

LRT and Streetcar Project Interface: Coordination for the Washington DC Metropolitan Area

Technical Memorandum: Compatibility of Systems and Infrastructure



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1.0 Introduction

Project sponsors across the Washington DC metropolitan region are currently planning a range of surface transit projects, including new LRT and streetcar lines. Although the Washington Metropolitan Area Transit Authority (WMATA), as the regional transit provider, has been involved to varying degrees in the planning for new lines, it is not anticipated that WMATA will own or operate the projects. The focus of the *LRT and Streetcar Project Interface* study, therefore, has been to provide a forum for project sponsors to discuss opportunities for coordination among the different systems being planned, and to identify places where coordination could result in cost savings and operating efficiencies. Regional stakeholders who have participated in this study are included in **Table 1-1**. Relevant projects are also noted in the table.

Regional Stakeholders



Table 1-1: Project Stakeholders and Relevant Projects

Participant	Relevant Projects
District of Columbia Department of Transportation (DDOT)	DC Streetcar Program
Maryland Transit Administration (MTA)	Purple Line
Montgomery County Department of Transportation (DOT)	
Prince George's County Department of Public Works and Transportation	
Fairfax County	Columbia Pike
Arlington County	Crystal City-Potomac Yard High Capacity Transit Way Corridor Study
City of Alexandria	
Metropolitan Washington Council of Governments (MWCOG)	
National Capital Planning Commission (NCPC)	

In addition, WMATA is currently developing a *Regional Transit System Plan*, which aims to reflect regional growth and sustainability goals and facilitate consensus around a set of recommendations focused on Metrorail core capacity improvements and surface-based transit network development. Outcomes of the *LRT and Streetcar Project Interface* study will shape priorities for expansion of the existing transit network and highlight points of interaction between existing and proposed services and among the proposed improvements.

Based on coordination among project sponsors and technical analysis to date, decisions about where to coordinate should be based on the following questions:

- Geographically, where are the likely points of interface?
- How important is seamless passenger experience, and what contributes to it?
- Where can cost savings be obtained through ongoing coordination?
- What decisions might preclude future interoperability?
- Where would locally-based decisions result in more cost-effective solutions?

1.1 Purpose

The purpose of the interface study is to identify the technical challenges related to maximizing the degree of interoperability among the Streetcar and LRT projects advancing across the region. The study aims to promote customer convenience, cost efficiency, and regional transit network coherence by maximizing the degree to which these projects can adopt compatible power, control, track, fare collection, and passenger information systems and - to the extent possible - make physical connections with one another. To the extent that vehicle technologies can be made compatible and storage and maintenance facilities consolidated, these also are being explored. Findings of this study will support project sponsors as they develop engineering specifications to design and implement these projects.

As jurisdictions around the Washington metropolitan region develop their own streetcar and LRT lines, it is likely that a system will develop where some but not all decisions are made based on compatibility across lines. A major goal of this study is to advance the conversation regarding which key decisions should be coordinated. **Table 1-2** lists features of an “ideal” regional system and compares them with features of the system that is likely to evolve.

Table 1-2: Ideal vs. Likely Regional System

Ideal System	Likely System	Key Considerations
All lines interconnected	Lines isolated	Geography and infrastructure investment
Same vehicles - capable of operating on any line	Different vehicles - vehicles stay primarily on their own system	Focus on basic compatibility to not preclude non-revenue moves over other lines
Same track & electrical standards	Same track & electrical standards	Off-wire capability may be more important in some jurisdictions than others
Standardized open payment system in place throughout region	Regional open payment system with local variations on cash payments	Level of investment and coordination required for seamless passenger experience
Common maintenance facility, fully equipped	Multiple facilities, some bare bones only	Opportunities to share depend on geography of interconnection and land availability.

1.2 Key Findings

This document presents the key opportunities for cost savings and operating efficiencies that could be realized during the build-out of the region’s light rail and streetcar systems. It also summarizes research into relevant aspects of other North American transit systems. The information provided in this document thus provides a starting point for conversations regarding levels of interface that are achievable or desirable. A summary of key technical findings of the study are listed by topic in **Table 1-3**. Section 8.0 has detailed findings of each topic based on technical issues and recommended actions.

Table 1-3: Key Technical Findings

Topic	Interoperability Opportunity
Fare collection systems	Ability to seamlessly integrate collection systems; share maintenance and operational costs.
Vehicle types and specifications	Operate over other lines for non-revenue moves to reach shared maintenance facilities. For like modes, option to share vehicles to meet temporary demand. Use of common vehicle type or family to simplify maintenance and training.
Operations and maintenance facilities	Common vehicle types or families will make maintenance easier. Special capabilities (wheel truing, overhaul, major painting/accident repairs) could be performed in an existing or "specialized" facility.
Power supply	Use of common design practices and parts to lower costs and simplify maintenance and training. To include standardized pantograph dimensions and wire height range for all vehicles in region.
Guideway design	Design criteria should seek to strike balance between unnecessarily restrictive criteria and adherence to recommended limits as a means of limiting risk that features might be built into infrastructure which limit compatibility with standard vehicle designs.
Passenger information and user interface	Coordination (in some cases mode-specific) on policies and passenger communication.

1.3 Meetings and Topics

Over the past year, regional stakeholders and project sponsors across the Washington DC region have participated in a series of work sessions, focused on general challenges and detailed issues affecting interface among proposed projects. **Table 1-4** provides a summary of the topics covered at each meeting.

Table 1-4: Regional Stakeholder Coordination Meetings

Meeting Date	Topics
October 29, 2010	Systems Interface and Integration <ul style="list-style-type: none"> ▪ Physical and operational connections ▪ Passenger interface, fare collection, and information ▪ Communications, maintenance, and training
March 11, 2011	Systems Interface and Integration <ul style="list-style-type: none"> ▪ Fare collection ▪ Streetcar vehicle selection
April 27, 2011	Fare Collection Strategies and Interface <ul style="list-style-type: none"> ▪ Off-board fare collection (Columbia Pike Streetcar) – implementation challenges ▪ DDOT's role in establishing fare collection policy
May 12, 2011	Fare Collection Strategies and Interface <ul style="list-style-type: none"> ▪ Costs and benefits of various methods ▪ MTA "Proof of Payment" system
June 7, 2011	Vehicles <ul style="list-style-type: none"> ▪ Trends in vehicle technology ▪ Opportunities for interface (vehicle size, propulsion, wheel/rail interface) ▪ Procurement methods and options
September 22, 2011	Operations and Maintenance <ul style="list-style-type: none"> ▪ Tour of Baltimore LRT O&M Facility ▪ Opportunities for interface among systems ▪ Layout, equipment, staffing, and maintenance schedule
February 10, 2012	Technical Memorandum: Summary of Findings <ul style="list-style-type: none"> ▪ Vehicles, O&M facilities, guideway, power, passenger interface, fare collection ▪ Next steps for coordination with decision makers

1.4 Related Efforts

Related study efforts are ongoing at both regional and national levels. These include work by the American Public Transportation Association (APTA) Streetcar Subcommittee to produce a national Streetcar Vehicle Guideline document and work by the District of Columbia on a Design Criteria document for its streetcar system.

DDOT Design Criteria Manual - DDOT is currently designing and constructing the region's first streetcar system. Vehicles have been procured and portions of the track alignment for the first two lines, as well as a number of the stops, have already been constructed in conjunction with adjacent projects. The agency is currently developing a comprehensive Design Criteria document and has opened the process to input from interested parties including neighboring jurisdictions. By participating in the development and review of the document, local agencies have a unique opportunity to address technical issues that may affect their own projects.

APTA Streetcar Guideline Document - the APTA Streetcar Subcommittee of the Rail Transit Committee was formed in 2000 with a mission "to promote the development of streetcar lines (both heritage and modern) in urban centers and to foster information exchange among those planning or operating such lines, and to encourage reasonable technical and safety standards". The Subcommittee meets several times each year in conjunction with APTA conferences as well as independently for in-depth technical tours of cities operating or planning streetcar systems. The Subcommittee is comprised of industry professionals who are voluntarily collaborating to help develop guidelines and standards that will benefit the streetcar field.

The Subcommittee is developing a guideline document entitled "North American Application of Modern Streetcar Vehicles". The stated goal is to "*facilitate the successful introduction of modern streetcar vehicles into North American systems by promoting understanding of the core technical and operational issues*". From this understanding, agencies will be able to better navigate the process of specifying streetcar vehicles and designing compatible infrastructure. Similarly, suppliers will be provided with a better understanding of the differences between North American and world operating and regulatory environments. The document will also serve as a scoping document to review where additional standards, or modifications of existing standards, may be needed to facilitate the successful introduction of modern streetcar vehicles in North America.

2.0 Vehicles

When selecting a transit vehicle, the project sponsor should consider the nature of corridor passenger demand and the overall operations strategy for the system. Where the transit needs of each project sponsor are similar, sponsors may collaborate on a decision to procure a single type of vehicle. Where needs differ, different vehicles may be desirable, but sponsors may wish to collaborate to select a vehicle or vehicle family which is flexible enough to meet the differences of need among sponsors.

2.1 Vehicle Width

Vehicle width is a key component of the interface between transit and the built environment; it determines passenger capacity and influences the vehicle/platform interface. Vehicle width determines the spacing between the station platform and the track centerline. This is a critical issue for interoperability between systems. Where the guideway is designed for a narrower vehicle, wider vehicles will typically be unable to operate past any station platforms and may also encounter other clearance issues. Where narrow vehicles operate along a guideway designed for wider vehicles, there may be an unacceptable gap between the vehicle and platform. Vehicle width also affects in-street operation, as vehicle widths relate to lane widths and street configuration.

There are three “standard” vehicle widths in the world light rail vehicle (LRV) and streetcar market:

- 2.3m (7'-6.5")
- 2.4m (7'-10.5")
- 2.65m (8'-8")

For the region's first streetcar system, DDOT has selected and procured the Czech designed “Portland” streetcar, which is a 2.46m (8'-0") wide, 20m (65'-7") long vehicle. All of these widths are maximums over the carbody, not including door thresholds or mirrors. Vehicle sides may also be tapered, so the critical dimension when interfacing with a platform is vehicle width at the door thresholds. Door thresholds will themselves often protrude several inches beyond the vehicle sides. For these reasons, the small $\frac{3}{4}$ inch (19 mm) difference per side between a 2.40m and 2.46m wide vehicle may make little or no practical difference, especially where “nearly level” boarding is in use.

Both the 2.4m and 2.65m vehicle widths are commonly used on new-start tramway or streetcar systems throughout the world. For systems where future expansion to or interoperability with light rail is envisaged, the use of a 2.65m (8'-8") width vehicle may

Figure 2-1: Vehicle Length



To date, modern streetcar vehicles used in the US have all been 20m (65.6 feet) in length. Worldwide, longer vehicles are widely used because of the operating cost advantages provided by their increased capacity. This 32m long vehicle was demonstrated in Vancouver BC during the 2010 Winter Olympics.

have important advantages, as this width has greater passenger capacity and is used by almost all US light rail systems.

2.2 Vehicle Length

In addition to being the primary determinant of a vehicle's capacity, vehicle length affects platform length as well as layout of maintenance and storage facilities. The minimum length for a typical modern streetcar is 20m (65.6 feet). Longer streetcar vehicles are also available and widely used throughout the world because of their additional capacity and resultant operating cost advantages (See Figure 2-1). For all projects, vehicle length and system capacity (both startup and future) should be carefully evaluated in light of local conditions. Capacity can be increased in the future by adding additional vehicles, by obtaining vehicles whose modular design allows additional sections to be added when needed, or by procuring longer vehicles initially.

2.3 Compatible Performance

Different vehicle designs will have different abilities in terms of turning radius, grade climbing abilities, acceptable amount of track twist and other operational characteristics, although all fall within basic ranges. Refer to Section 5.1 for additional discussion on turning radius.

Maximum existing vertical grades should be considered as they could limit the operation characteristics of a streetcar system and possibly exceed the limits of a given design vehicle. Streetcar vertical geometry consists of constant grade tangent segments

connected by parabolic curves. Most streetcar design criteria limit maximum grade to 6% for sustained lengths greater than 1000 feet, and allow up to 7% absolute maximum for short lengths between 500 to 1000 feet. Streetcars in San Francisco climb grades as steep as 9 percent, and Boston has 8 percent grades. Importantly, These the vehicles were however in these examples were specified and designed for this capability and have all wheels and axles powered, along with propulsion and braking systems designed accordingly. Like other aspects of streetcar system design, steep gradients are also a trade-off with operational speed and long-term maintenance costs.

