### **19.5 Specification Compliance Matrix**

The Specification Compliance Matrix (SCM) will be used to document the Contractor's compliance with each Specification requirement in spreadsheet format. It shall include the following:

- A comprehensive list of Specification requirements extracted from the Specifications
- The documentation the Contractor intends to submit to demonstrate compliance with each Specification requirement, such as reports, analyses, system descriptions, manuals, drawings, test procedures, and test reports
- Approved documents that certify compliance with each requirement
- An indication for each requirement when it is compliant

At least 15 calendar days prior to the Specification Review Meeting, specified above, the Contractor shall submit a Specification Compliance Matrix (SCM) shell in the format that will be used for the completed SCM and monthly updates. (CDRL 19-12)

The SCM will be populated during the Specification Review meeting, and shall be updated on a regular basis and submitted monthly. (CDRL 19-13).

## **19.6 Design Approvals, Contractors Drawings, Documentation, and Data Requirements**

### **19.6.1 Review Procedures for Drawings, Documents and Data**

The Contractor shall submit electronic copies of all documents, data, calculations, and assembly and installation drawings required to convey concept, design, dimensions, maintenance, operation, and overall assembly aspects and interfaces for review and approval. A drawing tree and indented drawing list sorted by subsystems shall accompany drawing review submittals. All documentation shall be compliant with ISO 32000-1 for Portable Document Format (PDF) files except where other formats are required in the Specifications. Additionally, documents shall be provided in their native format to expedite use of the document contents in review correspondence. Documents scanned into PDF files shall be processed for text recognition and made searchable prior to document assembly and submittal. Documents shall have no security or in case of documents containing very sensitive information password security will be allowed as long as the password is made available to Sound Transit project staff. The Contractor shall use a document/submittal tracking system approved by Sound Transit. (CDRL 19-14)

Sound Transit reserves the right to request additional drawings to support the review process of assembly and installation drawings. All documents submitted by the Contractor shall be in the English language.

Drawings shall be accompanied by calculations, material specifications, process specifications, flammability, smoke emission, and toxicity data, and test data required to support review and approval of the drawings. Detailed parts drawings need not be submitted unless requested by Sound Transit to permit review of another drawing.

When submitting drawings of structural parts or assemblies for the car body structure, equipment supports, and trucks, the Contractor shall also submit, for review and approval, stress analyses for these parts or assemblies in summary form.

Other contract deliverables shall be submitted in the quantities specified, including material samples, test plans, test procedures, and analyses, as required by the Specifications.

Review and approval of Contractor submittals shall be secured before manufacturing any parts.

All drawings, documents, and data submitted by the Contractor shall be accompanied by a letter of transmittal listing drawing and document titles, numbers, and revisions. If more than one drawing or document is submitted at a time, the drawings and documents shall be listed in the transmittal in numerical sequence.

Drawings shall be submitted in an orderly and logical sequence to enable Sound Transit to readily determine and review the interface relationships between all major structural elements and their subassemblies and also between the structural elements and the attached apparatus, equipment, wiring, piping and hardware.

Sound Transit will return submittals approved, or with the required changes noted, within 30 calendar days after receipt by Sound Transit. Due to Sound Transit's limited resources and to prevent grouping of documents into one large package for transmittal to Sound Transit, Sound

Transit will not be obligated to review more than 100 documents, or other mutually agreeable number, in a 30-day period. In the event that more than 100 documents are submitted for review in a 30-day period, Sound Transit will make every effort to review them within the 30 days. If this is not possible, Sound Transit will review them in accordance with priorities as mutually agreed between the Contractor and Sound Transit.

No extension of Contract time will be allowed for revision of Contractor's drawings or documents which have been either "disapproved" or "conditionally approved". Such drawings and documents shall be resubmitted and will be reviewed and returned to the Contractor within the same 30 day review time as when initially submitted.

The Contractor shall maintain a record of Contractor and subcontractor drawing and document status. This shall include drawing and document numbers, revision letter, drawing title, date submitted, transmittal document, disposition, and the document number identifying the disposition. This status shall be updated and submitted to Sound Transit not less than monthly. (CDRL 19-15)

### **19.6.2 Requirements for Drawings, Documents**

All dimensions shall be expressed in the English system; all wording shall be in the English language. Where other dimensional systems are used, the equivalent English measurements shall be added, leaving the original intact and readable. All terminology used shall be conventional to the U.S. transit and railroad industries. Drawings shall be made in the third-angle projection system.

All drawings submitted by the Contractor shall include a title block, drawing number, title, date, revision number, contract number, reference to next higher assembly, and signature of the Contractor's responsible engineer.

Unless otherwise approved by Sound Transit, every drawing shall include a complete list of materials and parts lists, including the Contractor's and Supplier part number, on the field of the drawing or on a separate sheet of the same drawing, describing all parts or sub-assemblies, and including subcontractor-furnished items, which form a part of the assembly, subassembly, or piece depicted. Every assembly drawing shall include the weight of the assembly and next higher drawing.

A revision block shall be provided for all documents, drawings, and data. The revision block shall identify the revision letter, date of revision, the initials of the Contractor's responsible engineer authorizing the revision, a description of the change, and the reason for making the change. Engineering Change Requests (ECRs) shall be classified and processed in accordance with requirements of the Modification and Configuration Control section, below.

The full description of the change and the reason for making the change shall be shown on a change sheet or similar document accompanying the drawing or document and appropriately referenced in the revision block. Subsequent to document, drawing and data approval by Sound Transit, engineering change requests (ECR) must be submitted to Sound Transit for Approval before incorporation of any document, drawing, and data revisions. Upon receipt of ECR approval, the document, drawing, and data shall be revised and the document, drawing, and data,

with the accompanying approved ECR, shall be submitted for approval. No additional revisions to an approved document, drawing and data shall be made without an approved ECR.

All structural drawings shall be of sufficient scale and size to clearly delineate the shape and size of all assemblies, members and components. The drawings shall be completely dimensioned. Buildup of materials shall be shown and identified (thicknesses dimensioned). Full and complete information regarding location, type, size and extent of all welds shall be clearly shown on the drawings. All joints and connections shall be detailed, with all dimensions, showing the size of the fasteners, and complete AWS, or equivalent, weld symbols (including size and process). The list of materials shall include the material's specification with grade, temper, thickness, and nominal size. Detail part dimensions shall be made on separate lower level detail drawings and not included within assembly level drawings.

