GRTC Bus Rapid Transit Project
Systems Engineering Management Plan (SEMP)
# Revision Record

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Appendix A – List of Acronyms
1. Introduction

1.1. Project Description, Definition and Background
GRTC, together with the Federal Transit Administration (FTA) and the Virginia Department of Rail and Public Transportation (DRPT), completed the planning phase for the Bus Rapid Transit (BRT) Project in 2014. With a proposed alignment of approximately 7.6 miles and 14 stations along the route, the project goals are to improve the mobility of regional and local transit users, develop a more efficient transit system, support existing transit-oriented land use, support plans to generate new transit-oriented development, and provide an attractive alternative to the automobile for east-west travel. Not only will the GRTC BRT Project improve transit service, the project will also increase livability, increase economic opportunity, revitalize commercial properties, provide an environmental benefit, and stimulate economic development in the City of Richmond, Henrico County, and the Greater Richmond area.

Figure 1 shows the proposed project alignment along Broad Street, 14th Street, and Main Street which covers four distinct areas: West End (Willow Lawn to Interstate 195), Museum District / Virginia Commonwealth University (VCU) (Thompson Street to Adams Street), Downtown (Adams Street to 14th Street), and East End (Main Street Station to Rocketts Landing).

1.2. Systems Engineering Management Plan Purpose
This report is a Systems Engineering Management Plan (SEMP) for the GRTC BRT project. Systems Engineering is a process of documenting project requirements, evaluating technology options, and presenting recommendations considering the life cycle of a project and interoperability with other systems in accordance with regionally and nationally adopted standards and system architectures. Since the GRTC BRT project received federal funding, compliance with the federal System Engineering process is required for the technology based elements of the BRT system. Therefore, this SEMP report follows the standard Systems Engineering process.
1.3. **Reference Documents**

A number of resources were used for the completion of this report. These resources include the following:

- Characteristics of BRT for Decision Makers, USDOT / FTA, February 2009
- National ITS Architecture, Version 7.0
- Virginia Department of Transportation Central Region ITS Architecture, January 2014
- Various technical specifications and brochures with information from equipment vendors

A list of acronyms can be found in Appendix A.
2. System Engineering and ITS Architecture Requirements

2.1. Systems Engineering Requirements

On January 8, 2011, the United States Department of Transportation (USDOT) enacted the Federal Highway Administration (FHWA) Rule / FTA Policy regarding the use of Systems Engineering process for Intelligent Transportation Systems (ITS) projects involving federal funding (§ 23 CFR 940.11). The Rule / Policy requires a Systems Engineering analysis to be performed for ITS projects that use funds from the Highway Trust Fund, including the Mass Transit Account. The Rule / Policy specifies, as a minimum, seven requirements that the Systems Engineering analysis must include for a technology-based project such as the GRTC BRT Project.

The Rule / Policy allows each project sponsor to use a Systems Engineering approach that is tailored to fit the needs of their project. The Systems Engineering approach is actually broader than the seven specific Systems Engineering requirements identified in the Rule / Policy and will typically exceed them.

The FHWA Division and FTA Regional Offices determine how the Systems Engineering analysis requirements in the Rule / Policy should be applied to projects in each region and how compliance should be demonstrated by each project sponsor. Federal oversight is provided based on requirements defined in the stewardship agreements with each state. To satisfy the Systems Engineering process, a SEMP is typically developed that outlines the project’s specific Systems Engineering approach.

Code of Federal Regulation (CFR) Title 23-Highways, Part 940-Intelligent Transportation Systems Architecture and Standards, Section 11-Project Implementation Guidance includes the following elements:

I. All ITS projects funded with highway trust funds shall be based on a Systems Engineering analysis
II. The analysis should be on a scale commensurate with the project scope
III. The Systems Engineering analysis shall include, at a minimum:
   1. Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture)
   2. Identification of participating agencies' roles and responsibilities
   3. Requirements definitions
   4. Analysis of alternative system configurations and technology options to meet requirements
   5. Procurement options
   6. Identification of applicable ITS standards and testing procedures
   7. Procedures and resources necessary for operations and maintenance

2.2. Systems Engineering Process

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both business and technical needs with the goal of providing a quality product that meets the user needs.

Many different process models have been developed over the years that specify the steps that make up the Systems Engineering approach. Among these models, the "V" or "Vee" model is commonly used as the de facto standard to represent Systems Engineering for ITS projects.
The "V" model has been refined and applied in many different industries. The left extension of the "V" model (see Figure 2) shows the regional ITS architecture, feasibility studies, and concept exploration that support initial identification and scoping of an ITS project based on regional needs. A gap follows the regional architecture(s) step as the regional architecture is a broader product of the planning process that covers all ITS projects within a region.

The central core of the "V" shows the project definition, implementation, and verification processes. The right extension shows the operations and maintenance, changes and upgrades, and ultimate retirement of the system.

As shown in the "V", the Systems Engineering approach defines project requirements before technology choices are made and the system is implemented. On the left side of the "V", the system definition progresses from a general user view of the system to a detailed specification of the system design. The system is comprised of subsystems, and the subsystems are then divided into components – a large system may be broken into smaller and smaller pieces through many layers of decomposition. As the system is broken down, the requirements are also separated into more specific requirements that are allocated to the system components.

As development progresses, a series of documented baselines are established that support the steps that follow. For example, a Concept of Operations supports System Requirements development. A baseline set of System Requirements then supports High-Level Design. The hardware and software are implemented at the bottom of the "V", and the components of the system are then integrated and verified in iterative fashion on the right. Ultimately, the completed system is validated to measure how well it meets the Project's needs.

Figure 2 shows the Systems Engineering process as depicted in the "V" diagram. The Systems Engineering process is used for simple to very complex transit and ITS projects. In many respects, it lays the foundation for many future decisions on the path to implementation. The concept of operations will provide detailed system elements and make specific recommendations for planning, design, and implementation of the ITS elements. Moreover, the process will set the pathway to other deployments, once the concept is proven and shown as viable.
Functional System Requirements and system design documents will follow the Concept of Operations phase of the project. As the diagram above shows, these elements will be defined in the project development phase, and will be followed through with the system and subsystem acceptance and validation process, during the implementation phase of the project. Functional requirements and system design documents will outline the specific requirements for the project from the software requirements, standards to be used, compliance with regional, statewide, and national ITS/Transit architecture. It will outline specific requirements for the ITS systems, including field to central sub-systems, infrastructure, communication, central equipment and processing, and user interfaces.

Systems and sub-system testing and acceptance are the other half of the system engineering process that map the requirements to the testing and acceptance tasks. A traceability matrix is required to map the requirements from the users' perspective to concept of operations and system/sub-system design. Systems testing is a combination of all sub-systems, including field sub-system, communications sub-system, central sub-system, and processing sub-system. System validation and acceptance is the final step in the process, where overall system requirements and user benefits are directly tied to the requirements and concept of operations.

2.3. ITS Architecture Requirements
The USDOT also requires that any ITS project funded through the Highway Trust Fund conform to the National ITS Architecture and applicable standards. These requirements are codified in the CFR Title 23-Highways, Part 940-Intelligent Transportation Systems Architecture and Standards. ITS projects are defined as any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture. Conformance to the National ITS Architecture includes the use of the National ITS Architecture to develop a statewide or regional ITS architecture and the subsequent adherence of the project to that statewide or regional ITS architecture.