With small order quantities major customization of vehicles will likely be economically infeasible. However, when selecting a design vehicle it is important to account for the requirements of existing street geometry, city blocks, existing grades, etc. It is easier to adopt a vehicle that conforms to the corridor requirements than to rebuild the corridor to conform to vehicle and associated track geometry requirements.

2.4 Platform Configuration

Vehicle-platform interface issues are driven by the need to comply with the requirements of the Americans with Disabilities Act (ADA) and the desire to provide easy access on and off vehicles for all users. Low-floor vehicle floor heights at low-floor doorways are generally standardized at a nominal 14 inches. There are two general approaches: “fully level” boarding and “nearly level” boarding.

Fully level boarding (both vehicle floor and platform height the same at 14 inches nominal) requires an active suspension (“load leveling”), to comply with the 5/8 inch vertical step requirement in ADA. Fully level boarding provides the best possible dwell times and eliminates vehicle-mounted bridgeplates; however it requires narrower tolerances for platform and track construction and will thus have higher costs. In addition, 14-inch platforms are not usually compatible with the rear doors on most modern transit buses. The active vehicle suspension also comes with additional capital and maintenance costs.

Nearly level boarding (vehicle floor height 14 inches, platform height 8 to 10 inches), requires bridgeplates for ADA compliance. Nearly level boarding permits less homogeneity of stops, which may vary slightly in height and distance from the track, and may also be located along curves. This flexibility can be translated into cost savings in constructing an urban streetcar project; slight alignment variations can be used to avoid conflicts with other street elements or even with underground utilities. Importantly, the nearly

level platform is also more compatible with buses sharing streetcar stops.

However, use of bridgeplates does add further complexity to the already complex vehicle doors subsystem. Deploying bridgeplates tends to increase stop dwell times, which may be a significant factor in high ridership applications, especially where the streetcar impacts traffic when stopped.

Streetcar vehicles are typically equipped either with load leveling or bridgeplates, but not both. It is technically possible to equip a vehicle with both features, although the bridgeplates cannot be deployed at stops equipped with a fully-level platform. Mixing types of stops may also create confusion for mobility impaired riders. The streetcar system in Atlanta will have vehicles with both features in the interest of flexibility for system expansion, and DDOT has also incorporated this feature into their design criteria.

2.5 Communication Equipment

All streetcars and light rail vehicles will incorporate some level of Train-to-Wayside Communication (TWC) capabilities. The required level of TWC functionality will be determined based on local requirements, with the light rail mode likely to have additional requirements beyond those needed for streetcar. Because the light rail mode typically includes higher speed running on segregated alignments, signal and train control system requirements will also be closely related to TWC capabilities. Streetcars typically use line-of-sight operation with minimal or no train control and signaling requirements. Since they operate mostly in-street, streetcar TWC technology in particular must also be considered together with similar equipment which may already be used by transit buses and emergency responders.

TWC can be accomplished using a variety of different technologies, the two most common being optical and inductive.

Optical TWC- Optical systems, such as the 3M Opticom system, utilize a vehicle-mounted infrared emitter that broadcasts an encoded priority request to an intersection it is approaching. Detector units mounted at the intersection above the roadway or trackway receive the transmission and relay the request to equipment installed in the traffic controller or other wayside equipment. The priority request equipment provides input to the traffic controller or other device.

Simplified Hardware Requirements:

- Emitter at each end of streetcar or light rail vehicle, with control box at each operator's position. The control box allows the operator to "call" signals as required.

At each intersection where traffic signal interface is required:

- Detector on pole or mast arm facing each direction along track.
- Phase Selectors in each traffic signal controller.

Inductive TWC- Inductive systems, such as the Vecom Vetag System, utilize a magnetic transponder mounted under the vehicle to broadcast a signal to an inductive loop either embedded in pavement or otherwise attached to the track structure. The inductive loops are wired to an Interrogator unit located in the traffic controller or other wayside equipment. The Interrogator unit validates the signal and provides input to the traffic controller or other device.

The Vecom Vetag is a basic one-way TWC system. More advanced two-way systems, in which the traffic signal system can send information back to the vehicle, are also available.

Simplified Hardware Requirements:

- Transponder at each end of the streetcar or light rail vehicle, with Code Control Box at each operator's position. The control box allows the operator to "call" signals as required.

At each intersection where traffic signal interface is required:

- Loop antenna for pavement or track application.
- Vetag Interrogator in each traffic signal controller.

Project sponsors will influence regional compatibility by selecting TWC equipment based on 1) the need to make use of procured technology, and 2) the degree to which they wish to coordinate operations with other LRT or Streetcar systems. The current DDOT Streetcar Design Criteria document specifies the use of a Phillips Vetag inductive type TWC system.

2.6 Coupling Type

Because light rail vehicles are typically equipped for multiple unit operation and streetcars are not, they will typically employ full couplers, whereas streetcars will often use a retractable or removable tow bar provision instead. For both modes, all vehicles must at a minimum be equipped with a safe means to permit towing so that a disabled vehicle can be cleared from the line. Where shared maintenance facilities may exist, towing might also be used to permit a vehicle to be moved to an off-line maintenance facility.

A related trend in the industry is the move towards eliminating protruding front couplers, particularly on lines with a high percentage of in-street operation. Replacing the protruding front coupler with a rounded, fully-skirted leading end design provides important safety benefits, protecting automobile occupants in the event of a collision with the rail vehicle. Industry standards such as

Tampa and San Francisco TWC Systems

TWC systems applications vary across the U.S. The Tampa Streetcar, for example, uses an Optical TWC system. The 3M Opticom system is used extensively for traffic signal interface, and is also used throughout the country for emergency vehicle priority systems. San Francisco uses an inductive TWC system. The Vecom Vetag system is used extensively throughout the SFMTA light rail and historic streetcar system.

ASME RT-1 (Safety Standard for Structural Requirements for Light Rail Vehicles) specifically address LRV and streetcar leading end design for protection of street vehicles.

At a minimum, all vehicles within a like mode should have compatible towbar / coupler provisions. A standard coupler type could be adopted for the region's light rail vehicles, and a common towing provision specified for the region's streetcars.

2.7 Crashworthiness Standard

This is an area where the industry is currently in a state of flux. Significant new standards relating to vehicle crashworthiness have emerged from both the EU and the US in the last decade, codifying a major design shift towards crash energy management (CEM) and away from fixed buff strength. However, they are separate standards, and some differences remain. The US ASME RT-1 *Safety Standard for Structural Requirements for Light Rail Vehicles* (which is also applicable to streetcars) arose from an industry groundswell to address the heavier-duty carbody requirements of North America versus those of Europe. Since the US market represents only a small percentage of the world market for rail transit equipment (12% of the world market for low-floor streetcars and light rail vehicles), the EU market drives design development. Significant cost impacts result from the need to make major changes when adapting these designs for use in the US.

Prior to the advent of RT-1, the widely divergent approaches between the US and EU also helped keep 100% low-floor vehicles out of the US market. 100% low-floor technology has now been used in Europe for over twenty years, but is only now beginning to appear in North America. 100% low-floor currently represents the majority of orders for EU streetcar and tramway vehicles, with 70% low-floor configurations still popular for Light Rail and Tram-Train applications.

EU designs for rail transit equipment are governed primarily by European standard EN15227- *Crashworthiness Requirements for Railway Vehicle Bodies*. Carbuilders are still evaluating the implications of the differences between the US ASME RT-1 and the EN standards, although they are clearly more compatible than was the case with the previous US approach. Both standards recognize the streetcar and light rail modes separately. It is also possible that future revisions may bring the US and EU standards even closer together.

Both the US and EU standards utilize Crash Energy Management (CEM) protocols. CEM represents the latest best-practices of design, testing, analysis and manufacture—enhancing

crashworthiness by assigning certain sections of the carbody the task of absorbing a portion of the energy of collision by crushing in a controlled manner. Proper application of CEM preserves occupant volume, while minimizing the consequences of occupant impacts with the vehicle interior. Vehicle manufacturing efficiencies may also be realized via CEM, although heightening passenger safety is the main intent.

As noted in Section 2.6 above, ASME RT-1 also addresses leading end design for protection of other street vehicles in the event of crashes, which raises the issue of eliminating exposed couplers in operating environments exposed to street traffic. Moving forward, design criteria for all projects in the region should specify compliance with RT-1 as the basis for carbody design / crashworthiness in order to take advantage of the benefits of industry standardization.

2.8 Vehicle Market and Procurement Issues

Streetcar systems and vehicle requirements vary considerably throughout the world. It is also common for cities to want a unique “look” for their vehicles. Carbuilders have responded by developing modular product lines that permit multiple vehicle configurations and visual design elements based around standardized vehicle “platforms”. Within these modular product families, customers can select from a catalog of “standard” options to tailor the vehicle configuration to their system. By selecting options from a standard product range, vehicle costs and delivery times should be minimized.

Because the North American market for LRT and streetcar vehicles is only a small portion of the global market, American project sponsors with small startup systems are not typically in a position to shape what vehicle manufacturers are offering. At the same time, American federal grants are contingent upon Buy America compliance, requiring that the major portion of materials and manufacturing be produced domestically. For American project sponsors, these factors have led to a more limited selection of vehicle types, higher costs of vehicle orders, and potential mismatches between system needs and available vehicles.

Fortunately, as interest in the streetcar mode continues to grow in the US, domestic suppliers are emerging, and more carbuilders are tailoring products to the US market with the expectation of meeting Buy America requirements. The continuing worldwide progress on developing industry standards is also helping, as are US efforts through APTA to define streetcar requirements and to better understand the differences between relevant US and European standards.

Washington DC Vehicle Procurement

The District Department of Transportation purchase of three streetcars using an option on the Portland Streetcar contract provides an example of an “option” procurement. The District’s vehicles were configured largely the same as Portland’s vehicles and were purchased at the same approximate price that Portland had negotiated. The DDOT vehicles included a different exterior paint scheme and the substitution of a load-leveling feature in place of bridgeplates in order to permit the use of “fully level” boarding. The Portland system uses “nearly level” boarding and has automatic bridgeplates installed on its vehicles instead of a load leveling feature.

If sponsors obtain common vehicle types, economies of scale are possible in several areas. Agreements with vendors can be made regarding the availability of parts, program management, and vehicle commissioning. Parts sharing among sponsors with similar vehicles can expedite the acquisition of needed items for repair and assist in troubleshooting. A greater supply of parts could be procured and warehoused for future use among sponsors. This would help the individual operating entities to mitigate the risks of delayed availability of parts and components.

As the size of a vehicle order increases, the cost per vehicle tends to decrease. Sponsors will however need to order vehicles at similar times to capitalize on the manufacturing efficiencies of a large order. Vehicles can be obtained through a variation on joint procurement, where a contract contains an option with specific pricing for additional vehicles, with the options being transferable to other agencies. For example, the DDOT streetcars were purchased as an option to the original Portland Streetcar contract.

The procurement method that each agency within the region is required to use should be examined for constraints and opportunities. For example, in a scenario where two sponsors wish to procure the same vehicle, but with some lag time between delivery dates, agency procurement rules might prevent a sole source approach. A requirement to use a low bid approach might be another example that could complicate trying to separately procure the same vehicle type. On the opportunities side, the Metropolitan Washington Council of Governments (MWCOCG) could be a resource for flexible, multi-jurisdiction procurement methods. One recent example is the DC Bikeshare program, a joint project of the District of Columbia and Arlington County.

For project sponsors operating systems in geographical proximity, the possibility of shared maintenance capabilities also exists. Shared maintenance facilities, shared maintenance staff, and training/coordination among staff from different systems could provide significant benefits (see Section 3.0).

3.0 Operations and Maintenance Facilities

The operation and maintenance (O&M) facility serves as a crew base of operations and provides the needed facilities for storage, cleaning, inspection, repair, and in some cases, overhaul of the vehicle fleet. Overall facility size is determined based on fleet size, the amount of work done “in house” versus “contracted out”, and the number of other operations, functions, and employees to be co-located in the facility. A new system may also need to initially accommodate manufacturer personnel involved in testing and vehicle commissioning.

Although vehicle types and supporting equipment will vary, the basic range of activities in any streetcar or light rail maintenance facility will be similar. Maintenance needs include scheduled (preventative) maintenance, unscheduled (emergency or unexpected) maintenance, and overhaul (refurbishment) needs. For larger systems, it is not uncommon to have multiple facilities with particular maintenance activities only at certain sites.

Since smaller startup systems may not be able to initially afford the major capital investments associated with some aspects of vehicle maintenance (wheel truing, heavy overhaul, repainting) on their own, project sponsors could examine opportunities for these functions to be performed in other existing rail facilities in the region. While trucking entire vehicles between facilities is not realistic for routine maintenance functions, it can be practical for major accident repairs and heavy overhaul work.