All drawings shall be zoned to make it easier to locate details. The vertical divisions shall be designated by letter and the horizontal divisions designated by number. When a cut, section, or detail is referenced on the drawing, the location where it can be found shall be given by sheet and zone. Where the cut, section, or detail is shown, the location from which it came shall be given by sheet number and zone.

All drawings supplied by the Contractor shall be delineated in a manner that permits the wiring, piping, and mechanical interface relationships between components furnished by the Contractor and its subcontractors to be clearly identifiable.

Whenever reference is made on a drawing to a material or process by the Contractor's own specification number, the drawing shall also give the commercial equivalent. If there is no commercial equivalent, the Contractor shall provide copies of its specification.

#### **19.6.2.1 Integrated Vehicle Schematics and Wire Lists**

Totally integrated vehicle schematics relating to all electrical, hydraulic, and pneumatic systems shall include component identification, component values, waveforms, voltages, currents, resistance values, wire identification, connector identification, and connector pin numbers. All components on PC boards shall be individually shown in the schematics. Schematics shall be comprehensive in nature and thoroughly detailed to permit Sound Transit shop personnel to troubleshoot and repair vehicle systems.

Schematic location (page number, for example) of the energization portion of each device (such as the coil in a relay) shall be noted adjacent to the operating portions (such as relay interlocks) of the device.

A set of device tables shall be located in a single section at the rear of the schematic book. This table shall be arranged in logical fashion by system device type. This table shall include data for all system and subsystem components including but not limited to:

- Electrical control and power components (groups, panels, PC cards, contactors, relays, circuit breakers, capacitors, inductors, resistors, specialized modules, rectifiers, thyristors, diodes, fuses, and other components, as appropriate);

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- Electrical machinery (rotating equipment, reactors, transformers, pumps, fans, compressors, switchgear, and other machinery);
- Hydraulic control and power devices (valves, strainers, filters, and other components); and
- Pneumatic control and power devices.

As a minimum, device listings shall include the following:

- Location in schematic and schematic designation;
- Type, model, and part number;
- Locations on vehicle;
- Function;
- Schematic symbol;
- Appropriate ratings data; and
- Interface information, as appropriate.

The integrated schematic drawings for this Contract shall be formatted by subsystem, using identical device symbols and wire and pipe designators for each subsystem. All interfaces, from page to page, and subsystem to subsystem, shall be clearly delineated. The integrated schematic and narrative shall be designed, drafted, assembled, and published by the Contractor, or by a single subcontractor placed under contract for that express purpose. It will not be acceptable to assemble a collection of subcontractor drawings, independently produced, into a single, vehicle integrated schematic. To ensure clarity, the Contractor shall select lettering and detail size to be legible for a schematic page reduced to a size of 8 1/2 in x 11 in; however, the schematic shall be submitted in an 11 in x 17 in page format.

Wiring diagrams shall be integrated connection diagrams and a wire list in book form based on the integrated schematic. The diagrams shall show all wiring, raceways, conduits, and connections.

The wire list shall include each individual wire segment in the vehicle, listed separately, whether the wire is used for the transfer of power or information.

As a minimum, the following information shall be provided for each wire segment:

- Wire code (schematic designation);
- Origin (FROM device and terminal);
- Destination (TO device and terminal);
- Wire size;
- Voltage rating;
- Length;
- Appropriate specifications;
- Jacket color; and
- Harness designation.

### **19.6.2.2 Drawing Standards**

Instructional drawings shall be prepared in accordance with the requirements of Air Transport Association of America (ATA) Specification No. A100 "Specification for Manufacturer's Technical Data" and shall be prepared so that reduction can be made to 5 in by 7 1/2 in from the 8 1/2 in by 11 in submittal dimensions.

The following standards for the preparation of drawings shall apply:

- ASME Y14.38, Abbreviations and Acronyms for Use on Drawings and Related Documents;
- ASME Y14.5, Dimensioning and Tolerancing;
- ASME Y14.2, Line Conventions and Lettering;
- ASME 14.3, Multiview and Sectional View Drawings;
- IEEE 315, Graphics Symbols for Electrical and Electronic Diagrams; and
- IEEE 91, Graphic Symbols for Logic Functions.

The requirements for ATA and ANSI/ASME standard graphic symbols and abbreviations may be waived by Sound Transit provided a system of standard abbreviations and symbols is used for all drawings submitted, and the Contractor provides Sound Transit with five copies of a bound booklet in a format that contains a legend cross-referencing all abbreviations and graphic symbols used on drawings to those required by the ATA and ANSI/ASME standards. (CDRL 19-16)

Refer to Section 17 for computer software documentation requirements.

### **19.6.3 Approval of Contractor Documents**

Sound Transit's approval or disapproval will be provided in one of the four following categories:

- Approved as submitted.
- Conditionally Approved. The Contractor may proceed in accordance with changes indicated and shall revise and resubmit the document, drawing, and data for Sound Transit's approval. For product given conditional approval, inspection may be scheduled and performed, but product shall not be released until the issues of the conditional acceptance have been satisfied.
- Disapproved. The Contractor shall revise and resubmit the document, drawing, and data for Sound Transit's approval prior to commencing the affected portion of the work.
- Accepted for Information Only. The submittal was provided as information to assist in review of a required submittal or to satisfy a request. Specific approval and comment not required.

All drawings, technical data, test procedures, test schedules, test results, test reports, progress schedules and reports, drawing lists, samples, and other data submitted by the Contractor and requiring review and approval by Sound Transit will be handled in accordance with the above provisions.

Approval does not relieve the Contractor of the obligation to meet all of the requirements of the Contract. Approval of a document, drawing, or data which contains deviations from, or violation of, the Specifications does not constitute authority for that deviation or violation. Such deviations must be specifically requested and granted.

Approval is intended to mean that Sound Transit is aware of the Contractor's intent and there are no objections to the methods, procedures, designs, or calculations.

The Contractor shall review subcontractor submittals (documents, drawings, procedures, data sheets, etc.) prior to sending them to Sound Transit. Sound Transit will review and respond to only those submittals that are stamped "Approved" or "Conditionally Approved" by the Contractor. Other submittals will be "Accepted for Information Only".

#### **19.6.4 Subcontractor Certification**

The Contractor shall obtain from each of its subcontractors and suppliers of any tier a written certification that the method being used for installation and connection of its equipment by the Contractor is satisfactory to the subcontractor. (CDRL 19-17) The certification shall be readily available to Sound Transit.