2.4. ITS Architecture Process
To ensure that ITS deployments are coordinated and integration opportunities are maximized, the USDOT requires the development of an ITS architecture. The ITS architecture helps identify opportunities for interagency communication to better coordinate deployment efforts and to support integration activities of multimodal transportation services. ITS architecture typically includes the following components:

- Subsystems
- Equipment Packages
- Service Packages
- Interconnects
- Information Flows

Subsystems represent the various ITS management centers (traffic operations centers), field infrastructure (signal controllers), and ITS equipment in vehicles (transit vehicle systems). Equipment Packages represent discrete functional capabilities of each subsystem. Equipment packages produce, receive, or process information that supports transportation service, which are known as Service Packages. Service Packages are comprised of multiple equipment packages and subsystems that interact to provide traffic management and other ITS services. The National ITS Architecture Service Packages that correspond to transit are covered within the Advanced Public Transportation Systems (APTS) packages. Finally, Interconnects and Information Flows represent the connections between subsystems in a Service Package and the information that is shared between them.
2.5. Virginia Department of Transportation Central Region ITS Architecture

In January 2014, the Virginia Department of Transportation (VDOT) completed an update of the Central Region ITS Architecture. The geographic boundaries of VDOT’s Central Region include all of the City of Richmond and Henrico County as well as GRTC as a stakeholder. Stakeholders developed the Regional ITS Architecture based on a 20-year vision of how they wanted to implement and operate ITS in Central Virginia. The Regional ITS Architecture was based on Version 7.0 of the National ITS Architecture and an accompanying Turbo Architecture database was also developed using Version 7.0 of the Turbo Architecture. The Regional ITS Architecture and Turbo Architecture database files can be found on the Commonwealth of Virginia Statewide and Regional ITS Architecture project website, currently maintained by VDOT’s consultant at the following website:


During the development of the Regional ITS Architecture, GRTC was identified as a stakeholder and selected nine of the ten available transit ITS Service Packages from the National ITS Architecture for customization to meet existing and planned ITS deployments. Figure 3 shows GRTC and City of Richmond existing and planned connections.

Figure 3 - VDOT Central Region ITS Architecture Flow Diagram for GRTC and City of Richmond
2.6. Compliance with VDOT Central Region ITS Architecture

Within the regional architecture, GRTC Transit Vehicles will communicate directly with the City of Richmond traffic signals and the GRTC Transit Operations Center. Additionally the City of Richmond Traffic Operations Center, the VDOT Central Region Traffic Operations Center, and the GRTC Transit Operations Center will communicate agreed upon information. No existing or planned connections are shown between Henrico County and GRTC.

It is important to note that the Regional ITS Architecture is considered a living document. As the GRTC BRT Project is finalized, it may be necessary to modify the ITS Service Package to reflect how the system will be deployed and operated. The VDOT Central Region ITS Architecture describes the process that should be used for documenting changes to the regional architecture to account for ITS deployments that differ from the Regional ITS Architecture. The most important component of these changes is that all impacted stakeholders (GRTC, City of Richmond, Henrico County, and VDOT) are in agreement of the changes and have an understanding and, if necessary, an agreement in place for future maintenance and operations of the system.
3. Existing System Description
The existing operations along the project corridor are outlined below, along with details summarizing the existing transit system and traffic signal system.

3.1. Existing Operational Conditions
The traffic signals along the proposed BRT alignment operate in a coordinated fashion. There are 52 traffic signals controlled by three different agencies: City of Richmond (50), VDOT (1), and Henrico County (1). The City of Richmond signals operate in four distinct groups; West End (signals along Broad Street between Staples Mills Road and Hamilton Street), Museum District / VCU (signals along Broad Street between Interstate 195 and Belvidere Street), Belvidere Street corridor (inclusive of the Broad Street and Belvidere Street intersection), and Downtown (all signals along Broad Street, 14th Street, and Main Street east of Belvidere Street).

The signals operate time of day plans and are predominantly fixed time with no vehicle detection and limited pedestrian actuation. Within the Museum District and Downtown, where the roadway network is a tight grid system, the City of Richmond has historically not installed detection for their traffic signals. In 2008 / 2009, the entire Richmond Signal System, which consisted of 280 coordinated intersections, was retimed with Congestion Mitigation and Air Quality Improvement (CMAQ) funds. Existing level of service and delay was analyzed for each of the project intersections for the AM and PM peak periods for existing conditions and for proposed BRT conditions; results are presented in the GRTC Bus Rapid Transit Project Traffic Analysis Report.

The Broad Street corridor is a six-lane, divided facility from Willow Lawn Drive (western end of the proposed BRT alignment) to 14th Street (eastern end of the proposed BRT alignment). Between 2nd Street and Old 14th Street, the outside curbs lanes function as exclusive transit lanes from 7:00 AM to 9:00 AM and from 4:00 PM to 6:00 PM Monday through Friday. At the majority of intersections, there are no exclusive left-turn or right-turn lanes, rather vehicles turn from shared through lanes. The intersection of Broad Street and Belvidere Street is the most congested intersection along the corridor with both eastbound and westbound left-turn lanes and an eastbound right-turn lane. Additionally, heavier congestion is experienced along Broad Street at Boulevard, Lombardy Street, Harrison Street, 8th Street / 9th Street, and 14th Street. On-street parking is allowed on Broad Street between Thompson Street and 14th Street, except when the exclusive transit lanes are in use between 2nd Street and Old 14th Street.

14th Street is a four-lane, divided facility between Broad Street and Main Street with parking allowed on both sides of the street. This area of the corridor is extremely congested during the PM peak period as Commonwealth of Virginia employees exit numerous large parking garages and travel northbound along 14th Street towards Interstate 95.

Main Street is a four-lane, undivided facility between 14th Street and Williamsburg Avenue. On-Street parking is allowed on both sides of the street in most blocks. During the AM peak period, the outside curb lane along westbound Main Street is used as a travel lane. During the PM peak period, the outside curb lane along eastbound Main Street is used as a travel lane. Between 26th Street and Orleans Street, Main Street reduces to a two-lane, undivided facility and on-street parking is prohibited. This area of the proposed BRT alignment is also congested during the peak periods. Travel speeds are also slower due to narrow lane widths, which can prohibit full capacity functionality of the Main Street corridor.
3.2. Existing Traffic Signal System

The City of Richmond’s traffic signal system is a comprehensive system consisting of Econolite ASC/3 advanced traffic signal controllers, an Econolite Centracs central communications system with Genetec video management software, and existing, or currently under construction, communications interconnectivity for nearly 400 of the City's 469 traffic signals. Details regarding each of these elements are described below.

3.2.1. TRAFFIC CONTROLLERS

The City of Richmond uses the Econolite ASC/3 controller throughout the proposed BRT alignment with one exception. At the intersection of Main Street and Williamsburg Avenue, the City uses an Eagle EPAC M40 controller. The City envisions upgrading this controller to an Econolite prior to BRT operations. Henrico County also uses the Econolite ASC/3 controller along the proposed BRT alignment at the intersection of Willow Lawn Drive and Markel Road. There is one signal controlled by VDOT located at the intersection of Broad Street and Willow Lawn Drive; this signal uses an Eagle EPAC M40 controller.

Most intersections currently utilize NEMA TS-1 signal cabinets. Both the City of Richmond and Henrico County have adopted NEMA TS-2 cabinets as their local standard; therefore as intersections are upgraded, new TS-2 cabinets are being installed. The VDOT Central Region, which controls the Broad Street corridor within Henrico County, also has plans for a phased migration to NEMA TS-2 cabinets.

3.2.2. CENTRAL SYSTEM

The City of Richmond operates the Econolite Centracs central system software. Server equipment is located in City Hall, G Level in the Department of Information Technology’s server bank, which is immediately adjacent to the City’s primary Traffic Operations Center. Backup servers are located at the City of Richmond Transportation Engineering Division Shop on Hermitage Road which serves as the City’s secondary Traffic Operations Center. All City of Richmond intersections along the project corridor, with the exception of Main Street and Williamsburg Road, are connected to Centracs.

Henrico County also operates the Econolite Centracs central system. The Willow Lawn Drive and Markel Road intersection communicates with Centracs via a 5.8 GHz wireless radio that repeats through several other intersections to reach a high speed Verizon drop at Monument Avenue and Bremo Road, which connects back to the County’s Operations Center.

VDOT manages its traffic signals using the Siemens Tactics software platform. VDOT does not currently have high speed communications to their traffic signals along Broad Street, but they have identified project concepts to upgrade the communications. The upgrades are not yet funded.

3.2.3. COMMUNICATION SYSTEM

City of Richmond fiber optic communications exist along the majority of the proposed BRT alignment. Fiber currently exists along Broad Street from Boulevard to 14th Street and along 14th Street from Broad Street to Main Street. Additionally, the City utilizes Ethernet communications over twisted pair copper interconnect along Broad Street from Staples Mill Road to Boulevard and along Main Street from 14th Street to 25th Street. No communications currently exist west of Staples Mill Road or east of 25th Street.
3.3. **Existing Transit System**
Transit operations are managed from the GRTC Transit Operations Center located on Belt Boulevard; computer systems are all housed at this location. There is no communications linkage between City of Richmond and GRTC. Global Positioning System (GPS) data communications between transit vehicles and the Transit Operations Center occur via radio.