Figure 3-1: Seattle and Denver O&M Facilities



O&M facilities vary in size depending on overall system size as well as land availability. The Seattle Streetcar (left) uses a very compact facility located in a commercial / residential area, while the Denver light rail system (right) has a large facility located in a rail yard / industrial area.

3.1 Scheduled Maintenance

Scheduled maintenance consists primarily of inspections, of which there are several different levels:

- Daily servicing, including cleaning following evening pull-in and refilling of traction sand.

Boston Sharing of Maintenance Facilities Among Non-Connecting Revenue Lines

The Massachusetts Bay Transportation Authority (MBTA) established a centralized location to facilitate maintenance needs for two physically separated commuter rail lines. Although there is no revenue service connection between the lines, there is restricted-use trackage that provides off-hour access to shared maintenance and storage facilities. Along the northern line, a full-service rail maintenance and storage facility provides major repairs and maintenance to locomotives and coaches for both lines. Along the southern line, there are two smaller facilities for lighter repairs and maintenance, cleaning, and upkeep of coaches for both lines.

Shared use of maintenance staff and equipment between LRT and subway systems also exists within the MBTA.

Toronto, ON Canada Sharing of Maintenance and Storage Yard Facility and Staff

The Toronto Transit Commission (TTC) presents an example of how storage and maintenance facilities can be shared among different modes. The city has a multi-line subway system, a large bus network, and the most extensive streetcar system in North America.

The Hillcrest Complex is TTC's largest facility and is responsible for most of the maintenance work on the system's surface vehicles, serving both streetcars and buses. The Wilson Complex is the largest bus facility and second largest subway facility in the system, serving both bus and subway vehicles.

- Other periodic inspections, including weekly, monthly, quarterly, and annual requirements. Includes inspection, preventative maintenance, and replacement of consumable components.
- Wheel truing done on a mileage basis, and also on a corrective basis (slid flats). See following section.

Basic inspection and maintenance requirements are similar for all streetcar and light rail vehicles, but parts and specific inspection requirements will vary between vehicle types.

3.2 Maintenance Activities

This section describes the typical maintenance activities within the O&M facility.

Unscheduled Maintenance

Unscheduled maintenance encompasses component repair or replacement work in response to road failures or vandalism, as well as accident repairs. Vehicles operating in-street with traffic are inevitably involved in collisions with other road vehicles. Most result in minor damage resolved with spot repairs and painting, although major damage can also occur, which in the extreme may require removal of the vehicle to a facility with accommodation for major bodywork.

Overhauls

Overhauls are typically performed at predetermined points in the vehicle's life cycle, normally including a "mid-life" overhaul. These activities, which may be performed in a different facility, include:

- Major body work and repainting from major accidents including frame straightening, welding repairs, replacement and repair of fiberglass and composite body panels, and repainting. At this level of repair, an entire carbody or carbody section is typically repainted, which is usually performed in a paint booth.
- Heavy overhaul, including replacement of running gear components, renewal or replacement of traction motors, and upgrades to electrical and other systems. Work typically involves removal of all major sub-system components from the vehicle for overhaul or upgrade. Floors, seating and other components are also renewed, and their removal permits access to structural components and other areas of the car frame normally hidden from view. These areas can then also be inspected and renewed as required. Following completion of repair and upgrade work the vehicle is then reassembled and repainted.

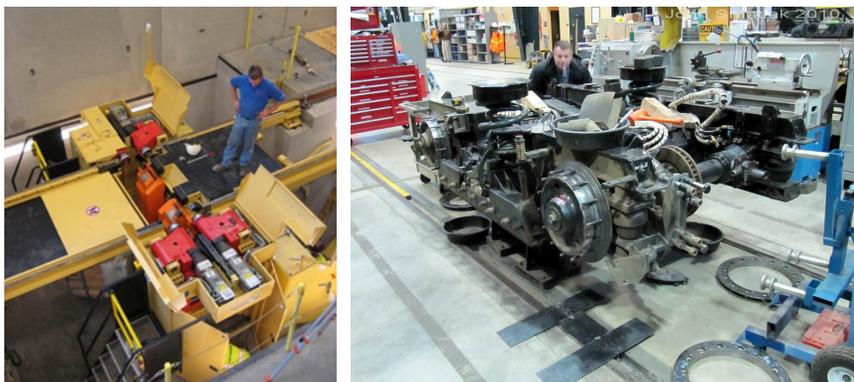
Wheel Truing

Wheels must be machined periodically to be kept within the necessary dimensional tolerances for safe and quiet operation. Such "truing" is done on a mileage basis which varies depending

on local conditions, and also on a corrective basis when wheels are damaged by slid flats and other defects. Mileage between wheel truing varies widely depending on local conditions, but can be as frequent as several times annually. Wheel truing can either be performed using a wheel truing machine installed in a pit under a track in the shop (see **Figure 3-2**), or by removing the trucks or wheels from the vehicle and sending them to an outside facility.

A wheel truing machine has a significant capital cost (approximately \$1.6M for equipment only if included in initial design and construction, more if retrofitting an existing facility), and will impact facility design, but allows the wheels to be trued without removing the trucks from under the vehicle. Removal of the trucks or wheels from the vehicle is labor intensive and will keep a vehicle out of service until these parts are replaced and reassembled. This process would be further complicated for 100 percent low-floor vehicles, which typically have traction motors and gearboxes located outboard of the wheels. Exchanging in spare trucks will reduce the time the vehicle is out of service, but the process is still very labor intensive and the spare trucks themselves have a significant capital cost. As fleet size grows (typically beyond about 12 vehicles, but this number could be smaller depending on local conditions) using a wheel-truing machine generally becomes the more cost-effective approach.

Figure 3-2: Wheel Truing Machines



In-ground wheel truing machine at Portland Streetcar permits truing wheels without removing the trucks from under the vehicle (left). An alternative to using a wheel truing machine is extracting the trucks from under the vehicle and removing the wheel tires so that they can be machined separately (right).

3.3 Facility Layout

Site layout is critical to the function and efficiency of the O&M facility. Layout should consider transit vehicle access from the revenue line, as well as street access for support functions, deliveries, and staff. Layout is often affected by the amount and shape of available land. Facilities in denser environments often suffer from a less efficient layout due to space constraints. Sites

Philadelphia Sharing of Maintenance Facilities and Equipment

The Southeastern Pennsylvania Transportation Authority (SEPTA) has three physically isolated rail divisions (City Transit, Suburban Transit, and Regional Rail). However, storage yards and maintenance facilities are shared among modes at the 69th Street Terminal and Fern Rock maintenance facilities.

The Suburban Division's trolley maintenance facility and the City Division's Market-Frankford subway facility are co-located at the 69th Street Terminal. Different vehicle sizes and power sources segregate some aspects of the facility, but there is sharing of common areas. At the Regional Rail shops at Fern Rock, wheel truing for both the regional rail and trolley are performed with trolley wheel sets delivered to the facility by truck.

Parts for signaling equipment are shared between the divisions when possible, although union work rules prohibit a sharing of workforces.

located in less dense environments can benefit from larger, more efficient designs with the availability of more land.

Key considerations for facility layout include:

- Access for vehicles to move in and out of the facility quickly and safely, and to be easily moved between tracks.
- Work flow through the facility must be understood and incorporated into the design. Longer-term work must not interfere with daily inspection / pull-in / pull-out.
- Secure storage space for all vehicles must be provided during the hours the system is not in operation. Local climatic conditions will influence whether outdoor or covered storage will be needed.
- Vehicle length (both startup and future) is a major factor in facility layout. Also, work areas should accommodate the maximum vehicle width, with ample space for maintenance activities and equipment.

Additional considerations for facility layout, including required equipment, are described below.

Figure 3-3: Portland Streetcar Shop and MTA's Baltimore Light Rail Facility



Streetcar on trestle pit in Portland with roof access platforms and mezzanine level above and overhead crane in background (left). An overhead crane is used to transfer components from the vehicle roof to the adjacent mezzanine level work area in Baltimore (right).

Inspection and Access

- Inspection pits permit convenient access to underbody and running gear without lifting the vehicle. There are two basic types of inspection pits:
 - Gauge pits are located between the running rails, with solid floor areas on either side, and are compatible with the use of portable lifting jacks.
 - Trestle pits are an open area with rails located on “trestles” (beams and piers) permitting access between the rails and alongside, and are generally not compatible with the use of portable lifting jacks.

- Roof inspection platforms allow for workers to access the vehicle roof, since most of the equipment on a low-floor vehicle is located on the top of the vehicle. A mezzanine level work area is often located immediately adjacent to the roof inspection platforms.

Lifting and Moving

- Vehicle lifts, which can either be permanent (in-ground) or portable.
- Overhead crane to lift truck assembly as well as roof-mounted components.
- Jib crane to support component break-down and build-up (e.g. trucks).
- Forklift
- Truck turntable for removal or replacement of truck assembly.

Cleaning

- Parts washing equipment
- Vehicle wash, which is either automated or manual.

Component Repair / Minor Accident Damage

- Parts storage
- Work areas with appropriate tools
- Space to work next to the vehicle
- Spot painting equipment
- Open floor space work area for larger component repair jobs (trucks)
- Basic metalworking and welding equipment and related shop machinery

3.4 Traction Electrification

For safety reasons, the track in the O&M facility is typically electrically grounded, whereas on the rest of the alignment it is “floating”. Track and overhead contact system (OCS) within the facility is separated from the rest of the system with insulated joints and section insulators. Consequently, a separate traction power substation is provided for the facility. The OCS inside the building typically provides a means for de-energizing each track individually, with visual display of status. The separate power supply also permits the O&M facility to continue functioning even when other sections of the traction electrification system may be shut off for maintenance. Vehicles using on-board power sources such as batteries may require specific additional equipment.

3.5 Other Facility Functions: Crew Base, Training, Administration

In addition to maintenance and operating personnel, other job functions associated with system operations and maintenance

Portland Sharing of Maintenance Services and Staff

In Portland, the LRT and streetcar systems share maintenance services and staff, despite being operated by different agencies and maintaining separate guideways. Portland Streetcar is not operated by the region’s transit system (Tri-Met), but rather by a non-profit entity that uses Tri-Met operating and maintenance personnel under contract.

Wheel truing for streetcars was originally performed at a TriMet facility; however, a streetcar maintenance facility expansion project in 2011 included a wheel truing machine. Since placing the wheel-truing machine in operation, Portland Streetcar has turned wheels for Seattle Streetcar, which shipped entire truck assemblies to their facility.

The streetcar’s initial operating segment included a track connection to the light rail system and was originally planned to operate streetcar vehicles along that connection to access the light rail maintenance facility for wheel truing. However, various institutional and capacity issues prevented this from happening and instead Portland Streetcar instituted the practice of removing the trucks from under the streetcars and sending them to the light rail maintenance facility.

New Jersey (Statewide) Contracted Services

NJ TRANSIT operations and maintenance are performed by both NJ Transit's unionized personnel and private contractors. The legacy Newark Light Rail line (the former Newark City Subway line) is maintained with the agency's own unionized personnel. The recently added Hudson-Bergen Light Rail and the River Line service were built under a design-build-operate-maintain approach for both of these new lines, and as a result are operated under a private outside contractor.

may be co-located in the facility. These include management, communications, and maintenance-of-way staff. Employee accommodations typically include restrooms, locker rooms, break / lunchrooms, meeting rooms, offices, and space for employee vehicle parking.

The facility may also serve as a base of operations for crews maintaining track and overhead wire. Where these functions are also co-located, space is required for service trucks and storage of large items such as rail, other track materials, poles, and reels of wire.

4.0 Power Supply

The term “power supply” is used to refer to the various components comprising the Traction Electrification System (TES) and related apparatus on the vehicle. The TES provides electrical power to the vehicles by means of the Traction Power System (TPS) (substations and related connections) and the Overhead Contact System (OCS) (overhead wires and related support structures).

Commonality among vehicle power supply is an important element of interoperability. Key issues include operating voltage and type of power supply. Of the three types of power supply, OCS is the traditional method used for LRT and streetcar vehicles. However, many vehicles can now be equipped with short range¹ (<0.5 mile) off-wire capabilities and it is likely that future vehicles will have extended off-wire range capabilities. Off-wire capabilities allow the vehicle to be powered using on-board energy storage for a portion of the route. A third power supply category is “ground level”, where vehicles operate along all or a portion of the alignment using a ground contact system.

The issue of operating streetcars without the use of overhead wire is particularly relevant within the District of Columbia, where existing legislation from 1888-89 specifically prohibited overhead wires in the federal city. In 2010, the city council passed a bill that modified the original legislation to allow overhead wires along the planned H Street line, which is set to begin operations in 2013. The legislation also required that DDOT procure vehicles that are capable of operating for up to a mile without overhead wires for new streetcar segments beyond H Street/Benning Road Phase II.