#### **19.6.5 Correspondence Control**

The Contractor shall identify all correspondence and submittals according to a coding scheme, which will be provided by Sound Transit at NTP.

### **19.7 Monthly Progress Reports and Schedule**

#### **19.7.1 Monthly Progress Report**

The Contractor shall prepare a progress report each month for Sound Transit, starting with the first full month after NTP. The report shall be submitted to Sound Transit no later than the 10th day of the following month (e.g., 10 July for the month of June) and shall be in a format, and with level of detail, as approved by Sound Transit. (CDRL 19-18) At the first Project Meeting, held 10 days after NTP, the Contractor shall present for Sound Transit approval a monthly progress report format.

Monthly Progress Report shall be based upon actual progress of the work and shall include as a minimum:

- A summary of work accomplished during the month, including actual completion dates and start dates;

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- Major work activities planned for the following month, including estimated remaining durations for activities in progress and estimated start dates;
- Dates and locations of the program review meetings for the next four months, with updates, if there are any, easily identifiable;
- Date and location for the forthcoming inspection and testing activities for the next three months, with the updates, if there are any, easily identifiable;
- An updated Change Order log;
- An updated vehicle weight estimate;
- An updated CDRL status;
- An updated Engineering Change Status Report;
- Status of correspondence; and
- An updated schedule submittal, as required below.

### **19.7.2 Updated Schedule Submittal**

The schedule submittal shall consist of two parts, schedule narrative and the CPM schedule. At the first Project Meeting, held 10 days after NTP, the Contractor shall present for Sound Transit approval a schedule narrative and schedule format.

#### **19.7.2.1 Schedule Narrative**

The narrative shall describe as a minimum the approach to the project and schedule, fabrication, manufacturing and assembly plants and methods, shipping methods and routes, Primavera coding structure, other schedule systems (MRP, ERP, etc.) used by the project and their relations to the CPM schedule. The schedule narrative shall also include a detailed statement of actions the Contractor intends to take if the schedule shows potential delays in project activities and an explanation of any proposed schedule changes, as identified by Sound Transit and/or the Contractor. Sound Transit reserves the right to approve or disapprove any proposed schedule changes.

#### **19.7.2.2 The CPM schedule**

The project schedule shall include a narrative introduction describing the approach to the project and schedule, fabrication, manufacturing and assembly plants and methods, shipping method, coding structure, other schedule systems (MRP, ERP, etc.) used by the project and their relations to the CPM schedule.

Activities shall be discrete items of work that must be accomplished under the Contract and that when complete, produce definable, recognizable entities or stages within the project. The project schedule shall have all critical paths indicated, showing all major work tasks, including:

- Payment milestones

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- Contractor and subcontractor/supplier submittals including review cycles
- Design review meetings
- Design review packages requiring approval
- Major off-site inspections and acceptance tests
- Major steps of carbody fabrication
- Major subsystem deliveries
- Assembly milestones
- All progress payments

The Contractor shall use an in-house production schedule for the manufacturing and assembly phases of the project. The final baseline schedule need only show activities defined as payment milestones in the Commercial Provisions. In order for Sound Transit to approve this alternative, the production schedules must show the relevant information listed above.

The schedule shall show the project milestones in calendar days, with NTP as starting date and project activities with duration shown in working days. The project milestones and activities shall be logically connected with NTP as a start date and the end of the warranty period as the end date. No other start and end activities shall exist.

Vehicle Final Acceptance milestones shall have a “finish no later than” date constraint so that if delays occur the negative floats shall appear on the critical path.

If baseline schedule shows that project is completed in less than contractual time the resulting positive float shall be shown. Positive float shall be at the Contractor’s disposition.

The main CPM schedule report shall be time scaled, have a clearly marked critical path and include the following:

- Activity Identification (ID) number
- Activity description
- Original duration
- Remaining duration
- Percent complete
- Early and late start
- Total float
- Activity area with bars

### **19.8 Modification and Configuration Control**

Throughout the Contract, the Contractor shall implement and maintain a configuration control system. Changes to the documents, drawings, and data shall be controlled by the processing of engineering change requests (ECR's). Changes shall be designated either Class I or Class II.

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Class I changes shall be defined as hardware, material, or software changes that affect vehicle performance, Specification requirements, previously approved documents and drawings, or interchangeability with previously produced components. Class II changes shall be defined as minor hardware, material, or software changes that do not affect vehicle performance, Specification requirements, previously approved documents, or interchangeability with previously produced components.

Following Sound Transit approval of final design, ECR's for all Class I changes shall be submitted, complete with documentation describing the effects of the change, for review and approval prior to implementation. Changes that would modify Specification requirements or any other aspects of this Contract shall be processed as Change Orders in accordance with the General Provisions. Class II changes shall be submitted for information only.

The Contractor shall submit a sample ECR format for Sound Transit approval (CDRL 19-19). The format shall, at minimum, include:

- Class of the change.
- Root cause of the change.
- Description of the change with supporting drawing(s), schematic(s) and documentation.
- Description of Car-level and Train-level effects of the proposed change.
- Description of backward compatibility.
- Validation process of the change at Contractor or supplier's facility.
- Field modification procedure to implement the change.
- Field validation procedure to validate the change.
- Identification of affected car number(s) and component serial number(s) including spares.
- Identification of all deliverables affected by the proposed change.

The Contractor shall maintain an Engineering Change Status Report that lists all changes, including document number, rev level, date of latest revision, their submittal/approval status, status of implementation, and completion dates. (CDRL 19-2019-19) The Engineering Change Status Report shall be included with the monthly progress report. Implementation of a change shall require incorporation in all vehicles unless approved by Sound Transit as an effective point change.

Upon completion of any Engineering Notice (EN) or modification to any of the LRVs that have been Accepted by Sound Transit, the Contractor shall submit in writing a letter to Sound Transit confirming the EN or modification has been completed on all affected LRVs. The confirmation shall include:

- A copy of the EN or modification and documentation showing the work has been completed on the affected LRVs. The documents shall contain as a minimum EN

number, Car number, date and the contractor QA representative who performed inspection of the work.

- All necessary documentation to support the EN or modification, including but not limited to updated wiring schematics, drawings and/or maintenance manual updates where changes are required
- Each vehicle Car History Book shall include a list of EN, modifications performed on the vehicle. If an EN or modification was not completed at the time of shipment and approved to be shipped by Sound Transit, the incomplete work shall be added to the vehicle open item list.