3.4. **Planned Projects**
Existing projects planned for completion may impact the GRTC BRT Project and should be taken into consideration when making design decisions. There are several known projects that may impact the BRT design and/or construction. The 2015 UCI Road World Championship network improvements including pavement resurfacing, sidewalk and ADA upgrades, and potential bleacher seating, which may eliminate some portions of the median on Broad Street in Downtown; final plans are not yet available. The City has a project that will install trees and sidewalk / ADA ramp improvements between Lombardy Street and Boulevard. The VCU Institute of Contemporary Arts, the Children’s Pavilion at the Children’s Hospital of Richmond at VCU, and Stone Brewing Co. Bistro and Restaurant are under construction along the proposed BRT alignment. The Richmond Signal System communications network south of the James River will be constructed in 2015; this project calls for the installation of fiber communications along many Southside corridors and will ultimately provide the fiber optic connection for the BRT project to the GRTC Transit Operations Center. Periodic traffic signal upgrades / modernizations may also be expected prior to or during BRT construction.
4. Transit Signal Priority System

Transit Signal Priority (TSP) is an operational strategy that facilitates the movement of transit vehicles through a signalized corridor. The objectives of TSP are to improve reliability and schedule adherence, and reduce delay and improve transit travel times while minimizing impacts to normal traffic operations. In this context, the TSP includes both the transit signal priority system and the Queue Jump (QJ) systems. Currently there is no TSP / QJ operating anywhere in the GRTC system.

TSP is different from pre-emption; pre-emption terminates normal traffic operation and provides service to a special task. Typical applications of pre-emption are at railroad crossings and for emergency vehicle passage. TSP provides preferential treatment to transit vehicles and is typically accomplished with limited disruption to coordinated traffic signal operations. Active TSP uses detection and subsequent priority request activation to alter traffic signal beginning green times, end green times, phase sequences, and inclusion of special phases.

4.1. TSP Goals and Objectives

TSP can improve the person throughput of an intersection and improve travel time reliability for transit vehicles, thus improving operations for transit service as well as any vehicle traveling in the same direction. Traditional Level of Service (LOS) measures do not recognize this aspect as they only account for individual vehicles passing through an intersection. Comparing the number of people moving through a given intersection versus the number of vehicles would produce different results. It should also be noted that general traffic can benefit from TSP. When the “mainline” is given an extended green phase not only does the bus benefit, but so do all the vehicles traveling through the intersection.

Signal priority can be accomplished through passive means where the signals are retimed to account for transit travel speeds, or active means where the bus requests a priority to a signal and the signal adjusts the timing based on predetermined parameters. TSP is different from signal pre-emption where the signal progression is interrupted. TSP modifies the normal signal operation process to better accommodate transit vehicles, while pre-emption immediately interrupts the normal process to provide exclusive right-of-way for a vehicle, which in turn causes the traffic signal to drop out of coordination.

Typically, a bus spends 60% of its run time in motion, 20% serving bus stops, and 20% stopped in traffic signal or other congestion-related delay. The benefits of implementing priority bus treatments can include reduced bus travel times, increased schedule reliability, a higher public profile, better integration with pedestrian ways, operating cost savings, reduced equipment requirements, decreased emissions, and increased transit ridership. Ideally, the total number of persons able to travel in a corridor will be higher with priority bus operations than without as more people use a bus lane in an hour than would be able to in cars.

These benefits can range from marginal to significant depending on the specifics of the application. In general, the more completely buses can operate in reserved rights-of-way, the better the signal system responds to the needs of the buses, the fewer intermediate stops (e.g. less than 1/3 mile), the quicker buses can be boarded or disembarked, and the longer the corridor in which these characteristics are incorporated, the greater the total benefits that can be achieved.

If all of these benefits could be achieved, priority bus treatments would be the norm across all transit systems. Implementation of bus priority treatments involves allocating the limited capacity of the roadways to transport people and goods.
4.2. TSP Standards

The transportation industry has adopted standards to help reduce costs and decrease risk associated with ITS projects. Without standards, public agencies risk the possibility of incompatible systems or being tied to one vendor and product. This can cause compatibility issues with existing equipment and software and since agencies will be "locked into" the same vendor for the foreseeable future. Standards will allow procurement of ITS and TSP hardware and software without concern for compatibility and will help open the industry for competition and price reduction. The standards are contained in both the National Transportation Communications for ITS Protocol (NTCIP) and the Transit Communications Interface Profiles (TCIP).

All standards are voluntary but as previously stated, the National ITS Architecture and Standards Final Rule issued on January 8, 2011 requires that ITS projects funded by the Highway Trust Fund and the Mass Transit Account conform to the National ITS Architecture, as well as to USDOT adopted ITS Standards.

4.2.1. THE NTCIP STANDARDS

The ITS traffic standards come under the NTCIP (www.ntcip.org). NTCIP is a family of standards that provides both the rules for communicating (protocols) and the vocabulary (objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. The NTCIP is the first set of standards for the transportation industry that allows traffic control systems to be built using a “mix and match” approach with equipment from different manufacturers. NTCIP standards reduce the need for reliance on specific equipment vendors and customized one-of-a-kind software.

The NTCIP effort is a joint undertaking of the National Electronics Manufacturers Association (NEMA), the American Association of State Highway and Transportation Officials (AASHTO), and the Institute of Transportation Engineers (ITE) to develop standards to be applied to traffic control systems. The NTCIP 1211 standard, Object Definitions for Signal Control and Prioritization (SCP), was developed to establish standards for use in implementing TSP applications within traffic signal systems.

The NTCIP 1211 SCP Concept of Operations is comprised of two primary elements, the Priority Request Generator (PRG) and a Priority Request Server (PRS), which are described in more detail in Section 4.3 of this SEMP. A transit vehicle, which could be a light rail train, bus, or other transit vehicle, through its agent, the PRG, submits a request for priority to the PRS. These two elements can be thought of as a logical process that could be physically implemented in more than one way, as discussed further in the document. The standardization occurs at the interface of these processes and represents the objects developed by NTCIP 1211. The two primary interfaces are (1) between PRG and PRS and (2) between PRS and the traffic signal controller coordinator, which implements special coordination operation.

Another element of the NTCIP SCP Concept of Operations, which directly relates to the traffic signal software, is the concept of granting priority while maintaining coordination with adjacent intersections. The functionality identified is intended to work in conjunction with the signal coordination object definitions and functions as defined in NTCIP 1202 – Object Definitions for Actuated Signal Controllers, also developed by the NTCIP Joint Committee. NTCIP 1211 includes a number of signal timing parameters that modify normal coordination parameters to allow implementation of a priority strategy. The strategies and timing parameters are under the control of the traffic signal system operator.

NTCIP 1211 also defines a Management Information Base (MIB) or data dictionary of parameter controls and status information for SCP related to:
- Generating and monitoring the status of a request for priority from a source to a logical entity referred to as the PRS
- Passing a prioritized list of priority requests to a controller and monitoring the status of the controller responses
- Setting configuration parameters to manage the process of receiving and responding to priority requests

The MIB was created in April 2004 by the NTCIP 1211 Signal Priority Working Group. This information is documented in the NTCIP 1211 report Objects Definitions for Signal Control and Prioritization.

The NTCIP 1211 standard addresses the four (4) likely signal control priority scenarios and includes cases that can be used to provide a logical architecture for implementation of TSP. The scenarios consist of the following:

- Fleet Vehicle Priority Request Through Fleet and Traffic Management Centers
- Fleet Management Priority Request Through Traffic Management Centers
- Traffic Management Priority Request
- Fleet Vehicle Priority Request

### 4.2.2. THE TCIP STANDARD

The TCIP ([www.aptatcip.com](http://www.aptatcip.com)) addresses the Transit Standards. The TCIP has addressed the transit portions of the NTCIP as it relates to transit signal priority. The Working Group has developed an interface standard as part of the TCIP that defines standardized mechanisms for the exchange of information in the form of data among transit business systems, subsystems, components, and devices.

The intent of this development process is to provide transit industry standards as a component of the US Intelligent Transportation Systems program. The latest version of the standard is described in the TCIP 3.04 Draft Standard for Transit Communications Interface Profiles report (APTA-TCIP-S-01 3.04, working draft issued 1/10/2011).