Without compatible power supply systems, LRT and streetcar lines that operate in close geographic proximity would not be able to share trackage for revenue or non-revenue operations.

4.1 Traction Power/OCS Standardization

There are three common operating voltages for traction power in streetcar and light rail - 600, 750, and 1,500 volts DC - with 750 volts being the most common for new systems. If sharing of trackage is expected, interfacing systems will need commonality among operating voltages (or additional equipment on the vehicles to convert between voltages). It is assumed that the region will adopt the most commonly used 750VDC operating voltage as its standard. It is further assumed that all vehicles would use the same basic pantograph dimensions.

¹ “Short range”, as distinguished from “emergency” off-wire operating capability intended for permitting a vehicle to clear an intersection in the event of a power failure or make other very short moves “off wire”.

San Francisco Vehicle Power Supply Interoperability

Streetcar and light rail operations within the City of San Francisco are designed such that certain portions of the system’s infrastructure and facilities are compatible with multiple vehicle types. It is an example of a “legacy” system which has continuously operated successive generations of light rail technology, operating an extensive



fleet of heritage streetcars along with modern LRVs.

The track and overhead power on a significant portion of the light rail system are compatible with both heritage streetcars and modern LRVs. The large fleet of heritage streetcars all use trolley poles, and the LRVs use pantographs. The overhead wire is compatible with both, made possible through compatible design criteria and construction techniques.

Kinkisharyo ameriTram Vehicle

In 2011, carbuilder Kinkisharyo began marketing the ameriTRAM, a prototype streetcar vehicle with extended off-wire capabilities specifically for the US market. The vehicle highlights some of the trade-offs involved with off-wire capabilities, in this case the



batteries limit the space available for doorways. The lithium-ion batteries are arranged along the floor line on both sides of the center section, occupying the space underneath the longitudinal seating along both walls. Each side of the vehicle thus has only two doorways, one double-width in the center section and one single-width on an end section.

Based on the J-Tram design for Hiroshima, the 100% low-floor, three-section ameriTRAM prototype is 66 feet (20m) long and 8 feet-8.5 inches (2.65m) wide. The relatively short length is compatible with the other modern streetcar designs now operating in the US. Longer five and seven-section lengths are also offered.

A TES is designed with consideration of a line's track plan and profile, operating plan, climatic conditions, and the specific vehicles to be used. The number of traction power substations, their size, and locations are determined accordingly. The system is designed to maintain voltage within a specified range over the entire alignment under all operating conditions. Computer simulations are typically used to model different operating scenarios (including operation with one or more substations out of service) and confirm design assumptions.

Implementing power supply compatibility will be most effective if done in the design stage; retrofitting a built system to match that of another will not be practical. Adopting common design criteria for the TES will also facilitate potential joint purchase of components and spare parts, and simplify ongoing maintenance of the different systems. In addition to operating voltage, specific areas which should be considered for regional standardization include:

- Pantograph Dimensions- Using IEEE Standard P1629 (Standard for Performance of DC Overhead Current Collectors for Rail Transit Vehicles) as a guide, key pantograph dimensions and operating parameters can be standardized or a compatible range of values established.
- Overhead Contact System (OCS) Styles- OCS style refers to the general configuration of the conductor wires and the way in which the wires are tensioned. OCS can be implemented in a number of different ways, ranging from "single contact wire fixed tension" to "auto-tensioned catenary". Different styles have different suitability for various applications and each involve a series of trade-offs between strength, cost, current-carrying capacity and aesthetics. Regional agreement could be established on limiting the number of different styles while still providing enough choices to meet a range of applications.
- OCS Components- reaching regional agreement on a catalog of component types to be used in system design could provide a means of facilitating potential joint purchase of components and spare parts, and simplify ongoing maintenance of the different systems. Maximum incorporation of industry standard components and minimizing the need for custom parts would be an overall goal.

In addition, the potential exists for coordination of joint purchasing agreements of energy with regional utility suppliers. Energy costs are a significant component of overall operating costs. Lower energy rates among LRT and streetcar systems are possible if energy is purchased in bulk or from a common provider, although this is dependent on the legal capabilities of coordinating transit agencies.

4.2 Off-Wire Capability

OCS is currently the most common and reliable system used for streetcar power supply. It has the advantage of more than 120 years of industry experience, but new technology is now offering additional options. Technology advances driven by the need for energy savings, combined with the desire to eliminate the visual impact of overhead wires in certain areas, have led the industry to develop “off-wire capable” vehicles. This term refers to a vehicle which can operate in revenue service using traditional OCS and also over line segments which have no overhead wire. The elimination of wires may be desired for a number of reasons, including aesthetic concerns in a historically sensitive area, simplifying a complicated junction or other wire arrangement, or to permit an alignment to pass under a restricted vertical clearance such as a low bridge.

Off-wire operation is accomplished through some form of energy storage or on-board generation. Batteries and super-capacitors are the most common sources for on-board energy storage, and are recharged enroute by capturing the energy generated during the vehicle braking cycle and while the vehicle is operating under the OCS or other powered alignment sections. Stationary “charging stations” are also used, typically in conjunction with station locations where vehicles will be stopped anyway. Systems using flywheel energy storage are also being tested.

A vehicle’s off-wire “range” will depend not only on the specific technology employed, but also the characteristics of the particular route. Operating conditions, grades and climatic conditions will thus have a significant influence on vehicle range and the longevity of energy storage components. The “holy grail” for an off-wire capable vehicle is to have enough range to permit an entire line to be constructed without overhead wires (or other external power sources), other than where necessary for charging purposes.

Cost issues are also frequently cited in conjunction with off-wire capabilities. Capital and maintenance cost savings will of course be realized for line segments where there is no OCS. However, while infrastructure may be made less costly to build and maintain, the opposite will happen to the vehicle; it will become heavier (how much heavier depends on the type of energy storage equipment used) and more costly to purchase and maintain versus a conventionally powered vehicle.

In summary, it is important to make comparisons on the basis of life-cycle cost, incorporating consideration of the cost of consumable energy-storage devices (e.g. batteries) over the life of the vehicle. A thorough operational analysis should also be made,

Alstom Citadis Vehicle in Nice, France

In 2007, Nice, France opened a new 5.4 mile tramway (streetcar) line. The line passes through two historic city squares, where conventional OCS was considered to be unsuitable. It was also desired to permit unimpeded passage of parade floats through these squares



during the annual Nice Carnival. Use of a ground-level power

supply system, an approach used successfully in other French cities, was originally considered, yet the relatively short distances for off-wire operation (0.27 and 0.3 miles), led to the decision to use on-board battery power.

The city commissioned twenty Alstom Citadis vehicles equipped with nickel metal hydride batteries for the off-wire operation. The relatively long sections of conventional OCS on the line provide for ample charging time. Now approaching five years of service, this pioneering application of on-board energy storage may be able to provide some very useful information regarding real-world application of this technology.

Savannah Hybrid Streetcar

In 2008, Savannah debuted a short one mile demonstrator streetcar line using a heritage trolley converted for “hybrid” propulsion, which supplements its energy storage capabilities with on-board electrical generator. The line uses part of an existing single track rail line and has no overhead wire. This variation of the off-wire capable vehicle is



powered by super-capacitors (no batteries are used),

while a pair of small bio-fuel recreational vehicle generators run continuously and keep the banks of super-capacitors charged.

Operating speeds are very low, and the tourist nature of the line does not place any heavy schedule demands on the vehicle. The vehicle is not air conditioned, and incorporates a bus-type lift to accommodate wheelchairs. The concept of the “hybrid” vehicle holds promise for application to other vehicle types, although power demands for a modern high-performance vehicle would be significantly different.

taking into account vehicle range and charging times, to determine whether or not extra vehicles might be required to maintain the desired headway and schedule.

The energy storage technologies involved with off-wire propulsion are also evolving very rapidly, and so the costs and capabilities of different solutions are constantly changing with the goal of expanding the power and range of storage devices while reducing weight and size. While it does seem certain that off-wire capable vehicles will be common in the future, interfacing agencies should consider selection of a power system that is interoperable between systems, and one that is upgradeable with future technological advancements. Vehicles without off-wire capability will not be able to operate in-service over sections of line that do not have OCS. Depending upon the equipment and infrastructure required for re-charging of energy storage devices, transit systems using different onboard energy storage technologies could be compatible or interoperable.

4.3 Ground Level Power Systems

Ground level power systems are external to the vehicle and require specialized infrastructure and vehicle equipment. The system uses a power rail or induction coil system located between the running rails and electrified only when a vehicle is present.

Figure 4-1:
Ground Level Power Supply in Europe



Bordeaux, France makes extensive use of ground-level power supply through many historic districts. Note the power rail between the running rails. Similar to the District of Columbia, portions of the original streetcar system in Bordeaux used conduit operation until abandonment in the 1960s.

Ground-level systems effectively take the traditional overhead power source and locate it on the ground instead. It can be provided as either a contact or a contactless system. In a contact system, a pickup shoe rides along the surface of the contact rail. In a contactless system, a magnetic field is used to inductively transfer power from the guideway to pick-up coils beneath the vehicle.

Debuted in 2003, the typical application of this technology to date has been to portions of a system otherwise equipped with traditional OCS, although the first system designed to use only ground-level power supply is now being built in Dubai. Ground-level power is also being considered for use in charging off-wire capable vehicles.

Ground-level power systems are costly and highly proprietary, with vehicles and guideway sourced together as a system from a single supplier. Ground-level systems typically require significantly more challenging track engineering, particularly when special trackwork is involved. Although there are systems that have proven themselves in Europe, none have even been seriously considered for use in the United States. It should be anticipated that such a system will also require a significantly more substantial safety certification effort than a traditional wired system, particularly for the first such application in the country. Project sponsors must therefore weigh the costs and risks associated with the use of a sole-source system.



5.0 Guideway Design

The streetcar and light rail transit modes are fundamentally very similar, with the primary differences being the scale of vehicles and infrastructure and the way in which they are integrated into the urban environment. In terms of guideway design, streetcar alignments are usually located primarily within the street (either in mixed traffic or in segregated lanes), whereas light rail is more likely to use a mix of mostly exclusive or semi-exclusive right-of-way and some in-street operation (typically in segregated lanes only). Embedded track guideway design for both modes is fundamentally very similar and in most cases design criteria for light rail would readily accommodate streetcar operation over the same route, provided that the wheel / rail and vehicle/platform interface was compatible. The reverse might not be true in some cases however; streetcar alignments must typically follow existing roadways through constrained urban areas and this frequently requires tighter track geometry and clearances than would typically be found on a North American light rail system.

In general, the major interoperability opportunity for guideway design is the creation of compatible, or potentially even standardized, design criteria within the region. This approach would help control costs and could be used to permit interoperation of vehicles. Such interoperation might only be conducted for purposes of sharing a common maintenance facility, or some limited sharing of a route segment or terminal might take place where lines are geographically adjacent. Opportunities to use common track components also exist, which could be part of a general strategy within the region to reduce capital and maintenance costs by limiting the number of component types and manufacturers for both track and traction power equipment.

5.1 Route Geometry

Streetcar alignments frequently require tighter track geometry and clearances than are typically found on a North American light rail system. Typical minimum horizontal curve radius for light rail systems varies by the type of right-of-way. In-street criteria for light rail horizontal curves typically specify 82 feet as absolute minimum, with 100 to 150 feet as desirable minimum. Streetcar curves are frequently tighter, particularly on legacy systems. Streetcar vehicle manufacturers have structured their modular streetcar product lines for a minimum horizontal curve radius of between 59 and 82 feet (18-25m), while most light rail vehicles are designed for 82 feet (25m) minimum.

Figure 5-1: Track Geometry



Streetcar systems are well known for compact track layouts. “Ladder” tracks leading into storage yard in San Francisco (left). A streetcar turns an urban street corner in Toronto; note the abundance of in-street special trackwork (right).

The *APTA Streetcar Guideline* advises that it is important to strike a balance between unnecessarily restrictive design criteria (e.g., curve radius requirements) and adherence to recommended limits as a means of limiting risk that features might be built into the infrastructure design which limit compatibility with standard vehicle designs. The use of extreme design values, while sometimes necessary, must be balanced against long-term costs for track and wheel maintenance as well as noise, operating speed, passenger comfort, and compatibility with standard vehicle designs. The *Guideline* emphasizes that utilizing minimum and maximum design criteria should always be done thoughtfully, and in the context of a system approach that considers the vehicles to be used and balances operational benefits with the related tradeoffs. This advice is especially relevant in the context of regional interoperability.