### **19.8.1 Component Identification and Serial Numbers**

#### **19.8.1.1 Component Identification**

All LRV equipment shall be permanently identified with a supplier's name, part number, serial number and revision level. Identification shall be by engraved metal labels riveted in place or other approved permanent method.

The Contractor shall also use barcode identification (part number, serial number, description) for each identified system, including Portable Test Equipment, Bench Test Units, Spare Parts, and Special Tools. As part of special tools supply a reader and printer shall be supplied to read and print information from the bar code.

The use of metalized polyester self-adhesive labels protected by a thick transparent silicone coating will be allowed for bar codes.

#### **19.8.1.2 Serial Numbers**

The Contractor shall assign discrete serial numbers to certain equipment listed below at the LRU and LLRU level. Serial numbers shall be in sequential, numerical order for the total quantity of each component, including spares.

All serial numbers presented in a comprehensive serial number list shall be subject to Sound Transit approval. (CDRL 19-21) Components shall be re-serialized by the original supplier upon request by Sound Transit.

Serial numbers of all components shall be presented to Sound Transit as each vehicle arrives on the property or when spare components are received. (CDRL 19-22) The Contractor shall track all serial number transfers and prepare a list of all serial numbered apparatus installed on each vehicle for inclusion in the car history book.

At a minimum, the following equipment shall have serial numbers applied:

- HVAC apparatus
- Converters
- Inverters

- Pantographs
- Couplers
- Master Controller
- Door operators and controls
- Motors within equipment
- All electronic cards
- Principal communications equipment items (not speakers)
- Principal items of traction and braking equipment
- Air compressors
- Truck castings
- Truck frames
- Primary and Secondary Suspension
- Shock Absorbers
- Axles
- Truck gear units
- Journal bearings
- Wheel hubs and tires
- Brake Disks
- Communications apparatus
- APC apparatus
- TWC apparatus
- Cab Signal Equipment
- Portable Test Units
- Monitoring and Diagnostic System
- Event Recorder
- CCTV
- Information/destination sign apparatus
- Ground brush assemblies
- Car shells
- All LLRU level assemblies

### **19.8.2 Car History Books**

Each car shall have a "history book" that reflects the status and manufacturing history of the car. The car history book shall accompany the car through the production line and be presented to Sound Transit for review prior to shipment. Any errors and omissions will be tracked on the open items list for each individual vehicle. Sound Transit may not release the car for shipment if critical open items have not been resolved. The completed car history book shall be submitted to Sound Transit when each car is accepted.

The Contractor shall submit the car history book format and a complete Table of Contents identifying the documents that will become the permanent manufacturing record within 180 days of NTP. (CDRL 19-23) While additional information may be required once Release for Shipment begins, each book shall contain the following minimum information:

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- Certified LRV weight in pounds, including scale tickets;
- Description and completion dates of all car modifications, and list of modifications pending with expected completion dates;
- List of car defects that were identified by Contractor QA or Sound Transit personnel during construction and the disposition of each as verified by inspection;
- List of serial-numbered apparatus;
- Shipping documents;
- Results of each functional test and pre-delivery test performed on the car or any part of the car;
- All car shell assembly inspection records;
- Assembled truck records (assembled truck, including component serial numbers, truck assembly weights, and mounting records for wheels, journal bearings, gears and other axle-mounted items, including pressing charts);
- Hold point inspection records;
- A record of any abnormalities that occurred during the manufacture of the car or any of its subsystems, including their authorized, validated, repair procedures;
- Any changes in recorded data made during performance of the Contract, clearly identified and justified to the satisfaction of Sound Transit;
- Open item status list;
- Software revision numbers; and
- Safety certificate.

### **19.9 Quality Management**

To provide a quality product to Sound Transit, the Contractor shall plan and establish a documented quality management program authorized by its chief executive. The Contractor shall enforce the elements of the quality management program within all parts of its organization and with all manufacturers, subcontractors, and suppliers performing Contract work.

This Section defines the minimum project quality management requirements. The objectives of the Contractor's QA Program for this project shall be to ensure that:

- The design, materials, processes, and workmanship comply with the Specifications;
- The design and manufacturing documentation is approved by the Contractor and by Sound Transit as required, and released in a timely manner.

The Contractor's quality system for this work shall utilize training, internal auditing, and periodic management review as means to support, maintain, and improve effectiveness of its quality program and its application to this work.

### **19.9.1 Quality System and Implementation**

The following sections define the requirements for the QA submittals, management responsibility and internal auditing.

#### **19.9.1.1 Quality Manual**

The Contractor shall submit its proposed Quality Manual 90 days after NTP. (CDRL 19-24) The Quality Manual shall cover all requirements of this quality assurance section. The manual shall establish and communicate the company's quality policy, which shall be a clear statement of top management's commitment and direction with regard to quality of its products and services. The Quality Manual must establish authority for its requirements and include or refer to all Contractor quality system procedures, explaining the hierarchical structure of quality system documents. Amendments may be included in the Quality Manual to fully comply with the quality assurance requirements of this Sound Transit Contract.

The degree of quality system documentation required shall be consistent with the skills needed, methods used, and training resident among personnel performing contract work in accordance with the requirements of the Specifications.

#### **19.9.1.2 Project Quality Management Plan**

The Contractor shall submit its proposed Project Quality Management Plan 90 days after NTP. (CDRL 19-25) This Plan shall identify the controls, resources and skills the Contractor will apply to satisfy project quality system requirements of this Section. For each specified quality system requirement, the Plan shall identify how it will be satisfied, when, where, and by which job function. It must include a flow chart of the manufacturing sequence with all planned inspections indicated. The chart shall indicate entities participating in the inspections and if inspections are customer-witnessed or hold-point verifications. Necessary inspection equipment, extraordinary measurement requirements, required personnel certifications, workmanship acceptance standards, methods of inspection, and required quality records documentation shall be identified in the Plan. The Project Quality Management Plan shall refer to specific sections of other Contractor documents, such as the Quality Manual and supporting Quality Assurance Procedures, if the appropriate description of Project Quality Management Plan details applicable to this Project are presented there.

#### **19.9.1.3 Quality Assurance Procedures**

The Contractor shall submit its Quality Assurance Procedures for review and comment.

#### **19.9.1.4 Management Responsibility for QA Program**

The Contractor shall assign to a member of its management the overall responsibility for implementing and maintaining its quality assurance program throughout the Contract period. The

interrelation of all Contractor personnel affecting the quality of this Contract's products and services shall appear on the company's organization chart. The Contractor shall provide for periodic reporting to management and management review of its quality system's effectiveness, taking appropriate action whenever so indicated.