TCIP provides building blocks for interfaces for several business areas:

- Common Public Transport
- Scheduling
- Passenger Information
- Transit Signal Priority
- Control Center
- On-board Systems
- Spatial Referencing
- Fare Collection

TCIP for TSP addresses the same four (4) signal control priority scenarios defined by NTCIP 1211, and a fifth scenario that accommodates implementations where the transit vehicle communicates directly to the roadside, but does not generate priority requests on-board.

The five (5) SCP scenarios provide a logical architecture for implementation of TSP in different transit and traffic operating environments. The purpose of the SCP scenarios is to show where logical decisions can be made and where standard NTCIP messages can be produced and transmitted. Two (2) primary elements in any TSP system are the PRG and the PRS, which are described in more detail in Section 4.3 of this SEMP. The defining characteristics of each of the five (5) scenarios are where the PRG and PRS are located and what inputs are being transmitted and received.
At a broader level, these scenarios can be categorized according to whether they are implementing TSP in a Centralized or Distributed Architecture. These architectures are based upon the traffic signal system, on-board vehicle equipment, and communication infrastructure.

As the public transit vehicle (PTV) operates on its route, it may encounter intersections that are equipped to provide priority treatment to PTVs (e.g. early green, extended green, phase rotation) to allow the PTV to operate more efficiently. Equipped intersections and agreeing on acceptable strategies for TSP requires extensive coordination between transit agencies, traffic management, and traffic engineering.

Although a PRG may request priority treatment, the traffic management system is not obliged to, and may not, grant it each time. PRGs may consider any or all of the following in creating a priority request (based on data available to the PRG at the time the request is generated):

- Business Rules
- Schedule Adherence Status of PTV
- Time of Day
- Equipment Type at Intersection
- Passenger Loading on PTV
- Scheduled time for PTV's current trip to arrive at intersection (many agencies do not schedule to this level)

4.3. TSP Components

TSP systems typically include four major elements: the transit vehicle, transit fleet management, traffic control, and traffic control management. These four sub-systems are then enhanced with four functional applications of vehicle detection system, PRG, PRS, and TSP control, as described below:

- Vehicle Detection System - A system to deliver vehicle data (location, arrival time, approach, etc.) to a device that is routed to a PRG
- Priority Request Generator - A system to request priority from the traffic control system and triage multiple requests as necessary
- Priority Request Server - A server that executes the TSP control logic that addresses the functional requirements of the traffic jurisdiction
- TSP System Management – Incorporates both traffic and transit TSP functions in both the transit management and traffic control management that can configure settings, log events, and provide reporting capabilities

4.3.1. VEHICLE DETECTION SYSTEMS

The main component of a successful TSP system is to equip each signalized intersection along the corridor with a transit vehicle detection system. The goal of the TSP detection system is to provide an advantage for buses to get additional time, if available, within the background cycle, to minimize the number of stops and to maintain the established headway. The traffic signal will implement the governing TSP strategy and provide priority to the approaching transit vehicle. In order to avoid a vehicle receiving priority while passengers are boarding, stations are traditionally located on the far-side of signalized intersections.
OPTICAL AND GPS BASED SYSTEMS

Figure 5 shows the predominant TSP detection technologies that are deployed for BRT systems. The left side of the figure represents the optical-based system. Using optical emitters, detectors, and phase selectors, BRT systems detect buses and receive and grant TSP. The right side of the figure shows the GPS-based system. Using GPS information for tracking buses and radios to communicate to roadside traffic cabinets, BRT systems detect buses and receive and grant transit signal priority. For both TSP technologies, BRT systems implement queue jumps using the same TSP elements. GPS systems are typically more advanced in capabilities and provide a greater transmission range and do not rely on line-of-sight technology as do optical systems.

Figure 5 – Optical and GPS Based Detection Systems

RADIO BASED SYSTEMS

Another TSP technology that has been deployed uses wireless signals to track each BRT bus and make determinations on when to place a low priority call. The overall system concept is illustrated in Figure 6. This TSP technology consists of several elements including wireless terminal servers, access points, and on-board wireless mobile clients. The access points communicate with other access points and the terminal servers to track the buses as they travel between intersections. The terminal servers communicate wirelessly with the BRT buses and are connected via wire line with the traffic controllers. Packets of information are sent via radio waves between the transit vehicle (mobile client) and each intersection (terminal client), both of which are IP addressable. Infrastructure on the bus and in the traffic signal controller cabinet communicates within the available range of the network. Wi-Fi can be implemented in a strategy known as a Mesh Network. Mesh networking is a way to route data between two or more network devices (bus, signal controllers, etc.) allowing for continuous connections and reconfiguring itself automatically around blocked and broken paths. Mesh networks differ from other networks in that the component parts can all connect to each other via multiple hops, which allow inexpensive peer network nodes to supply back haul services to other nodes in the same network. It effectively extends a network by sharing access to higher cost network infrastructure. This requires a degree of network traffic management planned into the design to avoid problems during automatic re-routing or failover. However, there are no current industry standards for mesh networks, and thus they are comprised of proprietary solutions that lead to vendor lock-in.
AUTOMATIC VEHICLE IDENTIFICATION

Automatic Vehicle Identification (AVI) system is an additional alternative for transit detection, which have been used, but appears to be decreasing in use and is included for information. Automatic Vehicle Identification (AVI) loop detection systems are commonly referred to as "smart" loop, because the technology distinguishes the transit vehicle from general traffic.

A typical AVI system consists of three components. The first component is a coded transmitter attached to the underside of the priority vehicle which has an unchangeable, unique identification code for AVI functionality. The transmitter provides an output signal to the second component, an antenna-based vehicle detection system integrated into a loop detector. The loop detector can be either a standard inductive loop for vehicle detection or a loop installed exclusively for transit vehicle detection. The third component is a receiver, typically located in the signal controller cabinet. AVI transmitters send the identification code of the transmitter itself.

4.3.2. PRIORITY REQUEST GENERATOR

The PRG system generates the request for priority and can be located in the transit vehicle, the transit operations center, the traffic operations center, or the traffic signal control system equipped with wayside transit vehicle detection. Alternative approaches exist for generating a request for priority: wayside detection of the transit vehicle by the local traffic signal control system; direct active communication from the transit vehicle; or communications via the transit and / or traffic operations centers based on knowledge of transit vehicle location. The VDOT Central Region ITS Architecture currently reflects GRTC transit vehicles generating the request for priority.
Once a transit vehicle has been detected or has communicated to the PRG, the PRG initiates requests for priority based on predefined criteria, which may be unconditional (for all transit vehicles) or conditional (based on either schedule adherence or headways).

Depending on the approach selected, the priority request system may be based at the local intersection level or at the operations center level. A transit vehicle may be detected at the local intersection through a combination of an on-board transmitter and a receiver at the intersection. For detection at the network level, a transit vehicle may communicate with a transit or traffic operations center, providing its location directly. When a priority request is generated, either at the intersection or through a network, it may be forwarded directly to the local intersection controller or first pass through a central management center for processing.

4.3.3. PRIORITY REQUEST SERVER

The PRS is the component that processes the transit signal priorities. The PRS usually is located within the traffic signal control system that receives and processes the requests for priority at the intersections based on predefined TSP control logic.

4.4. TSP Operational Descriptions

BRT includes physical and operational treatments applied along corridors to improve transit operations through decreasing travel times and improving reliability for the passenger. These treatments can result in faster travel times for the vehicle, more efficient boarding and alighting operations, and a reduction in the time the bus is stopped in traffic.

The following are some of the potential TSP operational conditions that may be considered for the GRTC project.

4.4.1. PASSIVE PRIORITY

Passive signal priority provides an advantage to transit vehicles traveling along a corridor without the vehicle communicating with the traffic signal to acquire priority. This is typically done through improvements in signal timing to provide progression for the buses and account for the differences in travel speeds between cars and buses, providing preference to buses versus cars. Passive timing changes can be accomplished on an intersection-by-intersection basis or for an entire corridor, depending upon the extent of priority needed.

Advantages can also be gained through the coordination or retiming of signals to accommodate bus travel patterns. This gives the bus a priority over general traffic and reduces delays for the bus, improving travel time for the passenger.