5.2 Track Design Criteria

There are two basic types of rail, “tee” rail and “grooved” (or “girder”) rail. A particular type of grooved rail known as “block” rail is also being introduced and has special implications. See **Figure 5-2** for the different rail types.

“Tee” rail is manufactured in the US, Europe, and Asia and is the most readily available and commonly used type of rail. It comes in different sizes, although 115RE is the most common for US light rail and streetcar projects. It can be used for both open (ballasted) and embedded track. For use in embedded track, some means of maintaining a suitable flangeway opening in the infill paving must

Figure 5-2: Rail Types

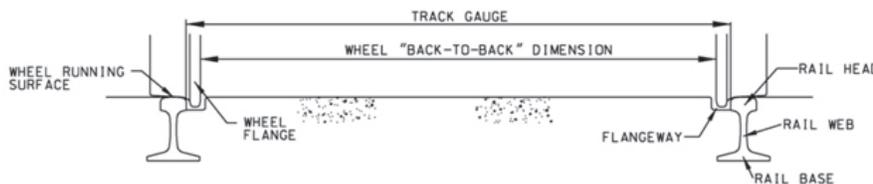


Left to right: Tee rail (with rubber boot), girder rail (with rubber boot), the two sections aligned together (note that the heads line up but the webs and bases do not), and block rail.

be employed. See **Figure 5-3** for a tee-rail application in embedded track. In concrete, a formed flangeway can be used, but asphalt and other less rigid paving infills will require the use of a separate flangeway guard. Turnouts and other special trackwork for use in open track are readily available, but are not well suited for use in embedded track applications. Tee rail special trackwork specifically designed for embedded track application is gradually becoming more readily available.

Grooved rail (or girder rail) is manufactured only in Europe and Asia, having disappeared from North American production several decades ago. Grooved rail is specifically designed for use in embedded trackwork applications and incorporates a built-in flangeway. This feature permits the use of a smaller flangeway than with tee rail, a significant advantage in the street environment where compatibility with pedestrians, wheelchairs and bicycles is required. The built-in flangeway also aids in constructability, as pavement may be poured or installed up against the flangeway portion of the rail. Grooved rail is available in numerous different sections, with compatible turnouts and other special trackwork readily available. Grooved rail has been used on numerous US light rail and streetcar projects, and is used extensively on European tramway systems.

Figure 5-3: Typical Tee-Rail Application in Embedded Track



In 2011, the FTA announced that it would no longer grant Buy America waivers for procurement of imported girder rail, and no domestic mill has been willing to begin production. In 2011, one supplier began suggesting block rail as an alternative to traditional girder rail. Block rail is a shallow section grooved rail with a rail head and flangeway section comparable to 51R1 girder rail.

Additional Track Design Considerations Relevant to Interoperability

- It may be desirable to accept that track geometry and wayside clearances may effectively segregate certain modes/ lines.
- Decide whether to use single or two-point contact for curving. Both approaches can work, but it is important to pick one approach and stick with it. The selected approach must be clearly communicated in the vehicle procurement process. Explore thoroughly the implications of horizontal and vertical curves, especially combined, and the resulting track twist.
- Decision should be made on whether or not to use flange-bearing special work, and what the best “universal” flangeway openings and check rail gauges are.
- Promote vehicle compatibility with both special trackwork and any girder/groove rail sections by adopting common wheel gauge standards (including both gauge freeplay and back-to-back dimensions), along with compatible wheel profile elements (including uniform flange height and width).
- Limit number of rail sections used in the region and ensure they are compatible with selected back to back wheel spacing and profile. Suggested starting point is 115RE tee rail and 51R1 and 59R2 grooved rail, (both of which have the same head profile as the American-made 112TRAM block rail section).
- Ensure special trackwork is compatible with being embedded in pavement from the standpoints of performance, maintenance and safety.

Portland Streetcar has installed a short section of it on an extension constructed in 2011 as a test. Without an FTA waiver for importing girder rail, other projects are moving ahead using tee rail.

It is common to find both tee and grooved type rails used on the same system, although most commonly with the tee rail used exclusively on open track. Joining together different rail sections creates numerous construction and maintenance issues. Where multiple sections are used on the same system, the design goal is to keep the number to a minimum, and minimize dissimilarities in the head and flange section.

5.3 System Approach to Wheel/Rail Interface

Wheel/rail interface is a key consideration in guideway design. Significant long-ranging benefits will result from a coordinated approach within the region to wheel/rail interface, which typically includes adopting common wheel gauge standards (including both gauge freeplay and back-to-back wheel dimension), along with compatible wheel profile elements (including uniform flange height and width) for all systems, and a limited number of compatible rail sections. Partial benefits include cost savings resulting from reduced wear on both wheels and rail, improved ride quality and lower noise, and reduction in the number of derailments. To achieve this, track and vehicle designers need to be working together and across systems to ensure a compatible interface.

TCRP Report 155, Track Design Handbook for Light Rail (the revised version of Report 57, to be released in 2012) provides detailed information on wheel design and selection for transit use. It also offers a candidate wheel profile that can serve as the starting point for development of a standardized wheel profile (see **Figure 5-4**). The profile is compatible with “tee rail” as well as with 51R1 and 59R1 girder rail sections. In some cases, specific vehicle configuration might require consideration of minor modifications to a common regional wheel profile. Chapter 12 in the AREMA Manual of Railway Engineering also has information on both alignment criteria and rail sections.

Because replacement of rail in embedded track is especially disruptive to both transit operations and the community in general, maintenance is especially important. Active management of the wheel / rail interface through a coordinated program of inspection and maintenance is the key to maximizing the life of both components as they wear over time (see **Figure 5-5**). Wheels must be regularly inspected to detect problems which can affect ride quality and safety against derailment, and periodically re-profiled on a wheel lathe. Rail, although it wears at a much slower rate than wheels, must be similarly inspected and re-profiled when required.

Charlotte Streetcar Utility Rules of Practice

As part of the City of Charlotte's preliminary streetcar design process, the city developed a comprehensive Utility Rules of Practice document that creates a planning and design guideline for both public and private utilities. The document sets forth protocols for how to identify and address conflicts between utilities and the streetcar system and establishes guidelines for several categories of utility infrastructure including water, sanitary sewer, and storm water. For each category, the streetcar "zone of influence" is established, followed by practice for access and crossings under the track. A range of conditions is established in each category along with recommended resolutions. The document does not address financial responsibility or stray current and corrosion control.

that access will be possible without impacting rail operations. The potential for damage to metallic infrastructure due to stray-current corrosion also impacts the utility relocation discussion. Nationwide, because of wide variation in the condition (or even knowledge of precise location) of sub-surface utilities, and the issue of upgrades, relocation costs can be difficult to estimate and budget. Exacerbating the situation is the variation in utility owner and transit agency familiarity with stray-current issues, and differing levels of agreement and legislation governing when relocation is necessary and who should pay. At present, similar utility relocation scenarios might be handled entirely differently in different parts of the country.

For these reasons, utility protection and relocation typically represent a major portion of streetcar and light rail project costs with a corresponding need for a high percentage of contingency in the project budget. As an interoperability issue, the region could explore the development of a standard "code of practice" with regard to utility protection and relocation. By developing guidelines to manage how the region's planned streetcar and light rail systems will interface with existing utility systems, significant project cost and time savings could result. Simply having agreement on the definition of the streetcar guideway's "zone of influence" on various categories of utilities could provide important time and cost savings to all parties.

On a related subject, DDOT has also discussed the concept of "Streetcar-Ready Streets", wherein streets identified as future streetcar corridors would be subject to streetcar-compatible design criteria during all infrastructure projects. Street improvements, utility installation and upgrade, and similar public works would be done in a manner that would not preclude future streetcar installation or create unnecessary infrastructure rework.

6.0 Fare Collection Systems

Fare collection approaches among the Washington, DC area streetcar and LRT systems are at varying stages of planning and implementation. If the region's rail transit providers can agree early on standard fare technology, equipment, protocols, and regulations, several significant benefits could result:

- Commonality among fare collection systems and protocols provides easier experience for users of the transit system, and can lead to increased patronage and revenue and potential cost savings for operators.
- Obtaining common fare collection logic, equipment, technical support, and maintenance would lead to economies of scale during procurement and throughout operations.
- Resolving technological bugs for one system, as opposed to many systems, could be significantly less labor-intensive.
- Setting common standards for fare collection enforcement would potentially reduce fare evasion.

Worldwide, there are two general approaches for streetcar and LRT fare collection: pay-on-entry/operator-collected fares and proof-of-payment fares. Pay-on-entry/ operator-collected fares requires each passenger to provide payment when boarding. This method is typical of bus systems, with fareboxes located next to the operator at the entry door. Some U.S. legacy streetcar systems, like New Orleans, use this system, and some modern European and Australian systems use a similar conductor collected system. Proof-of-payment (POP) is the most common fare collection method used on the world's light rail and streetcar systems and is used by all new streetcar and LRT projects. POP fare collection requires each passenger to carry a valid ticket or pass proving that they have paid the appropriate fare. Ticket inspectors make periodic checks to deter fare evasion. Low-floor streetcars and LRVs almost universally use POP systems (or conductors in some European cities), maximizing the benefits of multiple doorways and stepless entry, with an accompanying positive impact on dwell time (See Figure 6-1).

With fare collection, the level of expected user benefits and fare revenue must be balanced against the costs of installing and maintaining equipment and enforcing payment. This tradeoff also relates to the expected rate of fare compliance. Additional useful information on this topic can be found in the recently released TCRP Synthesis 96, *Off-Board Fare Payment Using POP Verification*.

Maryland Transit Administration's Charmcard

In September 2010, the Maryland Transit Administration (MTA) implemented electronic fare media called the CharmCard for use on the Baltimore LRT, HRT, and bus system, with direct compatibility with WMATA's SmarTrip Card. The new CharmCard system allows for greater payment flexibility as the card is ISO 14443 compliant and will function with an open payment system. Fares can be loaded on



MTA's Charmcard

CharmCards at Ticket Vending Machines (TVM) and paid with

either cash or credit card. In the future, CharmCard will allow automatic reloading through links to credit cards or bank accounts.

Handheld validation units are used by fare enforcement personnel to check payments using CharmCard. Smart phones are compatible with this electronic fare payment system and have the potential to read CharmCard, which could lead to a faster and more reliable validation.

Figure 6-1: Proof of Payment Vehicle Design



The new DC Streetcar vehicle illustrates why most modern streetcars are not designed for operator collected fares; The operator is in a cab that is isolated from the passenger area, and the adjacent passenger doorway is not in the low-floor part of the vehicle. Instead, there are two extra-wide door openings in the low-floor area, providing for smooth passenger flow on and off the vehicle, but not intended for passengers to pay a fare on entry.

6.1 Fare Media and User Interface

Current transit fares in the Washington DC area are primarily paid for in four ways: cash, credit or debit cards, paper farecards, and SmarTrip. Cash is accepted as direct payment only on Metrobus fareboxes. Cash and credit or debit cards are accepted at Metrorail vending machines, where passengers receive paper farecards or load money onto SmarTrip. SmarTrip is a contact-less stored-value smart card used for payment in all Metrorail stations (including parking fees at station lots), all Metrobuses, and nearly all other public transit systems in the Washington, DC area, including reciprocity with the CharmCard system in Baltimore. SmarTrip cards are designed to be permanent and reloadable, and fares using SmarTrip cards are 20 cents lower per trip on Metrobus, and 25 cents lower per trip on Metrorail. In April 2011, WMATA reported that SmarTrip makes up 79% of all Metrorail transactions. Within FY 2011, there has been a significant shift to SmarTrip for Metrobus transactions from 64% to 76%, primarily due to an increase in surcharges for using cash or paper fare media.

In 2010, WMATA announced that it was working on a replacement system for SmarTrip. The WMATA procurement of a new system-wide “open payment” fare collection system is advancing. This change will be a major factor in the evolution of fare payment systems region-wide across all modes. The timetable for implementing the new system will likely impact the decision-making process for new streetcar and light rail systems coming on line in the immediate future.

Planned WMATA Fare System (NEPP)

“Open payment” systems based on industry standards are expected to be the norm in a few years. Open payment systems are generally envisioned to accept a wide variety of ISO-standards based fare media such as contactless transit cards, contactless

bank cards, mobile phones, identity credentials and other emerging payment options. It is important to note that an open payment system can accommodate the diverse needs of an agency's customers, and such systems are not limited only to those with credit cards or smartphones.