The Contractor shall provide adequate trained resources to perform verification activities. These activities include inspection, test witnessing, monitoring operations, participating in and supporting design reviews, and conducting internal and subcontractor quality audits.

Management responsibility for Quality Assurance shall have sufficient authority and organizational freedom to ensure that a nonconforming or discrepant product will not be delivered to Sound Transit. The responsibility for the QA function shall be placed within the Contractor's own organization such that the quality of products under the terms of this Contract shall not be compromised in order to meet schedule and cost projections. Any conflict that arises as a result of this provision shall be brought to Sound Transit's attention by the Contractor's QA Manager and shall be resolved to the satisfaction of Sound Transit prior to shipment.

#### **19.9.1.5 Internal Quality Auditing**

Auditing is a crucial activity for maintaining effectiveness of quality systems. The Contractor shall establish and maintain procedures for internal quality system auditing. The Contractor shall schedule audits of its operations so that it assesses compliance with each Quality Manual section throughout its organization on a planned periodic basis. Contractor's auditors shall be independent of operations they audit and perform audits in accordance with established auditing procedures. Auditors shall communicate results to appropriate personnel. Follow-up shall occur to verify and document that personnel have determined and applied effective corrective action with respect to deficiencies.

#### **19.9.1.6 Sound Transit Quality Assurance Inspector**

Sound Transit shall have the right to visit facilities of the Contractor and subcontractors to conduct assessments of its quality assurance programs and monitor the work being performed.

The Contractor shall extend to Sound Transit its full cooperation and, at no cost to Sound Transit, provide facilities at the car construction plants, including final assembly site. These facilities shall enable convenient inspection of materials, work, and equipment, and shall include the following:

- A heated, cooled, and adequately lighted private office with appropriate desks, chairs and file cabinets for a minimum of three people, with access to restrooms.
- Three telephones, with one dedicated outside line independent of the Contractor's switchboard, available and dedicated to Sound Transit's use within the private office space.
- Internet access for all three people available in the office.

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- Copies of all drawings, diagrams, schedules, changes, deviations, and sufficient data to verify design, construction, assembly, installation, workmanship, clearance, tolerance, and functioning of the vehicles.
- Copier, fax machine, scanner/all in one.

### **19.9.2 Planning For Quality**

Before performing contract work, the Contractor shall have prepared written procedures to ensure that Sound Transit's requirements are met in planning the quality-related functions listed below.

#### **19.9.2.1 Contract Review**

To ensure that Sound Transit's needs are met throughout the performance of Contract work, Sound Transit requires the Contractor to review and continually consider contract requirements, both as work is planned and as it is carried out. The Contractor shall take steps to ensure that all work reflects a thorough understanding of Contract provisions, and that any disagreements with contract requirements are resolved through established channels for change control. Contract review shall also serve to ensure that sufficient resources are available and applied to furnish products and services of the required quality within the time allotted under the Contract.

#### **19.9.2.2 Design Control**

The Contractor and suppliers shall establish and maintain documented procedures to control and verify design of products and services while ensuring compliance with all Contract requirements.

Design tasks shall be assigned to qualified personnel provided with adequate resources. To this end the Contractor shall define, document, coordinate, and control sources of design input. This shall be accomplished by identifying interfaces between different groups, both within, and outside of its organization; then reviewing and updating design input on a regular basis to ensure designs are adequate for their intended applications and free from conflict.

Design output, including drawings, specifications, instructions, software, and procedures shall be documented in such a way that they can be verified as meeting design input requirements. Design output documents shall contain or refer to acceptance criteria and identify any design characteristics that are crucial to safety. The Contractor shall subject all design output to a documented system of review and authorized approval prior to releasing designs for procurement or manufacturing. This shall include Sound Transit's prior approval for design documentation so specified.

At appropriate times during processes of design development, manufacturing, and testing, the Contractor shall validate design, confirming that it meets defined Sound Transit needs.

#### **19.9.2.3 Document and Data Control**

The Contractor shall establish and maintain procedures for controlling all project documents and data. The Contractor's procedures shall identify who is responsible to maintain its master listing

of documents, revision levels, and status. The Contractor shall ensure that documents are reviewed and approved prior to their release, and that current versions are available where needed. Obsolete documents shall be controlled to prevent unintended use, and if retained, segregated and suitably identified as obsolete.

Changes to released documents and data shall be subject to processes of review and approval by the same functions and organizations that performed the original review, whether internal or external.

#### **19.9.2.4 Control of Purchased Items and Services**

The Contractor shall establish and maintain procedures to ensure that products and services purchased to complete this work comply with requirements of the Specifications. Procedures shall describe the Contractor's method of evaluating subcontractors and suppliers on the basis of their ability to meet requirements, and establish methods of controlling subcontractor and supplier activities and products to obtain that result within the time allotted under the Contract. The Contractor's records of acceptable subcontractors and suppliers for this Contract shall be available for Sound Transit's examination.

Contractor shall ensure that purchasing documents describe clearly the products and services ordered, including precise description of items, relevant data, and all applicable Specification requirements, codes, and standards, including revision levels. Requirements for quality assurance, documentation, including certificate of conformance, testing, packaging and shipping shall also be included, as applicable. The Contractor's purchasing procedures shall require purchasing documents to be reviewed by appropriate personnel for adequacy in meeting specified requirements.

Refer to the Inspection, Testing, and Correction section, below, for inspection verification requirements for purchased products.

#### **19.9.2.5 Control of Customer-Supplied Products**

The Contractor shall establish and maintain procedures for controlling any products or equipment, furnished or loaned to the Contractor by Sound Transit. Procedures shall ensure that all such items are properly accounted, stored, maintained, and protected from loss or damage. The Contractor shall report to Sound Transit in writing any Sound Transit-supplied items that may become lost, damaged or degraded, and any items that are unsuited for the intended use.

Sound Transit furnished or loaned equipment, materials or otherwise that are damaged, lost, stolen or in some way deemed unusable while in the contractor's possession shall be replaced with new identical or improved like items by the contractor at no cost to Sound Transit.

### **19.9.3 Quality Assurance Provisions for Work In-Progress**

#### **19.9.3.1 Process Control**

A significant part of the Contractor's quality program shall be to prevent problems by controlling manufacturing processes, thereby lessening the demands on required inspection and correction

activities. To this end, the Contractor shall identify and plan processing necessary to produce, under controlled conditions, products and services of the specified quality. Where necessary to accomplish this, the Contractor shall prepare documented instructions and workmanship criteria, and monitor and approve production processes. Production equipment and processes shall be maintained as necessary to ensure that products satisfy specified requirements.