4.4.2. ACTIVE PRIORITY

Active TSP is the process by which an advantage is given to transit vehicles operating along the corridor through the traffic signals. The advantage can be received through the extension of green time for buses approaching an intersection or advancing green time for buses waiting at the red phase. The use of TSP can be scheduled for all-day, during peak hours, or some other defined time period of the day. Signal priority can be implemented at single intersections or throughout an entire corridor. More advanced signal priority systems can be tied to the bus schedule, only giving priority when a bus is behind schedule. One other option includes headway consistency, where a transit priority is granted if buses are behind a pre-defined headway. Other systems provide the benefit to the bus every time it approaches an intersection regardless of schedule. The latter ensures that buses not only remain on schedule, but also improve overall travel times. Figure 7 shows the theory behind active priority.
4.4.3. EARLY GREEN AND EXTENSION OF GREEN

An early green strategy shortens the green time of preceding phases to expedite the return to green (i.e., red truncation) for the movement where a TSP equipped vehicle has been detected and the priority logic has been satisfied. This strategy only applies when the signal is red for the approaching TSP-equipped vehicle. Typically, the Early Green interval is set at up to 20% of the cycle length or 10 seconds minimum. Depending on the typical queue length, this amount may be increased to allow more vehicles to get the advantage of the Early Green, and clear the intersection, including the transit vehicle. Since it is desired that the cycle return back to normal coordination and be in-sync with the signal coordination, too long of an interval will reduce the possibility of the signal getting back in coordination thereby minimizing impacts to the background cycle length, during signal coordination. Figure 8 shows how early green operation works.
A green phase extension strategy extends the green time for the TSP movement when a TSP-equipped vehicle is approaching and the priority logic has been satisfied. This strategy only applies when the signal is green for the approaching TSP equipped vehicle. Green extension is one of the most effective forms of TSP since a green extension does not require additional clearance intervals, yet allows a transit vehicle to be served, and significantly reduces the delay to that vehicle relative to waiting for an early green or special transit phase. Typically, the Extension of Green interval is set to a maximum time of up to 20% of the cycle length or 10 seconds minimum. The extension of green will be truncated, once the bus leaves the intersection.

Figure 9 shows how extension of green operations works.

Figure 10 shows a flow chart for typical early green and extension of green operations.
4.4.4. PHASE INSERTION AND PHASE ROTATION

Phase Insertion is a terminology that refers to the condition when a special priority phase is inserted within the normal signal sequence. The phase is only inserted when a transit vehicle is detected and requests priority for this phase. An example would be an exclusive transit phase or when there is an insertion of a leading left-turn-only phase for transit vehicles entering an off-street terminal on the opposite side of the street. The controller must possess the ability to process that additional phase, beyond the normal eight-phase limitation (if needed). Figure 11 shows an example of an exclusive bus phase implemented by phase insertion.
Phase Rotation is a terminology that refers to the order of signal phases to provide TSP. For example, a northbound left-turn phase could normally be a lagging phase, meaning it follows the opposing southbound through signal phase. A northbound left turning bus requesting priority that arrives before the start of the green phase for the through movement could request the left-turn phase. With the phase rotation concept, the left-turn phase could be served as a leading phase in order to expedite the passage of the transit vehicle.

4.4.5. QUEUE JUMP OPERATION

The actuated transit phases TSP strategy provides an actuated phase when transit vehicles are detected. Following priority activation, an actuated phase that is not typical to normal operations is initiated for transit vehicles. Typical actuated transit phases include QJ phases.

QJ operation allows the transit vehicles to bypass regular traffic, through either a separate turn-bay, through a right-turn lane, or at a transition lane between exclusive transit lanes and mixed flow lanes, through the use of special bus phasing operation. The bus bay allows the bus to proceed straight through the intersection, bypassing traffic at the intersection to access a far-side bus stop or to continue without waiting at the intersection. The use of a QJ and signal priority treatments can provide a means for transit to gain an advantage over general traffic when used in conjunction with a near-side bus stop or at a transition point. QJs and signal priority can also be an effective way to provide time savings to buses in corridors in which it is not feasible to dedicate the entire corridor as exclusive transit lanes. The bus would travel in mixed traffic until it reaches the QJ and bypasses traffic before proceeding through the intersection.

While not providing the level of priority an exclusive transit lane does, the QJ provides a certain level of time savings the bus would not otherwise receive. The QJ operation, however, requires either a dedicated bus bay or a shared right-turn lane. Due to the advantage of a QJ operation, it should be considered wherever there is an...
appropriate right-turn lane, room for an additional lane, or at a transition point between dedicated and mixed flow lanes. Figure 12 shows a typical queue jump operation for a combined BRT/right turn lane, in accordance with Manual of Uniform Traffic Control Device (MUTCD) signal display layout.

Figure 12 – Typical Queue Jump Photo

4.5. TSP Control Options

Priority logic is the set of parameters defined to either grant or deny a priority request, depending on several factors. Advantages for each option will be explored in detail.

4.5.1. ALWAYS-ON

The “Always-On” operation will grant priority at all times, when a bus is in operation, independent of schedule or headway. This option provides maximum benefit to the transit vehicles. It provides an advantage to a bus vehicle, regardless of its schedule (on, ahead, or behind schedule). The “Always On” operation can be programmed on a time of day or day or week basis as well. In such an operating condition, TSP will be granted during certain times of day or days of week. For example, a TSP can be granted during non-peak hours. The advantage of “Always On” system is simplicity in operation and the advantage that it can provide to transit vehicles.

If the “Always On” logic is selected, that decision can be made locally at the controller level, with firmware capability added. If the TSP firmware does not already exist in the traffic signal controller, there is a license and integration cost to enable this capability.

4.5.2. HEADWAY BASED

In a headway-based operation, the priority logic will be granted based on a pre-defined headway between buses. The headway parameter can be user defined and can be variable based on time of day, day of week, or any other desired parameters. The bus transmits its priority request to the intersection, and the PRS will manage the priority activity to maintain the desired headways between buses. Buses that arrive sooner than the headway will not receive priority and those that arrive later will get the benefit of priority.
The headway-based priority is not dependent on the bus schedule. Once the first bus travels along the corridor, subsequent buses, independent of direction, will set an established headway. This headway, as described earlier, can be changed during the day, based on the bus schedule or priority request importance. A headway-based system manages to provide an advantage to the buses that are behind schedule (indirectly) by maintaining a consistent headway among the bus fleet. It also tends to reduce “bunching” of the buses and improve system operation. Buses which are running faster than anticipated are “penalized” by denying the priority request as the goal is to maintain a consistent headway among the buses.

### 4.5.3. SCHEDULE BASED

In a Schedule-Based operation, the priority logic will be granted based on the actual, real-time location of the buses. A priority will be granted if a bus is behind a pre-defined schedule, based on the Automatic Vehicle Location (AVL) system described in Section 6.1 of this SEMP. The AVL system must receive information from scheduling software / databases to compare actual bus location to the bus’s schedule. This is a key portion of the conditional priority system because only late buses should receive signal priority. This will create a more efficient use of the signal priority modifications at the intersection, where only priority is granted if a bus is behind schedule. This system requires a robust communications system and an updated schedule database of the bus operation.

### 4.6. Adaptive Transit Signal Priority

Adaptive TSP provides priority while simultaneously optimizing general traffic progression and vehicular delays. Adaptive signal control systems continuously monitor traffic conditions and adjust control strategies. When using an adaptive system it is possible to take into account person delay, transit delay, vehicle delay, and / or a combination of these criteria.

To take advantage of adaptive signal control systems, TSP would typically require early detection of a transit vehicle in order to provide more time to adjust the signals to provide priority while minimizing traffic impacts. Adaptive systems combined with TSP also may require the ability to update the transit vehicle’s arrival time, which can vary due to the number of stops and traffic conditions. The updated arrival time can then be fed back into the process of adjusting the signal timings.