Current contactless bank cards include Visa's payWave, MasterCard's PayPass, Discover's Zip, and American Express's ExpressPay. Contactless credit or debit cards and smart phones can be used to pay for numerous transactions, allowing customers to pay for transit in a manner similar to that used in their daily lives. In addition to accepting cards and devices issued by non-transit entities, the region will accept agency-issued smart cards and limited use smart media.

A major driver in the move toward open payment systems is the desire to minimize cash collection and to improve customer convenience with acceptance of contactless credit/ debit cards or smart phones for transit payments. Making this work requires a sound business plan with estimates of the risk and rewards for all parties.

WMATA plans to award an initial contract for pilot roll-out of the New Electronic Payments Program (NEPP) in mid 2012 and begin a pilot demonstration of the system in 2013. The two-year design cycle will culminate in system-wide start-up in 2014. The new system is planned to overlap with the current SmarTrip as regional transit operators migrate to the open payment system. The ongoing use of the SmarTrip Card will use a new microchip that contains the existing proprietary technology (provided by Cubic Transportation Systems) that will be sold in new cards in 2012. Any LRT and streetcar projects expected to be operational within 7-8 years should anticipate the opportunity to use the new technology and could consider use of the current SmarTrip technology as well.

Along with traditional fare collection systems (fareboxes, vending machines), NEPP will also be supported by a media distribution and reload network where customers purchase regional fare media, add value or purchase fare products from approved vendors and a web based account management and sales application where customers can manage their accounts on-line. With implementation of the new fare payment system, new smart cards and fare vending will be ubiquitous, available at local locations such as drug stores and newsstands, accessible through smart phone applications and through the internet.

The proposed fare payment architecture is envisioned to be adaptable to the needs and desires of the streetcar and LRT project sponsors, within the framework provided under the ongoing fare payment procurement.

New York City BRT Off-Board Fare Collection

New York City's Select Bus Service (SBS) corridors use fare vending machines through adapted 'pay and display' parking meters that sell time-limited receipts for proof-of-payment (TIs). Riders do not show the receipt to the driver and only produce it upon request of a NYCT



Fare collecting machines at SBS stop.

fare inspector. The off-board fare collection has been successful. On one existing route, the pre-SBS fare evasion level was 13%. Post-implementation, the fare evasion levels fell to 6.1%. In Manhattan, the fare evasion rate pre-SBS implementation for a route was already low at 6.4% and fell even lower to 4.2% after implementation.

6.2 Fare Vending

Fare vending is the process of passengers paying for trips and the manner in which the transit system manages and receives those payments. Fare vending revolves around a transaction involving cash or the refilling of electronic fare media through cash or a debit/credit card. The fare vending machines which are used for these transactions fall into two basic categories depending on whether they are located on the platform (TVMs or "Ticket Vending Machines") or on the vehicle (OTMs or "On Board Ticket Machines").

TVMs are the most popular type of fare vending for streetcar and LRT systems and are planned to be procured through NEPP. TVMs are a mature technology which is generally reliable and requires little maintenance, with paper jams and coin jams being the most common maintenance needs. Cash transactions and paper tickets are important for occasional users such as tourists and users without credit cards. Although TVMs allow for full-service vending and validation, they are expensive and may invite vandalism. In some cases they may only be installed at selected high-volume stations. Another alternative is the use of simpler ticket issuers (TIs), which allow single payment cash and card transactions and distribute paper tickets. TIs are similar to proof of payment parking machines, which are less expensive than traditional TVMs, but have fewer capabilities.

On-board ticket machines (OTMs) allow tickets to be purchased on board the vehicle while still permitting all-door boarding. OTMs do not require NEPP fare vending capabilities and are planned to be procured outside of the NEPP. OTMs are similar to TIs except that OTMs are typically used where proof-of-payment systems are deployed. Unlike the farebox on a bus, the OTM(s) are not located adjacent to the vehicle operator, but are placed somewhere in the low-floor section of the vehicle. OTMs are typically less expensive and less robust than traditional TVMs, but occupy space that could otherwise be used by passengers. Their use may also create passenger bottlenecks during crowded conditions, making them hard to access and generally slowing passenger flow through the vehicle. Their locations within the vehicle must therefore be carefully thought out.

Across the country, there is little standardization of TVM/OTM design as each transit agency tends to seek customization, which tends to increase unit cost and reduce economies of scale. Although standardization is rare, building systems with

open payment capabilities is feasible, especially with the NEPP procurement. In the future, fare vending would be more like open payment systems by being integrated with other transactions widely available in stores, on the internet, and other non-transit outlets. A feasible solution to fare vending is to accept a common open payment system with similar equipment and similar cash transaction capabilities across all the DC area transit systems through the options available under NEPP.

6.3 Fare Validation

Fare validation is the process of “activating” fare media, whether the passenger has just purchased a ticket or is using a card with stored value. This is accomplished either by time-stamping of paper media or electronically deducting a “ride” from a stored value card. As with fare vending, there are two varieties of equipment: platform validators (PVs) or on-vehicle validators (OBPs, ‘on-board processor’), both of which are being procured through NEPP.

Both PVs and OBPs have the ability to validate cash, credit/debit card, smart card, and open payment media. Cash and debit/card payments typically receive a paper ticket/receipt or require paper media to be time stamped. Smart card payment can also receive paper verification (typically needed only upon request) or have electronic verification. Open payment media can go one step beyond smart card verification depending upon the media used for payment. For example, if a smart phone was used, verification could possibly be emailed or texted to the passenger.

Fare validation equipment is tied to the type of fare vending equipment available. PVs are only feasible with TVMs, while OBPs are feasible with both TVMs and OTMs. With PVs, typical LRT or streetcar stations have two platform validators per stop. With OBPs, a limited number of on-vehicle validators can be used, which could be under the control of the operator or fare inspector. OBPs are convenient for passengers who rush onto a train and do not have time for off-board validation. OBPs have some limitations, including occupying space that could otherwise be used by passengers. Also, there is the potential risk of passengers avoiding validation until a fare inspection person boards the vehicle. Washington DC area LRT and streetcar projects would be most compatible if they used the common NEPP validation equipment for fare card and open payment media and similar protocols in regards to paper validations.

Fare Evasion Enforcement on Existing Systems

The direction for fare payment on LRT, Streetcar, and BRT systems is towards a proof-of-payment system. Transit systems experience varying levels of fare evasion behavior and utilize a range of different approaches to address it. Some systems such as Houston and Charlotte use police to enforce fare adherence. New York MTA uses security personnel who can issue citations. New Jersey Transit (NJT) handles fare enforcement for all three LRT lines by a single staff group that rotates amongst



Portland TriMet Fare Inspectors

the system. Baltimore MTA fare inspectors do not have the legal standing to enforce citations. The Portland, OR system does not ticket people but requests that they exit trains at the next stop.

6.4 Fare Enforcement

The effectiveness of fare enforcement is dependent on the strength of the transit agency's regulations and the resources devoted to enforcement. No system will ever be able to maintain perfect enforcement, but proactive enforcement can deter fare evasion (See **Figure 6-2**). Depending upon the fare vending and validation system in place, fare evasion could become an issue. For example, fare evasion could be more prevalent with OBPs because passengers are able to validate tickets when they see fare inspectors (although the inspector could look at the time stamp or electronic validation), yet they allow passengers to board more quickly. Beyond the goal of setting consistent expectations for passengers regarding fare enforcement, it may not be necessary to coordinate enforcement among DC area transit systems.

Fare inspection involves checking a portion of riders for proper fare payment and validation. Fare inspection is typically performed by personnel assigned to be fare inspectors; the specific methodology and equipment they use is dependent upon the fare vending and validation equipment in use. Proof of payment can be completed in two ways: passengers can present their paper media/receipt, or electronic inspections can be completed by equipment known as handheld fare media processor (HFMP). HFMPs are being procured through NEPP. Although due to proprietary electronics, it may be costly to procure hand-held smart card validators.

Figure 6-2: Fare Evasion Deterrent



In Melbourne, the exterior of some streetcar vehicles have been turned into advertisements to deter fare evasion.

6.5 Examples of Fare Equipment

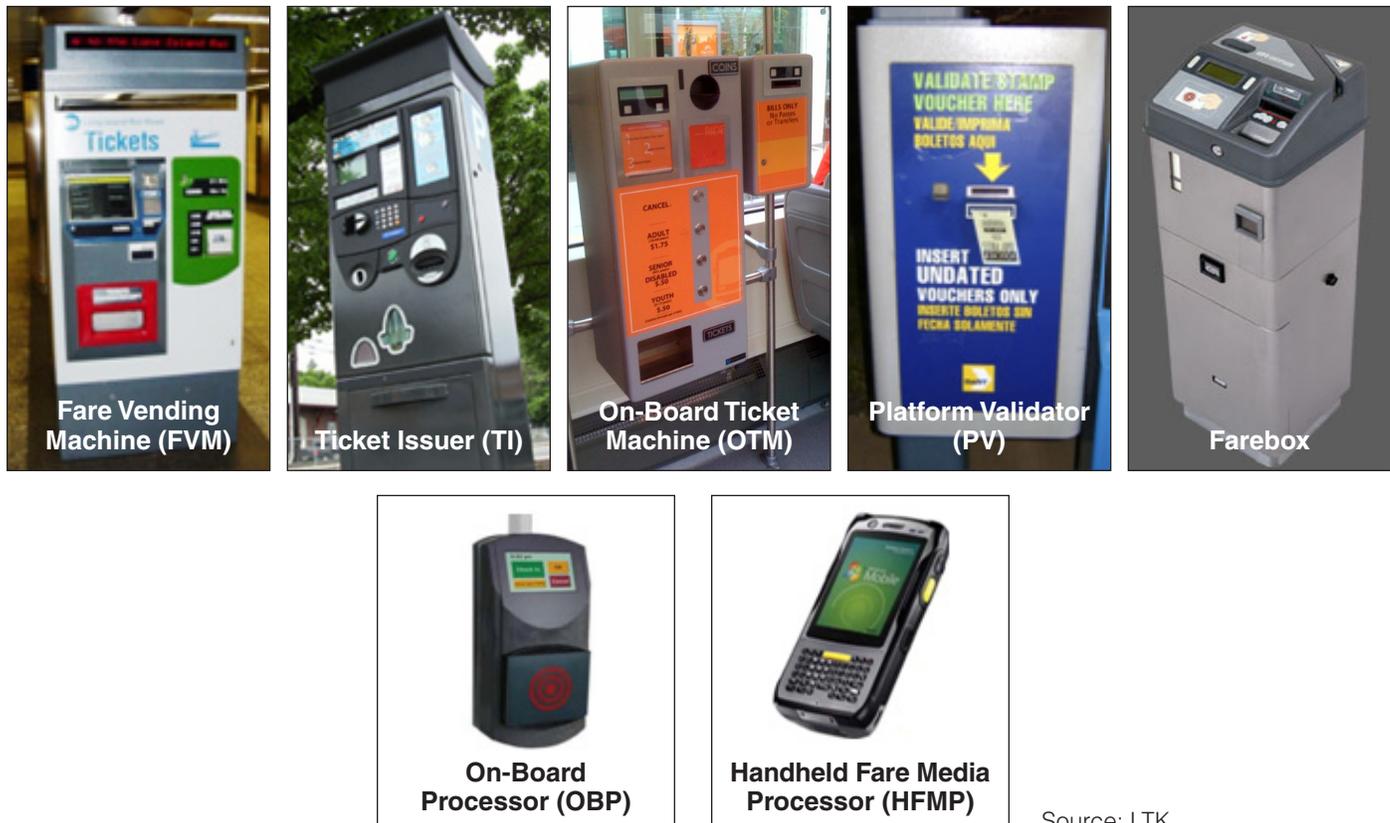
As highlighted in the previous sections, multiple possibilities of fare equipment exist for LRT and streetcar systems. Modern fare collection equipment is capable of a variety of functions in regards to fare media, user interface, vending, validation, and enforcement. Table 6-6 outlines the characteristics for the different fare equipment available, and whether or how they are included in NEPP. Figure 6-3 provides examples of the various types of fare equipment.