### **19.9.3.2 Product Identification and Traceability**

The Contractor shall establish and maintain procedures for identifying product, where appropriate, during all stages of production, installation, and delivery. As practical, individual items or lots shall retain unique identification of the items and their acceptance, rejection, or uninspected status.

### **19.9.4 Inspection, Testing, and Correction**

#### **19.9.4.1 General**

Inspections and testing are specified as means for the Contractor to demonstrate Specification compliance to Sound Transit. As such, inspections and tests are tools for assessing the quality yielded by the Contractor and supplier quality systems and processes.

The Contractor shall establish and maintain procedures for inspection/verification activities listed below. Procedures shall be suitably documented to provide objective evidence that specified product requirements have been met.

The Contractor shall maintain and apply sufficient resources for inspection and testing verification. While production worker inspection of output is strongly encouraged, inspection by trained and certified Contractor inspectors who are independent of the means of production is required under this Contract.

The Contractor shall establish an Inspection and Test Plan (ITP) that will include a production flow chart that includes all Hold and Witness Point inspections and tests. The ITP shall identify all the inspection and testing procedures for this project that address the quality functions listed below. The Inspection and Test procedures shall be submitted to Sound Transit for review and approval. (CDRL 19-26)

#### **19.9.4.2 Control of Inspection, Measuring, and Test Equipment**

The Contractor shall establish and maintain procedures to control, calibrate, and maintain inspection, measuring, and test equipment to demonstrate to Sound Transit that products conform to requirements. Calibrated equipment shall be used consistent with the required measurement accuracy. The capability of test software and hardware used for inspection shall be checked periodically. Procedure shall include provisions for determining the validity of previous inspection and test results when measurement equipment is found out of calibration, and taking appropriate corrective action. Inspection, measuring, and test equipment shall be suitably stored to ensure continued accuracy and fitness for use.

#### **19.9.4.3 Inspection and Test Status**

The Contractor shall identify by suitable means the inspection and test status of products throughout production and installation so that only acceptable products are used. The Project Quality Management Plan shall identify the inspection authority responsible for releasing product as conforming at each stage of production.

#### **19.9.4.4 Controlling Nonconforming Products and Services**

The Contractor shall establish and maintain a procedure to prevent the inadvertent use or installation of nonconforming product. Nonconforming products shall be segregated from acceptable items and documented in a Nonconformance Report and shall only be accessible to QA, Material Control and management. All Nonconformance Reports shall be submitted to Sound Transit for review and disposition. Dispositions appropriate for discrepant product include:

- Rework - Action on a nonconforming product to make it conform to the Requirements;
- Repair - Action on a nonconforming product to make it acceptable for the intended use;
- Use-As-Is, and;
- Scrap.

Dispositions; repair and Use-As-Is require Sound Transit approval. The Contractor remains solely responsible for ensuring that nonconforming material is not used.

#### **19.9.4.5 Corrective and Preventive Action**

The difference between corrective and preventive action shall be clearly expressed in the Quality Manual. Corrective Action procedures shall address actual nonconformities that have occurred. Preventive Action procedures shall address the potential for nonconformity. The Contractor shall establish and maintain procedures for taking corrective and preventive action that is appropriate to the size of the problems and commensurate to the risks they present.

Corrective Action procedures shall be effective in handling complaints from nonconformance reports and from all entities, including Sound Transit. Methods shall include problem analysis, recording results, determining the most effective corrective action, verifying that corrective actions have been taken, and that they are effective.

Preventive Action procedures shall require use of all available information to eliminate potential sources of nonconformity. Methods shall include data and information analysis, determining the best approaches to preventing nonconformity, implementing and ensuring effectiveness of preventive action plans, and forwarding significant details of actions taken for review by management.

#### **19.9.4.6 Use of Statistical Techniques**

Specific needs for statistical techniques in controlling production processes shall be identified in the Project Quality Management Plan for the Project. Statistical quality control applications used in acceptance of parts, materials, or processes by the Contractor or its suppliers shall be fully

documented and based on generally recognized and accepted statistical quality control methods. A Statistical Quality Control procedure shall be submitted to Sound Transit for review and approval as part of the Project Quality Management Plan.

#### **19.9.4.7 First Article Inspection**

A First Article Inspection (FAI) will be performed jointly by Sound Transit and the Contractor on all major components, assemblies and subassemblies identified in the Project Quality Management Plan, including the fully assembled vehicle. The Contractor shall provide an individual notice to Sound Transit for each FAI a minimum of 30 calendar days prior to the FAI. (CDRL 19-27) The Contractor shall not schedule more than two FAIs in the same work week without prior approval by Sound Transit. Equipment shall be shipped from the point of manufacture only after an FAI has been offered and either passed, or waived by Sound Transit. The Contractor shall perform independent pre-FAIs to ensure that the subcontractor is prepared.

A First Article Inspection will evaluate component and system maintainability where possible. An FAI will be performed on components built using approved production processes and tooling, and shall establish the quality of workmanship for the balance of like components. The level shall be established jointly by Sound Transit and the Contractor.

A First Article Inspection will not be conducted until the design drawings of the article have been conditionally approved or approved. If conditionally approved drawings are used, Sound Transit's conditions for approval shall be satisfied at the FAI and represented by the inspection article. Production may only begin once product has successfully passed the FAI and written notice of approval has been received from Sound Transit.

The inspection work space shall provide a proper, well-lit environment for inspection of piece part, subassembly or car final assembly. When appropriate, the inspection article shall be displayed on a stand or table with all necessary inspection tools, go/no-go gauges, plug gauges, and handling aids. Correct tools and labor to take mechanical or electrical measurements shall be provided, including tools and labor for disassembly and removal of covers.

Where applicable, functional testing shall be performed in conjunction with the FAI.

As a minimum for car body and truck items, First Article Inspections shall be performed on the following:

- Completed underframe
- Side Frames
- Roof
- Ends
- Floor
- Completed car body structure (all three sections)
- Articulation
- Completed Interior equipment and appointments installation
- Seats
- Underfloor equipment installation

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- Roof equipment installation
- Wheel-axle set (motor and trailer)
- Truck frame
- Truck Assembly

As a minimum for major systems, First Article Inspection shall be performed on the following:

- Communications
- Lighting
- Propulsion
- Friction Brakes
- Doors
- Coupler
- Pantograph
- HVAC
- Event Recorder
- Monitoring and Diagnostic
- CCTV
- Cab Signaling
- Automatic Passenger Counting

The requirements below shall apply to each FAI.