Typically, an adaptive TSP needs to have the following components:

1. A detection means that allows accurate prediction of bus time-to-arrival to the intersection in real-time when vehicle is within a specified range
2. A traffic detection system
3. A signal control algorithm that adjusts the signals to provide priority while explicitly considering the impacts on the rest of the traffic and ensuring pedestrian safety
4. A vehicle to infrastructure communication links; PRG(s), a PRS, and a control system with real-time signal timing strategies to facilitate adaptive TSP

### 4.7. TSP Architecture

TSP systems consist of three components: the PRG (detection device), the PRS (signal controllers and embedded priority logic), and the support systems that allow the agencies access to data for management of the system (transit monitoring system). There are three options for generating the priority requests: a distributed system, a centralized system, and a “Smart Bus” concept. The following is a general description of each option. Since most of the traffic signals are interconnected to the City of Richmond’s Centracs system, City of Richmond is shown as the central connection to the traffic controller. For this project, Henrico County and VDOT can either connect to the City of Richmond system or operate on a distributed (standalone system).
4.7.1. DISTRIBUTED SYSTEM

A distributed priority system does not involve a centralized location in the decision making process. All decisions to request and grant priority are made at the local intersection level. A distributed priority system is where the priority request is generated on the transit vehicle and is detected and served at the local traffic signal controller. The signal controller software contains the priority logic and serves the request locally. Also, regardless of which system is used, the controller software must be capable of processing low priority. For this project, a distributed priority system would not involve the GRTC Transit Operations Center or the City of Richmond Traffic Operations Center in the decision making process. A graphic illustrating a distributed system as it pertains to this project is included in Figure 13.

![Figure 13 - Distributed System](image)

4.7.2. CENTRALIZED SYSTEM

The centralized priority system is where the priority request is generated either at the City of Richmond Traffic Operations Center or at the GRTC Transit Operations Center. The decision regarding the location for the centralized system should be made through discussions between the City of Richmond and GRTC.

Priority is granted on the local controller level based on direction from either operations center. This system is advantageous in situations where the local jurisdiction has their signal controllers connected to a centralized system with real-time communication, and the central system has the capability to determine whether to grant priority based on predefined conditions - schedule adherence, headways, conflicting calls, ridership, etc. Another advantage of a centralized system is that all records of the system operation can be maintained centrally and changes can be easily implemented across all systems from the central location. An example of a centralized system configuration is shown below in Figure 14 (using the City of Richmond Traffic Operations Center for illustrative purposes).
There are three variations for a centralized system:

- **Scenario 1** - The Priority Request Generator (PRG) is located on the transit vehicle and there is no direct communication connection between the vehicle and the traffic signal controller. The transit vehicle transmits a priority request to the GRTC Transit Operations Center (TOC), which then forwards the request to the Priority Request Server (PRS). The PRS may exist as a physical device either at the City of Richmond Traffic Operations Center or in the traffic signal controller. Implementation of this scenario requires the transit vehicle to be capable of generating and transmitting a NTCIP 1211 compliant request for priority. Therefore, the transit vehicle must be capable of determining its location and, if conditional priority is being used, generating a request based on specific operating characteristics (e.g. schedule adherence, ridership). Furthermore, the transit vehicle must have the proper communication equipment in order to transmit a NTCIP 1211 message. In order to be effective, this alternative requires second-by-second communications between the transit vehicle and the GRTC Transit Operations Center, between the GRTC Transit Operations Center and the City of Richmond Traffic Operations Center, and between the City of Richmond Traffic Operations Center and the traffic signal controllers. The effectiveness and efficiency of a TSP implementation quickly degrades as the communication latency increases. The polling rates used by many transit agencies to receive messages and data from their transit vehicles may preclude this option.
- **Scenario 2** - The PRG is located in the GRTC Transit Operations Center rather than on the transit vehicle. The GRTC Transit Operations Center makes a decision to request priority, which is then forwarded to the PRS through the City of Richmond Traffic Operations Center. As in the first option, the PRS may be located in the City of Richmond Traffic Operations Center or in the traffic signal controller cabinet. The GRTC Transit Operations Center should make the decision to request priority on information collected from the transit vehicle (e.g., location, ridership, etc.) in real-time, through an AVL system. After the City of Richmond Traffic Operations Center generates the request for priority, this scenario follows the same architecture as Scenario 1. This option is most effective when real-time communication connections exist between the GRTC Transit Operations Center and the City of Richmond Traffic Operations Center and between the City of Richmond Traffic Operations Center and the local traffic controllers. One benefit of this scenario is that the GRTC Transit Operations Center maintains responsibility for all decisions to request priority. The central system can weigh inputs from multiple vehicles in the fleet against each other and decide for which vehicles to generate priority requests. However, the demand on the communication system will be heavier under this scenario as every vehicle is passing information to the GRTC Transit Operations Center rather than only those that have pre-determined a need for priority.

- **Scenario 3** - The PRG is located at the City of Richmond Traffic Operations Center. The information necessary to generate a priority request is channeled to Richmond’s Traffic Operations Center, which contains the processes necessary to determine whether to request priority based on predefined conditions such as schedule adherence, conflicting calls, and ridership. The actual physical routing of information to the City of Richmond Traffic Operations Center may occur in several ways. It is possible that the transit vehicle may communicate with the GRTC Transit Operations Center, which would then communicate with the City of Richmond Traffic Operations Center. A more likely, and efficient, path would be through the local traffic controller to the City of Richmond Traffic Operations Center (recommended option). In this alternative, the fleet vehicle is detected approaching the intersection and the local controller transmits a message to the City of Richmond Traffic Operations Center that a transit vehicle is approaching. The City of Richmond Traffic Operations Center either communicates with the GRTC Transit Operations Center regarding schedule adherence of the approaching vehicle or consults information it has locally regarding transit operations. Based upon that information and other traffic information received from the traffic controller, the decision is made whether to grant priority. The updated signal timing parameters are then sent back to the local controller. The key aspect to the effectiveness of this system is the communications infrastructure, which is proposed as a fiber optic backbone. It is imperative that the communications between the signal controller, the City of Richmond Traffic Operations Center, and the GRTC Transit Operations Center, if involved, happen in a second-by-second fashion, or else communications latency will result in an inefficient priority system.

### 4.7.3. SMART BUS CONCEPT

The Smart Bus Concept is a variation of a distributed system that provides the TSP logic on the bus. The characteristic of this alternative is that the fleet vehicle contains the information necessary to determine whether to request priority based on predefined conditions, which will consider schedule adherence, location, route, doors closed, etc. In order for the vehicle to meet the schedule adherence condition and request priority, the on-board AVL system is integrated with the scheduling system. This is accomplished on-board the vehicle with the AVL system comparing its location to time points in the schedule. The schedule is uploaded to the vehicle daily. Once the vehicle is behind its schedule by a predefined threshold, the priority system is activated. The equipment for TSP is integrated with the schedule status within the AVL or duplicates that information by using the existing data flows within the system. This type of system does not require a center-to-center connection between the GRTC Transit Operations Center and the City of Richmond Traffic Operations Center. **Figure 15** offers a graphical representation of the Smart Bus Concept.
The individual traffic controllers would receive the priority message from the fleet vehicle via the detection hardware located at the intersections. The priority message would be transmitted from the wireless antenna to the signal cabinet, where the priority request is processed and the signal timing parameters are adjusted.

A real-time connection between the traffic signal and the City of Richmond Traffic Operations Center is not required for this distributed alternative to work. The distributed priority system will work regardless of whether a signal system is centralized, closed loop, or isolated, since the ability to request and serve priority rests within the fleet vehicle and the local controller, respectively.

There are some limitations with this type of system. Without connection between the signal controller and the traffic operation center that provides real-time information, feedback may be necessary to inform GRTC whether the TSP system is active and granting priority and which vehicles are being granted priority. The feedback could also identify how frequently priority is being granted at certain locations. This information could then be used when adjusting schedules of a specific route. In lieu of real-time feedback, the signal system can be utilized to record and store the priority request information. Periodically, that information could be processed in the form of status reports.

**Figure 15 – Smart Bus Concept**

4.8. Technology Options

There are four major TSP systems to consider for the GRTC BRT system. The four systems include the GTT system, the Iteris system, the Novax system, and the Emtrac™ system. Custom design systems can also be developed, but there are inherent risks and costs associated with tailored systems and algorithms. Information regarding the details of each system and its capabilities are listed below.
4.8.1. GTT TSP SYSTEM

The Opticom™ system offered by Global Traffic Technologies (GTT) offers two technologies for Transit Signal Priority application: optical / infrared and GPS. The Opticom™ unit also provides an emergency vehicle pre-emption system, using the Infrared or GPS technology, using the same detector system mounted on the signal.

The optical system consists of infrared or light emitting diode (LED) based emitters mounted on board the transit vehicle, detectors mounted on traffic signal mast arms or luminaire arms, and phase selectors installed inside the controller cabinets. The transit vehicle is recognized by the light intensity received by the phase selector through the detector. Once the received light intensity reaches a user-defined level, the phase selector will then process a low priority request to the traffic controller. A higher intensity results in a shorter arrival distance for the bus to the intersection. Today, the optical infrared system is not often used for transit applications due to the high precision requirements for transit vehicle locations, which can be achieved with a GPS based system.