Table 6-1: Fare Equipment Characteristics

Equipment Type	Description	User Interface	Costs	NEPP
Fare Vending Machine (FVM/TVM)	Found on station platforms and can refill electronic fare media and accepts cash as payment.	ATM-style interface or touch screens.	Full Service: \$40,000 – \$65,000 Cashless: \$29,500 – \$50,000	Included
Ticket Issuer (TI)	Found on station platforms and accepts cash and cards for the sale of paper tickets.	Similar to proof of payment parking machines.	\$12,500 – \$17,000	Similar cashless option included; Ticket issuer could include NEPP OBP-like option.
On-Board Ticket Machine (OTM)	Found on vehicles and are used where Proof-of-Payment systems are deployed.	Small keypad and small visual display screen.	\$22,500 – \$30,000	Not required and procured outside of NEPP; could include NEPP OBP-like option.
Platform Validator (PV)	Activates and validates pre-sold fare media on the platform.	Small keypad and small visual display screen.	\$9,000 – \$13,000	Included
On-Board Processor (OBP)	Validates pre-sold smart card fare media on the vehicle.	Small visual display and audible tones. Validity displayed to the driver.	\$2,000 – \$4,500	Included (similar to On-Board Bus Payment Target)
Handheld Fare Media Processor (HFMP)	Portable devices used by inspectors to verify smart cards and magnetic fare media.	Touch screen or data entry keys for use by an operator.	\$150 – \$550 for a new smart phone and smart card processor.	Included
Farebox	Device normally installed on a vehicle that is used by passengers for any type of fare payment.	Inserted cash value or smart card balance is displayed to driver and passenger. Unit controlled by the driver.	Validating: \$10,000 – \$14,000 Registering: \$9,500 – \$11,500	Not required

Source: WMATA, LTK, AECOM

Figure 6-3: Examples of Fare Equipment



Source: LTK

6.6 Fare Equipment and NEPP

NEPP includes provisions for on-vehicle payment targets, cash and cashless fare vending machines, platform validators, and handheld devices for fare sales and enforcement. Based on the various equipment options available, several optional scenarios can be considered. The scenarios are primarily driven by fare vending and validation, with inspection as a secondary factor. The pros and cons of three possible scenarios are compared in **Table 6-2**.

Based on these scenarios, basic equipment at streetcar and LRT stations would include:

- Platform-located fare vending machines, with full-service machines located at selected streetcar or LRT stations.
- Platform-located validators, allows open payment customers to validate while others occupy the cash-enabled machines. The validator machines may dispense paper proof of payment to open payment user.
- Ticket Issuers, which would serve as supplements to platform fare vending machines and provide time stamped paper receipts as Proof-of-payment.

Other desirable equipment (possibly for longer-term implementation) on the placement of vehicles would include:

- On-vehicle fare vending machines, with capacity to dispense tickets and refill and validate open payment cards and transactions.

Table 6-2: Pros and Cons of Optional Scenarios

Proof-of-Payment Options	Description	Pros	Cons	Equipment
a) Off-vehicle fare vending and off-vehicle validation	Fare vending machines and open payment targets* at all stops; board at all doors.	Rapid boarding. Facilitates on-board fare inspection.	Highest capital and maintenance costs. No opportunity for late-arriving passengers to pay fare. Risk of fare machine vandalism.	Fare vending machines (Include ticket issuers if necessary) Platform validators
b) Off-vehicle fare vending and on-vehicle validation	Fare vending and validation machines at stops; passengers board at all doors; some on-board open payment targets*.	Provides greatest flexibility for all passengers.	On-board targets may facilitate fare evasion. Risk of fare machine vandalism.	Fare vending machines (Include ticket issuers if necessary) On-board processors
c) On-vehicle fare vending and on-vehicle validation	Board at all doors; open payment targets* at all doors; pay fare or fill card at on-board vending machine.	Lowest capital and maintenance costs. Reduced risk of fare machine vandalism.	Highest likelihood of fare evasion. Fare payment machine difficult to access on crowded vehicles.	On-board ticket machine On-board processors

*Note: Further discussion required regarding the efforts and timeframes of WMATA open payment system. Some open payment systems may need to incorporate SmarTrip capabilities.

DDOT Potential Streetcar Fare Collection Scenario

DDOT is initiating service on its H Street line in late 2012, and must decide how to make use of current technologies while anticipating future WMATA applications. As the agency most advanced on streetcar implementation, DDOT's decision may influence the decisions of other project sponsors. DDOT plans to collect fares for its initial operations. Riders will be able to use SmarTrip cards (possibly with paper validations) or paper tickets; validations and tickets would be dispensed at machines located at stops.

An off board fare collection infrastructure "lite" approach could be adopted to introduce passengers to portions of the full fare collection system. This approach would use less expensive Ticket Issuers (TI) as temporary machines. Vehicles could be ordered with capabilities to adapt to future installation of equipment such as on-board fare validation.



7.0 Passenger Information and User Interface

Like fare collection, passenger information and user interface is another important component for interoperability from a public perspective. By achieving commonalities in passenger information and user interface, there are potential benefits to both the transit system operations and the passenger experience. The reality that multiple agencies will operate different streetcars and LRT systems throughout the region should have little bearing on the passenger experience. The ability of riders to move seamlessly between systems will be a key component of customer satisfaction. Transit riders in the Washington DC area are already familiar with a ubiquitous Metrorail system and will expect a similar level of commonality in the regional LRT and streetcar system despite the jurisdictional differences.

7.1 Signage and Graphics

Signage and graphics are a key component of any transit system, serving as a marketing tool and allowing users to readily identify station locations. As various agencies in the region develop their own streetcar lines, unique signage, graphics, and livery may be developed, but some common attributes could also be used to help make all of the systems easier to use. Some commonalities that could be shared include developing regional, common graphics for streetcar and LRT systems that could be placed on regional maps, wayfinding signs, and other identification materials.

In the Washington, DC metropolitan area, the iconic Metrorail map has particular significance and utility. The new LRT and streetcar lines and stations could be incorporated into the regional map and station-specific maps for a greater sense of interconnectivity among services. Much like the ubiquitous 'H' for hospital, 'P' for parking, or 'M' for Metrorail, a common streetcar identifier symbol would help passengers identify streetcar and LRT stations (see **Figure 7-1** for examples). The consistent appearance of signage through common symbology standards allows passengers to easily distinguish transit signage from other types of signage, and to clearly and quickly understand the conveyed message. Symbol commonality could help passengers visualize individual transit systems as a unified system across the region. Since passengers respond better to a system name (i.e. 'Metro'), the local streetcar or LRT livery could be included or incorporated into the common system identifier.

In addition to developing common symbology, LRT and streetcar systems could develop regional wayfinding signage guidelines and standards. All transit systems must meet current ADA requirements in regards to signage and transportation. WMATA currently has a

Figure 7-1: Common Streetcar Signage



Developing common streetcar and LRT signage is important for passenger identification. Examples (from left to Right): Toronto, Seattle (2), Baltimore (top 2), Clermont-Ferrand, France, and Manchester, England.

Manual of Graphics Standards that includes signage standards at Metrorail stations in regards to sign placement, typeface, illumination requirements, and materials. In the San Francisco Bay Area, the Metropolitan Transportation Commission's Transit Connectivity Study includes signage guidelines on contrast and finish of signs, color coding, directional arrows, and message size. Message size is particularly important as viewing distance should determine the minimum character height. In general, every 1" of character height would equal readability from a 30' interval of distance, given adequate contrast and illumination. Developing a set of signage presentation guidelines and standards would help passengers navigate and understand the system, while also allowing for simplified maintenance opportunities.

7.2 Stop Design Criteria

Much like signage and graphics, stop design criteria make up an important aspect of user interface. Although stops are designed to handle specific operational aspects of a transit system, their look and format are an important part of how the passenger interacts with the system. For example, most transit riders in the DC area are familiar with the WMATA 'M' logo. Yet just as important are the similar station design and amenities available at all Metrorail stations. Passengers can easily identify the Metrorail stations since they all maintain a similar universal design (See Figure 7-2). With similar amenities and stop design vocabulary and criteria throughout a regional LRT and streetcar system, the new surface transit investments would establish themselves in a strong,

“imageable” way for area residents and visitors. Passengers would manage the systems more safely and efficiently. Also, developing a stop design criteria regionally could help reduce maintenance costs.

Figure 7-2: Metrorail Common Design



Metrorail maintains the same architectural design standards throughout the system. For example, the two photos on the right are of station canopies at the Clarendon and Eastern Market Stations, while the photos on the left are of station platforms at Woodley Park and Congress Heights Stations.

7.3 Bus/Streetcar Shared Stops

Another issue related to stop design criteria is how passengers interface with streetcars and buses at shared stops. Most of the amenities at joint streetcar and bus stops can be shared, such as benches, lighting, and shelters, and developing common design criteria for these amenities will provide for better passenger convenience. The one major difficulty for shared stops to overcome is the issue of level boarding. Passengers will expect the most convenient and safest way possible to board vehicles and variation in vehicle or curb heights should be minimized however possible. The technical issues involved with level boarding and shared stops are addressed in Section 3.2. Other technical and engineering issues such as the vehicle-to-curb gap and stop length should be standardized where possible throughout the system for passenger safety and convenience.

7.4 Bicycle Interface

Bicyclists accessing streetcar and LRT systems require additional considerations beyond the typical pedestrian. Bicycle interface addresses three categories:

- Bicycles on vehicles
- In-street tracks
- Bicycle facilities

Most streetcars and LRVs may be customized to accommodate bicycles on-board, yet developing common protocols for bicyclists will provide for a simplified experience. Bicyclists in the region already interact with Metrorail, Metrobus, and other local transit systems on a regular basis, and will expect similar regional regulations. Bicyclists who choose to ride streetcars may expect

Bus/Streetcar Shared Stops in the DC Area

Two examples from local jurisdictions illustrate different ways of accommodating bus and streetcar stops along a shared route.

Along the planned H Street streetcar route in Washington, stop platforms have been constructed to allow level boarding for streetcars. Adjacent to these stops are lower boarding areas for corridor buses. Signage is provided, directing passengers to the service that they wish to use.

Along the proposed Columbia Pike corridor in Arlington, “super stops” are being constructed to accommodate regional and local bus service and future streetcar service (assuming nearly level boarding) at the same boarding area.

regulations that are similar to Metrorail's regulations, which allow for bicycles except during rush hour and are limited to a certain number per car. In addition, the center door of each car is the emergency door and is only for pedestrians. Developing a similar set of protocols for the multiple streetcar and LRT systems will create a seamless experience for bicyclists.

Embedded streetcar tracks present potential hazards to bicyclists crossing or riding along LRT and streetcar systems. Bicycle turning movements across tracks are a particular focus of attention, especially where riders cross tracks at shallow oblique angles. A range of safety strategies exists, from education programs for cyclists and motorists, to physical separation between bicycle and streetcar facilities, to design treatments that facilitate bicycle turns over streetcar tracks at safe angles. Regional coordination between LRT and streetcar systems on standards and best practices could alleviate potential conflicts between bicyclists and in-street tracks.

Commonality among bicycle facilities across the regional streetcar and LRT systems will provide a simplified passenger experience. For example, WMATA currently maintains a bicycle rack and locker system. Approximately 1,700 bicycle racks are found at 84 of the 86 Metrorail stations and the agency is replacing older racks with inverted-U racks for uniformity and convenience. Capital Bikeshare, the region's bicycle sharing system, maintains over 100 modular stations across the area. Each station consists of a variable number of bicycle docking ports, an electronic kiosk for membership purchase, and an information panel which displays local and regional maps and usage instructions. Capital Bikeshare has seen rapid growth over its first year and could potentially have stops within close proximity to LRT and streetcar stations. Both WMATA's bicycle facilities and Capital Bikeshare have standard design criteria to simplify maintenance as well as user understanding. Similar uniform bicycle facilities among the region's streetcar and LRT systems could be easily coordinated for passenger convenience and maintenance savings.

7.5 Passenger Regulations

Maintaining a common set of regional regulations and protocols for LRT and streetcar use will provide passengers with a seamless experience. Transit riders in the DC area are already accustomed to uniform Metrorail regulations. Although each project sponsor or jurisdiction may want to adopt its own set of regulations, any major discrepancies between system rules or expectations would be a burden on passengers. By maintaining uniformity, passenger confusion and rider conflicts could be minimized and synergy among the systems could be maximized.

7.6 Passenger Communication

The ability to communicate with passengers efficiently and effectively is a critical component of transit systems. Systems need to communicate service notices, vehicle arrival times, and most importantly, emergency situations. Most fixed transit rail stations have both audio and visual communication capabilities, usually in the form of an intercom system and digital displays. In addition to fixed communication systems, digital communication via websites, emails, and social media could provide convenient updates to passengers. The most ideal setting would be creating a centralized communication center between the various systems which could control and distribute both station and digitally-based communications for the entire region. By developing streetcar and LRT systems with uniform communication capabilities (at both stations and digitally), important advisories on service and emergencies could be disseminated regionally.

Bay Area's Regional Transit Website

In the Bay Area, the Metropolitan Transportation Commission developed the website transit.511.org, which maintains fare information, routes, and schedules for the region's various transit options, as well as real time departures and regional announcements. The website is part of the larger 511.org which provides comprehensive multimodal travel information.