A FAI package shall be submitted for each FAI as a separate CDRL in advance of the FAI (CDRL 19-28). It shall provide the following details:

- Schedule and agenda
- Vendor
  - Vendor Address
  - Vendor Phone Number
  - Vendor Contact
- Component List with latest drawing status
- Contractor Inspection Plan
- A complete set of approved or conditionally approved drawings and software documentation (with Sound Transit's comments) for the item to be inspected.
- For purchased items, a copy of the Vendor's purchase order with commercial items excluded, shall be available;
- Completed Vendor inspection forms that control and document acceptance of in-process work
- Complete vendor and Contractor final inspection forms;
- A complete list of letters, MOC's and action items with status;

- Completed test documents that reflect that the component or system has passed testing;

In the event that an item fails to pass its FAI and another FAI for the same item must be performed at a later time, the Contractor shall reimburse Sound Transit for its reasonable expenses involved in witnessing any subsequent FAI's to qualify the item. Upon completion of the FAI, the completed test documents showing the component or system has passed testing must be submitted and approved by Sound Transit before the FAI can be considered complete.

Any change to material, process, design, facility, manufacturer or supplier shall, at the discretion of Sound Transit, warrant a new FAI.

The FAI unit shall remain at the manufacturer or supplier facility as a reference unit until the last shipment to the Contractor's facility. Use of the FAI unit prior to the last shipment shall require Sound Transit approval.

#### **19.9.4.8 Receiving Inspection and Testing**

The Contractor shall utilize Receiving Inspection to verify that subcontractors and suppliers are meeting all requirements of the Specifications, and as listed on purchasing documents. The Contractor's procedure for this activity shall prohibit use, including processing, of purchased items and materials until they have been inspected per approved procedure and verified with respect to requirements. The inspection status of items shall be positively identified and recorded to support recall and replacement, should that be necessary.

#### **19.9.4.9 In-Process Inspection and Testing**

The Contractor shall ensure that all products are inspected and tested as required elsewhere in the Specifications and the approved Master Test Plan. The Contractor must identify all Contractor and subcontractor hold and witness inspection points in its ITP. Products shall be withheld from release to the next stage of production or delivery until required inspections and tests have been completed to Sound Transit's satisfaction.

#### **19.9.4.10 Pre-shipment Inspection**

Pre-shipment inspections shall be conducted for items listed in the Project Quality Management Plan. The Contractor shall provide Sound Transit a minimum of 10 days' notice for each inspection, including the agenda and list of items to be inspected. (CDRL 19-29) The Contractor shall ensure that all necessary drawings, specifications, standards, tools and facilities are provided to support these inspections.

#### **19.9.4.11 Final Inspection and Testing**

The Contractor's Project Quality Management Plan shall identify all Final Inspections and Tests upon which the final release of vehicles and equipment are based. Products shall not be released for shipment to Sound Transit until all final inspections and tests have been completed to Sound Transit's satisfaction.

#### **19.9.4.12 Inspection and Test Records**

The Contractor shall establish and maintain records that indicate whether products have passed required inspections and tests. Any items that have failed inspection or test shall have such failure documented and processed via the Contractor's nonconformance procedures. Inspection and Test Records shall identify the Contractor authority responsible for releasing inspected and tested products.

#### **19.9.5 Quality Assurance Support Systems**

To support the QA process the Contractor shall develop procedures for the handling of all products, records, and training necessary to properly meet the QA requirements. There shall be procedures for QA during the warranty period. These procedures shall be followed by the Contractor and its suppliers.

##### **19.9.5.1 Handling, Storage, Preservation and Delivery**

The Contractor shall establish and maintain procedures for handling, storage, packaging, preservation, and delivery of items furnished under this Contract. The Contractor and suppliers shall implement procedures that:

- Identify methods for preventing damage or deterioration;
- Provide for secure storage that includes documented receipt and dispatch;
- Control packaging, packing, stacking allowance when stored and marking processes;
- Provides methods for preserving and segregating products in production, assembly, and storage;
- Provide instructions against weathering & corrosion, drying agents, moisture barriers, ESD damage in production, assembly and storage, and control of shelf life, and
- Preserve product quality following final inspection and testing until delivered.(includes preventative maintenance measures)

##### **19.9.5.2 Control of Quality Records**

The Contractor shall establish and maintain procedures for handling, maintaining, and disposing of quality records, including pertinent quality records of subcontractors. Quality records may be in the form of paper copies, electronic files, or other media. All quality records shall be legible and traceable to the items they describe. Quality records shall be stored to prevent loss or damage, and shall be available for Sound Transit examination upon request. The Contractor shall establish retention periods for quality records that comply with the requirements of this Contract.

##### **19.9.5.3 Quality Assurance & Training**

The Contractor shall establish and maintain procedures to identify training needs as necessary to complete work successfully under this Contract. The Contractor shall provide appropriate

training to personnel performing activities that affect the quality of products and services. Records of training needs and training completed shall be maintained and available upon request by ST personnel.

#### **19.9.5.4 Quality Assurance during the Warranty Period**

The Contractor shall establish and maintain procedures for servicing delivered products during the warranty period that include verifying warranty requirements are being met. Procedures shall clarify the Contractor's servicing and warranty responsibilities in accordance with this Sound Transit Contract. Both Contractor and any subcontracted servicing and warranty activities shall be planned and supported by suitable instructions, documentation, and competent, trained personnel. These activities shall include the procedure required to ensure a smooth and timely replenishment of Warranty spares at the Acceptance site during the car acceptance phase when those spares are needed to address car acceptance issues.

The Contractor's staff shall collect and feed back to responsible Departments any information during the warranty period that supports servicing, design, and product improvements necessary to fulfill Specification requirements reliably.

At any time up to and including the completion of the warranty period, for any relevant failure as defined in Section 2 Reliability, the Contractor shall review the failure and provide a failure analysis report to Sound Transit.

Accurate and timely Failure Analysis Reporting (FAR) is necessary for the proper execution of the reliability program. Accordingly, the Contractor shall submit FAR forms to Sound Transit for each failure occurrence within 30 days of each incident.