The GPS system consists of a GPS receiver, a radio and vehicle logic unit on board the transit vehicle, a GPS radio unit mounted on a traffic signal pole or on the cabinet, and a phase selector installed inside the controller cabinet. Opticom™ offers phase selectors in GPS and GPS / optical (multimode) configurations which have now become their standard offering for phase selectors. The transit vehicle is recognized by the phase selector by using user-defined detection zones based on GPS coordinates. When a transit vehicle enters the defined detection zone, the phase selector will then process a low priority call to the traffic controller.

Using the multimode equipment, the Opticom™ system is able to function using both GPS and optical (infrared or LED) using the same equipment in the cabinet for both. In addition, GTT offers a hybrid optical / GPS emitter, which consists of an infrared emitter with a GPS unit. This hybrid emitter is used for transit agencies who want to operate TSP in both an infrared and a GPS-based system. The Opticom™ system can process both high priority (Emergency Vehicle Preemption (EVP)) and low priority TSP requests. The intelligence on the bus, and whether or not it can be granted transit priority, lies within the equipment in the cabinet (i.e., phase selector). This unit receives and processes the low priority requests from the buses, and based on pre-defined parameters, the priority request is forwarded to the traffic controller.

The priority logic used with the GTT systems must be integrated with the AVL system, such as a Smart Bus Concept, based upon user defined parameters. The unit does not offer any other internal conditional service capabilities.

The GTT Opticom™ GPS system consists of the following components:

- **On-Vehicle Units** - GPS Vehicle Control Unit, GPS Radio Unit, and GPS / Radio Antenna
- **At Intersection Units** - Cabinet Mount GPS Radio Unit, GPS / Radio Antenna, GPS Auxiliary Interface Panel and GPS Phase Selector
- **Central Management Software (CMS)** - CMS provides a single-system view of the entire Opticom™ priority control system for both the pre-emption or priority calls. Regions utilizing infrared, GPS radio or both priority control technologies can operate as an integrated solution using CMS. Opticom™ CMS is a server-based software program that provides interoperability between traffic, transit, and emergency operations agencies. Remote management of an Opticom™ priority control system is achieved through wide-spread deployment of IP-based communications to the intersection in conjunction with GTT’s central management software package. This would require an Ethernet connection between the phase selector and a communication network to transmit the data to the central location. The Ethernet connection can either be achieved with an Ethernet over copper transmission or on a fiber optic communications backbone. There are no real-time graphical displays, like an AVL system.
4.8.2. ITERIS TSP SYSTEM

Iteris manufactures and provides the Transit Helper™ Transit Priority System. The TSP system utilizes GPS, a wireless LAN (802.11) and the AVL system to track the vehicles position and direction. The central system performs the background calculations and initiates the request for priority to the traffic signal controllers. The vehicles communicate via the wireless LAN with the traffic controllers. Because it uses a wireless LAN, the issue of line of sight for radio communications as well as using optical signals is not much of a concern since the wireless LAN will route the associated TSP information through the network of wireless access points.

The following are the components of the Iteris Transit Helper™ system:

- **Priority Request Generator** – Works with existing on-bus systems that generate transit priority messages. The system must be integrated to an on-board AVL system. The vendor indicated that their system has been tested with all major Computer-Aided Dispatch / AVL systems.

- **Bus to intersection Communication system** – The Iteris wireless solution can be implemented on the 2.4GHz, 5.8 GHz, or the 4.9GHz public safety radio frequency bands, and can be deployed using 5.9GHz DSRC bus-to-intersection communications to align with the FHWA Connected Vehicle Initiative. This infrastructure can also be utilized for additional services such as WiFi Internet access for transit riders, on-bus transit information for patrons, real-time data collection of transit vehicle occupancy as well as real-time distribution of on-bus video for surveillance and security. The system has the following features:
  - IEEE 802.11 Broadband Wireless Network
  - Network Clients
    - Mobile network clients: IEEE 802.11b/g; Installed for transit operations management system data transfers
    - Intersection network clients: IEEE 802.11b/g; Fits in traffic controller cabinet with small omnidirectional antenna
  - Network Access Points
    - Provides wireless bridging at up to 54 Mbps data throughput
    - Provides network access for mobile and intersection network clients
  - Network Backhaul
    - Cellular or DSL for network monitoring
    - Radio or fiber optics for expanded applications
    - Bus-to-intersection message protocol
    - Customized for intersection controller software requirements
    - NTCIP 1211 Compliant
  - Utilizes existing traffic management communications or municipal WiFi infrastructure where available

- **Iteris Transit Helper™ Processor** – An interface used for communication between transit vehicles and intersection traffic controllers.
  - Serial or Ethernet direct interface for select Type 170E, Type 2070 and NEMA-based traffic controllers
  - Processes wireless messages initiated by approaching transit and emergency vehicles
  - Pulsed electrical interface using Iteris Transit Helper™, a hardened priority request server
  - Compatible with emergency vehicle pre-emption (EVP) systems
Central Monitoring and Reporting System

- Predictive and actionable information
- Cost of delay and congestion to network
- Real-time vehicle locations and status
- Detailed transit line analytics for operations
- Integrated intelligence simplified for system optimization
- Visualization of transit line load and schedule adherence
- Iteris NetScene™
  - Wireless network health and performance monitoring
  - SNMP-Based network management
  - Remote configuration of network ITS equipment

4.8.3. NOVAX TSP SYSTEM

Novax Industry manufactures and provides the TransPOD™ Transit Signal Priority system, in combination with third party communication equipment. TransPOD™ uses open protocols to enable conditional and adaptive priority, real time remote telemetry and logging, and AVL as well as other system capabilities. TransPOD™ equipped buses act as independent autonomous units with no dependence on central control. Each TransPOD™ bus has an advanced positioning system that allows the bus to determine its location. This is accomplished by a combination of GPS devices with inertial navigation and distance measurement. The unit is a self-calibrating system that operates in urban canyons, underground parking lots, and open spaces.

The wireless broadband communications system creates a network of buses and intersections as if they were in the same building connected with network cables. The on-street network can also be connected to a command center to facilitate real-time remote monitoring.

There are a number of different approaches in the determination of the need for priority. TransPOD™ can deliver TSP based on unconditional priority, as well as conditional priority based on schedule or headway.

TransPOD™ can also enable the following TSP strategies:

- Conditional priority based on real-time traffic conditions – A TransPOD™ equipped transit vehicle is aware of its position and speed as well as the location of the upcoming intersection and as such can be programmed to predict its arrival time at the intersection.
- Conditional priority based on passenger counts – A TransPOD™ equipped transit vehicle can interface with an onboard APC system and can determine the need for priority based on passenger load.

TransPOD™ components include the following:

- **Priority Request Generator** (Vehicle Resident Hardware) – The PRG is an embedded computer that requests priority (checks in) as the vehicle approaches a signalized intersection and indicates that priority is no longer required when entering the signalized intersection (checks out). The PRG offers flexibility as it can interface with AVL or other onboard systems and sensors; overlapping check-ins and provide priority by direction or time of day.
- **Position Determination System (PDS)** (Vehicle Resident Hardware) – The PDS combines GPS with ‘dead reckoning’ technology to provide dynamic positioning information to the PRG.
- **Mobile Mesh Network Router** (Vehicle Resident Hardware) – A broadband communications device that ‘networks’ moving vehicles with a fixed mesh network. The mobile mesh router has resources for low latency telemetry and other uses such as on demand full motion emergency video from a moving vehicle.
- **Priority Request Server** (Intersection Resident Hardware) – An embedded computer that interfaces with traffic signal controllers at signalized intersections. The PRS provides whatever traffic signal controller input is required; typically a closed contact or 6.25 Hz pulsed signal. Lightning suppression is in keeping with NEMA standards.

- **Outdoor Mesh Network Router (Node)** (Intersection Resident Hardware) – The outdoor mesh network router is the wayside communication device that establishes a fixed wireless network to ‘network’ vehicles and signalized intersections. Based on the size of the mesh network and bandwidth requirements one or more outdoor mesh network routers will be configured as gateways to connect the mesh network to a backhaul network, to NEMS (further defined below) and an operations management center.