MTC works with all public transit services in the nine-county San Francisco Bay Area to manage the entry and updating of transit service information for the benefit of the Bay Area riding public. Through the 511 Transit project, MTC currently oversees all aspects of these transit websites.



8.0 Interoperability Issues and Recommended Actions

The following tables present the key opportunities for cost savings and operating efficiencies that could be realized during the build-out of the region's light rail and streetcar systems. The information provides a starting point for further conversation regarding levels of interface that are achievable or desirable. Key technical findings are listed by subject area.

Summary tables present findings in terms of technical issues and recommended actions. Rows in the tables that are highlighted indicate high priority recommendations that may be easily accepted by project sponsors and carried forward through design and implementation.

Table 8-1: Vehicle Technical Issues and Recommended Actions

Vehicle		
Interoperability Opportunity: Operate over other lines for non-revenue moves to reach shared maintenance facilities. For like modes, option to share vehicles to meet temporary demand. Use regionally coordinated design criteria to achieve economies of scale for like modes; combining vehicle orders and parts supplies, and simplifying maintenance and training.		
TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
<i>Vehicle Synopsis</i>	See sub-topics below	Build maximum practical compatibility into vehicle design criteria / performance specification.
Vehicle width	Wide vehicle may not be able to operate over narrow vehicle guideway due to platform and other wayside clearances. (DDOT already has three 2.4m vehicles. LRV Purple Line will likely be 2.65m. LRVs can't operate over DC trackage.)	Use regionally coordinated design criteria to develop common approach among like modes; limit to two standard widths (LRT 2.65m, Streetcar either 2.4 or 2.65); Explore procurement of common vehicle "family".
Vehicle length	Capacity (startup and future) vs. initial cost / demand; ops costs per passenger; platform configuration; maintenance shop configuration.	Use regionally coordinated design criteria to develop common approach among like modes; standardize on 2 or 3 different lengths only; consider procuring vehicle "family" with expandable length.
Compatible performance (speed, acceleration, braking distance)	Most vehicles have minimum performance characteristics within a common range; different alignments may require special grade climbing and braking abilities.	Use regionally coordinated design criteria to facilitate compatibility.
Platform configuration (level or nearly-level)	Level vs. nearly-level boarding, and platform height: Vehicles that have both bridge plates and load leveling can use either type of stop (provided that vehicle width is the same).	Use regionally coordinated design criteria to establish common range of platform dimensions for like modes. Avoid mixing platform heights where possible. Otherwise, specify vehicles with both bridge plates and load leveling.
Communication Equipment (traffic signal interface, radio communication)	Potentially different existing communications equipment among systems could pose procurement issues and limit compatibility.	Use regionally coordinated design criteria to facilitate compatibility.
Coupling type	LRVs use full couplers for MU operation, streetcars don't. Streetcars (and some LRVs) do not have exposed coupler (use retractable coupler or drawbar for recovery only); procurement issues.	Use regionally coordinated design criteria to facilitate compatibility for recovery operations.

TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
Crashworthiness Standard	Different standards are in use across industry, although streetcar and LRT are recognized separately with differing requirements based on operating speed. Industry currently in flux on this issue.	Use regionally coordinated design criteria to facilitate compatibility among like modes. Shared revenue trackage between LRT and Streetcar may require additional mitigations. Streetcars allowed to meet lesser strength requirements due to lower operating speeds.
Vehicle Market and Procurement Issues	Small American market for streetcars. Differences between European and American standards.	Use regionally coordinated design criteria to achieve economies of scale for like modes. Coordinate with other U.S. projects for potential “options” on vehicle fleet purchases.

Table 8-2: Operations and Maintenance Facilities Technical Issues and Recommended Actions

Operations and Maintenance Facilities		
Interoperability Opportunity: Common vehicle types / families will simplify maintenance. Develop coordinated “specialized” facilities where specific capabilities (wheel truing, overhaul, major painting/accident repairs) could be performed for multiple lines.		
TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
<i>Operations and Maintenance Facilities Synopsis</i>	Each system/operator has basic maintenance facility to perform typical PM/CM. Cost sharing/procurement constraints.	Region could consider options for work in existing rail or bus facilities; develop and evaluate options for shared "specialty" facilities (wheel truing, overhaul, major painting/accident repairs).
Scheduled Maintenance	Basic inspection requirements similar on all streetcar / LRV vehicles, but parts and specific inspection requirements will vary between vehicle types.	For like modes, specify similar vehicles using regionally coordinated design criteria, facilitating coordination on maintenance protocols, component performance logs, and staff training.
Maintenance Activities	Startup systems may not be able to afford all needed "specialty" maintenance facilities and equipment (wheel truing, overhaul, major painting/accident repairs). Training needs will be similar throughout region, but different agencies will be involved.	Consider specialized maintenance needs at a regional level, reducing redundancy and overall cost to region. Specify similar vehicles using regionally-coordinated design criteria, facilitating coordination among lines for "specialized" maintenance activities. Consider training needs at a regional level; training of staff tends to be standardized around key disciplines.
Facility Layout	Varying site characteristics and vehicle types lead to different layout configurations.	Use regionally coordinated design criteria to emphasize most important facility layout concepts (access, efficient work layout, etc.) Specifying similar vehicles leads to more efficient facility layout and design to accommodate vehicle configurations and specialized activities.

Table 8-3: Power Supply Technical Issues and Recommended Actions

Power Supply		
Interoperability Opportunity: Use regionally-coordinated design criteria to create common design practices / parts, lowering costs and simplifying maintenance and training. Standardize key pantograph dimensions and wire height range for all vehicles in region.		
TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
<i>Power Supply Synopsis</i>	See sub-topics below.	Use regionally coordinated design criteria among like modes, pursue compatibility where practical between streetcar / LRT
Traction Power / OCS standardization	Need to facilitate interoperability with consistent operating voltage and current collection methodology throughout region. Need to control design, construction and maintenance costs by limiting the number of overhead construction styles and related variables including components.	Standardize regional operating voltage at 750V. Standardize basic pantograph dimensional / operating criteria using IEEE P1629 as basis. Limit overhead construction styles using regionally coordinated design criteria. Develop standard catalog of OCS components for regional use, maximizing incorporation of industry standard components and minimizing the need for custom parts.
Off-Wire Capability	Wire-free line segments may be legal requirement in DC. Vehicles without off-wire capability can't operate on line sections without OCS (towing may still be possible). Lines with steep grades and other unusual operating requirements will have different cost/benefit equation for off-wire capability life cycle cost.	Design criteria to address off-wire capabilities. Opportunity to develop common performance specifications for off-wire operation.
Ground Level Power Supply Systems	Regulatory, cost, lack of interoperability.	Highly proprietary systems are involved, commitment required to a specific technology.

Table 8-4: Guideway Design Technical Issues and Recommended Actions

Guideway Design		
Interoperability Opportunity: Design criteria needs to strike balance between unnecessarily restrictive criteria and adherence to recommended limits as a means of limiting risk that features might be built into the infrastructure design which limit compatibility with standard vehicle designs.		
TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
<i>Guideway Design Synopsis</i>	See sub-topics below	Use regionally coordinated design criteria among like modes; pursue compatibility where practical between streetcar and LRT.
Route Geometry	Streetcar mode frequently requires tighter track geometry than LRT. Max grades may vary between systems.	Identify lines / circumstances where interoperation is most likely. Use regionally coordinated design criteria to provide maximum flexibility for future interoperability. Review relationship between curve radius and vehicle availability.
Track Design Criteria	Need to maximize vehicle / track compatibility while controlling track design, construction and maintenance costs. Numerous Buy-America related procurement issues for rail (e.g. girder vs. block rail) and specialwork.	Use regionally-coordinated design criteria to achieve efficiencies in design process, procurement, operations & maintenance. Limit the number of rail sections and related component variables.

TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
System Approach to Wheel/Rail Interface	Need to minimize wear on both wheels and rail, facilitate highest possible ride quality and lowest noise, and reduce number of derailments to a minimum.	Use regionally-coordinated design criteria to develop common wheel gauge standards and compatible wheel profile elements. Coordinate approach to single- versus two-point contact for curves, use of flange-bearing special work, and European vs. AREMA standard turnouts.
Traffic Control Signage and Pavement Markings	Need for consistent approach within the region for traffic controls and signage related to the trackway	Use regionally coordinated design criteria to ensure systems create uniform expectations for travelers regarding transit operations.
Utility Protection / Relocation	Need to control costs associated with utility relocation. Consistent regional approach to defining "utility impact zone" and related protection / relocation requirements for various utility types could help reduce project costs. May need to be mode specific.	Use regionally coordinated design criteria to provide uniform expectations for regional utility providers; coordinate standard details for utilities of similar type.

Table 8-5: Fare Collection Technical Issues and Recommended Actions

Fare Collection		
Interoperability Opportunity: Ability to seamlessly integrate collection systems through Next Electronic Payment Program (NEPP); share maintenance and operational costs.		
TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
<i>Fare Collection Synopsis</i>	Phasing in new technologies and legacy system integration and maintaining comparable enforcement regulations.	Accept universal open payment standards through NEPP with traditional cash payment options that are compatible across systems.
Fare Media/User Interface (smartcards etc.)	Phasing in new technologies and legacy system integration; Managing and keeping up with technological expectations.	Accept a common open payment system compliant with ISO standards; coordinate cash payment capabilities.
Fare Vending	Phasing in new technologies and managing various proof-of-payment systems.	Accept equipment design criteria that can handle common open payment system and common cash payment capabilities through NEPP standards.
Fare Validation	Phasing in new technologies; communicating validation protocols to passengers.	Accept equipment design criteria for common open payment system and validation protocols.
Fare Enforcement	Varying levels of enforcement (officers, jurisdictions, fines, equipment, etc.); enforcement technology linked to vending and validation.	Adopt common enforcement regulations and adaptable equipment.
Fare Equipment and NEPP	Different systems have different operating environments, e.g. exclusive LRT right-of-way vs. mixed traffic streetcar with interlined buses.	Coordinate to procure similar equipment for similar operating environments. Facilitate equivalent protocols across systems.

Table 8-6: Passenger Information/User Interface Technical Issues and Recommended Actions

Passenger Information/ User Interface		
Coordinated user interface leads to uniform experience for passengers across region. Coordinated communications across lines to increases overall system efficiency.		
TOPIC	TECHNICAL ISSUES	RECOMMENDED ACTION
<i>Passenger Information Synopsis</i>	See sub-topics below.	Adopt common design criteria to facilitate continued regional coordination.
Signage/graphics	Different graphics standards of existing agencies.	Adopt common design criteria to facilitate passenger wayfinding and present image of a unified system.
Stop design criteria	Varying design processes and platform standards Procurement standards.	Use regionally-coordinated design criteria to provide standardized approach to stop design, facilitating access for all passengers, including mobility- challenged.
Bus/Streetcar shared stops	Different service patterns of bus vs. streetcar/ LRT. Platform design assumptions--level boarding vs. nearly level. Fare policy and fare collection methods.	Continue regional coordination and common design criteria for consistent passenger expectations.
Bicycle interface	Accommodations / protocols for bikes on-board vehicles and at stops. Coordinated approach to cyclist safety on trackway.	Continue regional coordination and common design criteria for consistent user experience.
Passenger regulations (stroller policies, etc.)	Varying accommodations by mode and operator.	Continue regional coordination and common design criteria for consistent user experience.
Passenger communication across systems (e.g. service outages)	Variation in hardware/systems. Coordination among already busy operations/supervision officials. Responsibility for emergency response.	Continue regional coordination to identify obstacles and opportunities for information sharing across systems.



9.0 References

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9.1 APPENDIX

Interface of LRT and Streetcar Systems in other North American Regions

An earlier stage of the LRT and Streetcar Project Interface (May 2010) study considered other North American transit lines and systems with some degree of interface among different transit modes or activities. These examples continue to serve as useful points of comparison regarding interface opportunities between systems and between modes within systems. The most common areas for interface include maintenance facilities, vehicles, trackwork, communications, passenger stations, fare collection systems, and workforce.

Table B-1: Summary of Current Interface Practices

	Maintenance facilities	Vehicles	Trackwork	Communications	Passenger Stations	Fare Collection Systems	Workforce	Route Selection	Scheduling and Service Integration	Traction Power	Train Control
Baltimore, MD						√	√				
Boston, MA	√	√					√				
New Jersey (Statewide)	√	√		√	√	√			√		
Philadelphia, PA	√				√			√			
Portland, OR	√		√				√	√			
Phoenix, AZ		√		√		√			√		
San Francisco, CA		√	√		√						
Seattle, WA	√		√	√	√		√		√	√	
Tacoma, WA			√					√			
Toronto, ON Canada	√	√									√
Washington, DC				√		√					