Failure analysis of reported failures shall identify the cause and corrective action. The Contractor shall establish a Failure Review Board to meet with Sound Transit, as required, to determine the need and depth of failure analyses.

### **19.10 Technical Support Personnel**

The objective of technical support personnel is to assist Sound Transit to keep vehicle downtime to a minimum. Two levels of technical support are expected, routine technical support and technical support during acceptance testing of the first two vehicles, as described in this Section. 90 days prior to shipment of the first vehicle, the Contractor shall submit an organization chart, and individual's names and qualifications for routine technical support and technical support during initial testing. (CDRL 19-30)

The Contractor shall also ensure, and show on the organizational chart, that the expert services of equipment suppliers and designers are available, on short notice, during the same period to assist the on-site personnel in the investigation and resolution of car and equipment malfunctions.

#### **19.10.1 Routine Technical Support**

The Contractor shall furnish the services of at least two field service engineers or technicians at Sound Transit facilities. These personnel shall be provided on a full time basis before arrival of

the first car and shall remain until the end of the main vehicle warranty period. If Sound Transit exercises any LRV options the Contractor shall be provided at least two field service engineers or technicians at Sound Transit facilities on a full time basis starting at least 20 working days before arrival of the first option car and shall remain until two years after acceptance of the last option car. The Contractor must ensure that technical support personnel are fully aware of modifications performed during the production. The support personnel shall be fluent in the English language.

The Contractor must ensure that the technical support office is ready and documentation, replacement parts, tools, and instruments necessary for the technical support arrive at Sound Transit facility 60 days before arrival of the first vehicle. The support personnel shall provide assistance during inspection, operation, testing, and adjustment of the LRV both before and after acceptance by Sound Transit and during warranty period.

The support personnel shall be available to work any of three, eight-hour shifts, as may be required by the Sound Transit working schedule. The Contractor shall also ensure that the expert services of equipment suppliers and designers are available, on short notice, during the same period to assist the on-site personnel in the investigation and resolution of car and equipment malfunctions.

If requested by Sound Transit, the Contractor shall provide on-site technical assistance within 24 hours from receipt of request during the time period from delivery of the first car to final acceptance of the last car; and within 48 hours from receipt of a request for service during the warranty period.

### **19.10.2 Technical Support during Initial Testing**

The Contractor shall ensure an adequate level of support during qualification testing of the first two vehicles on Sound Transit property or at an alternate testing facility. As a minimum, the support shall include the Contractor's field service engineers, system engineers, QA and workforce as required for a successful test program. The Contractor shall ensure that major equipment suppliers provide adequate hardware and software support, including but not limited to field service technicians, software engineers capable of major software changes in the field, system engineers, and workforce as required for a successful test program.

### **19.11 Obsolescence Management Plan**

The Contractor shall submit for Sound Transit approval, an Obsolescence Management Plan (CDRL 19-31). The Obsolescence Management Plan shall show all planned processes and coordinated activities to monitor, report and assess the impact of impending or occurred obsolescence of hardware and software delivered under this Contract.

## **19.12 Deliverables**

The Contract Deliverables Requirements List items (CDRLs) required by this Section are summarized below. They are described in detail at the referenced location. Refer to CDRL requirements in this Section.

- 19-1 Confirmation of Contractor's project manager (Section 19.2)
- 19-2 Contractor's project management plan (Section 19.2)
- 19-3 Preliminary dynamic and static envelope (Section 19.3.2)
- 19-4 Jacking points and load distribution (Section 19.3.2)
- 19-5 Acceleration and braking performance (Section 19.3.2)
- 19-6 EMI data and ongoing coordination (Section 19.3.2)
- 19-7 Mounting locations communications, cab signal, and TWC antennae (Section 19.3.2)
- 19-8 Pantograph mounting location with wire tracking and forces data (Section 19.3.2)
- 19-9 Vehicle electrical load data for both propulsion and auxiliary systems, with vehicle at rest, accelerating and at balancing speed (Section 19.3.2)
- 19-10 Meeting agenda and data package (Section 19.4.3.1)
- 19-11 Meeting minutes (Section 19.4.4)
- 19-12 Specification Compliance Matrix (SCM) shell (Section 19.5)
- 19-13 Specification Compliance Matrix (SCM) final and monthly updates (Section 19.5)
- 19-14 Document/submittal tracking system (Section 19.6.1)
- 19-15 Monthly update of Contractor and subcontractor drawing and document status (Section 19.6.1)
- 19-16 Drawing symbol cross-reference (Section 19.6.2.2)
- 19-17 Subcontractor certification of installation of its equipment by Contractor (Section 19.6.4)
- 19-18 Monthly progress reports (Section 19.7.1)
- 19-19 ECR sample format (Section 19.8)
- 19-20 Engineering Change Status Report (Section 19.8)

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- 19-21 Serial numbers list for Sound Transit approval (Section 19.8.1.2)
- 19-22 Serial numbers of all components on each vehicle (Section 19.8.1.2)
- 19-23 Car history book format and complete Table of Contents (Section 19.8.2)
- 19-24 Quality Manual (Section 19.9.1.1)
- 19-25 Project Quality Management Plan (Section 19.9.1.2)
- 19-26 Inspection and Test Plan (Section 19.9.4.1)
- 19-27 First article inspection notice (Section 19.9.4.7)
- 19-28 First Article Inspection package submittals (Section 19.9.4.7)
- 19-29 Pre-shipment inspection notice (Section 19.9.4.10)
- 19-30 Technical support organization chart, names, and qualifications (Section 19.10)
- 19-31 Obsolescence Management Plan (Section 19.11)

### **19.13 Cited References**

The following standards or references were cited in this Section at the referenced location:

ASME Y14.2	Line Conventions and Lettering (Section 19.5.2.3)
ASME Y14.3	Multiview and Sectional View Drawings (Section 19.5.2.3)
ASME Y14.5	Dimensioning and Tolerancing (Section 19.5.2.3)
ASME Y14.38	Abbreviations and Acronyms for Use on Drawings and Related Documents (Section 19.5.2.3)
ATA A100	Air Transport Association of America Specification No. A100 “Specification for Manufacturer’s Technical Data” (Section 19.5.2.3)
IEEE 91	Graphics Symbols for Logic Functions (Section 19.5.2.3)
IEEE 315	Graphics Symbols for Electrical and Electronics Diagrams (Section 19.5.2.3)
ISO 32000-1	Document management – Portable document format – Part 1: PDF (Section 19.5.1)

**END OF SECTION 19**