- **Backhaul Network** – A wireless mesh network requires a connection or number of connections to a backbone communication network to facilitate communication from within the network to outside of the network. Backhaul circuits may be provisioned with copper wire, fiber optics, or wireless facilities and must be capable of supporting an IP-based connection preferably using an Ethernet interface and transmission layer. The wireless mesh network and its components are WPA2/802.11i capable. Connectivity via the Internet from the wireless network to the NEMS uses IPSec-capable routers for secure communications at both the network and the NEMS gateway. Communications take place via a secure encrypted tunnel inside the Internet. User access to the NEMS and the active PRG and PRS components is controlled using multi-level access control providing view only to full configuration control of the system.

- **Novax Elements Management System (NEMS)** - The NEMS is a server / software package that facilitates remote logging, equipment configuration, and performance management of vehicle and signalized intersection components of the TransPOD system. The NEMS is connected to a wireless mesh network through wired or wireless backhaul connections directly or through a VPN tunnel. The management unit provides logging of TSP activity and real-time monitoring of bus location on the system.

### 4.8.4. EMTRAC™ TSP SYSTEM

The Emtrac™ system offers a GPS / radio based TSP system. It consists of a GPS and radio antenna and a GPS / radio unit installed within the transit vehicle, a radio antenna mounted on a traffic signal pole or cabinet, and a receiver / detector module installed within the controller cabinet. Emtrac™ does not offer an optical-based TSP system, but can process both high and low priority requests. The TSP detection system uses detection zones along the approaches to the intersection. Each detection zone can be up to 3000 feet in length. Once the transit vehicle enters the detection zone using the GPS location coordinates, the on board GPS / radio unit communicates with the receiver / detector module in the traffic controller cabinet relaying the request for transit priority service. The Emtrac™ system provides the intelligence for the bus and the conditions for low priority within the on-board equipment such as the bus ID and whether or not the bus can ask for, and be granted, transit priority. The equipment in the cabinet is designed to simply receive and forward the TSP request to the traffic controller. The components communicate wirelessly using Frequency-Hopping Spread Spectrum radio. Mobile components, such as the Vehicle Control Unit, utilize GPS and internal navigation to determine locations at all times.

Conditional Priority application conditions need to be integrated with the AVL system. The logic function can either be set by the AVL system or through the Emtrac™ Vehicle Control Unit. For example, with conditional signal priority, a green phase is not requested unless specified conditions are met. Buses may be configured to request signal priority only when behind schedule by a set number of minutes. When the on-board schedule-adherence system recognizes that the bus is behind schedule, the Emtrac™ system requests a green phase(s) through intersections until the bus is on schedule once again.
The Emtrac™ system is capable of requesting signal priority based on any number of situational factors. Conditional factors include:

- **Schedule Adherence**: Priority is requested only when the bus is a set number of minutes behind schedule.
- **Transit Headway**: Priority is requested or denied based on the amount of time between buses on the same route, enabling transit agencies to avoid bus bunching.
- **Estimated Time of Arrival**: Priority is anticipated by the signal controller and is granted when the bus is a pre-defined number of seconds from the intersection.
- **Door Status**: Priority is requested when the doors open or closed at near-side bus stops. Requests are not sent when the doors are open or a stop has been requested.
- **Passenger Count**: Priority is requested when the number of passengers exceeds a pre-defined threshold.

The main components of the Emtrac™ system include:

- **Vehicle Control Unit** – This unit is installed behind interior panels of the bus emitting the radio signals. A GPS / UHF antenna is mounted on the top of the vehicle. Features of the unit include:
  - 900 MHz, frequency-hopping spread spectrum radio with secure encryption
  - Typical transmission range of 3,000 feet, enabling approach zones of the same length
  - Capable of communications through Ethernet, RS-232, or wireless connection
  - Capable of storing up to 5,000 intersection approach zones
  - Ability to accept multiple inputs to prompt priority requests, including bus-door or pull cord activity, schedule adherence, passenger count, and emergency light-bar.
  - Time-out feature configurable to cease transmission after designated amount of inactivity
  - Programmable with Windows XP, Vista, 7 (or later) operating systems

- **Intersection Components** – Priority Detector: This unit is available in either a rack-mount version (for Model 170 controllers) or a shelf-mount version (for NEMA-based controllers). An omni-directional antenna mounts on a traffic pole (or traffic cabinet) at each equipped intersection.

- **Vehicle Integrator** – A unit that is installed on the bus. As the bus returns to the garage after its shift, the Vehicle Interrogator wirelessly downloads activity logs from the onboard VCUs. As with other Emtrac™ components, the Vehicle Interrogator uses Frequency Hopping Spread Spectrum radio to facilitate communication. Downloaded logs are saved on the Central Monitor server and are accessible from connected workstations. The Central Monitor automatically emails saved logs to designated personnel on a daily basis. In addition to data downloads, the Vehicle Interrogator also offers the ability to upload firmware or database updates to VCUs.

- **Central Monitoring Unit (CMU)** – The Central Monitor application is an Automatic Vehicle Location (AVL) system that enables monitoring personnel to track vehicle activity in real time while vehicle locations are displayed on integrated maps. Agencies are able to designate key events that trigger alarms to notify workers at central locations. The CMU has the following features and capabilities:
  - Integrated map display of city streets, showing location and activity for multiple equipped vehicles and personnel
  - Ability to monitor vehicle “events” by user-definable types
  - Audible and pop-up alarms notify control center personnel of critical events
  - Automatically generates user-definable reports, which can be automatically archived and/or emailed on a recurring basis.
  - Verifies proper system functionality by monitoring signal controller responses to priority requests.
  - Remotely checks Emtrac™ system diagnostics.
4.9. Recommendations
The GTT TSP System (Opticom™ GPS) is the recommended technology for the BRT Project. The GTT infrared Emergency Vehicle Preemption system is currently deployed by VDOT and Henrico County. The GTT Opticom™ system has the capability to process both high priority (Emergency Vehicle Preemption) and low priority (Transit Signal Priority) requests. Selection of the GTT Opticom™ GPS System will have the ability to integrate the current infrared Emergency Vehicle Preemption system with the proposed GTT GPS unit for TSP by installing a dual card in the signal cabinets and a GPS receiver on the signal pole. While Henrico County and VDOT will be operating TSP equipment in their jurisdiction, the ultimate system selection should be based on City of Richmond input due to longer term operations and maintenance considerations with a greater number of impacted intersections.
5. Traffic Signal Upgrades

Improved signal coordination is a requirement for successful BRT implementation. Signal coordination will be used to improve travel times along the corridors and assist in keeping transit vehicles on schedule by utilizing signal priority. To accomplish signal coordination, traffic signals along the corridors need to be interconnected so all signals can be controlled and the optimal timing plan for the corridors can be implemented. Signal timing at each intersection can be modified to accommodate the traffic demand during recurring congestion and also in response to incidents.

5.1. Traffic Signal Infrastructure Upgrades

To accommodate BRT operations along the project corridor, several signalized intersections must be rebuilt or modified and several stop controlled intersections must be converted to signalized intersections. Table 5.1 identifies these intersections and provides justification for the proposed upgrades. Figure 16 shows the location of signalized intersections along the project corridor to accommodate BRT operations.

Table 5.1 – Traffic Signal Upgrades

<table>
<thead>
<tr>
<th>Signal Rebuilds</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad Street and Cleveland Street</td>
<td>This intersection needs to accommodate BRT median operations for which transit signal heads will need to be installed. Existing mast arms are too short to accommodate transit signal heads.</td>
</tr>
<tr>
<td>Broad Street and Altamont Avenue</td>
<td>Existing signal poles in the median would need to be removed and new signal poles installed curbside so this intersection can accommodate BRT median operations.</td>
</tr>
<tr>
<td>Broad Street and Sheppard Street</td>
<td>Existing signal poles in the median would need to be removed and new signal poles installed curbside so this intersection can accommodate BRT median operations. Since westbound left-turn movements will be prohibited at this intersection, the protected / permissive five-section signal head must be removed and left-turn restriction signs added. Although eastbound left-turn movements are currently allowed at this intersection, the permissive three-section signal head must be replaced with a protected only three-section signal head.</td>
</tr>
<tr>
<td>Broad Street and Boulevard</td>
<td>This intersection needs to accommodate BRT median operations for which transit signal heads will need to be installed. Existing mast arms are too short to accommodate transit signal heads. In addition, westbound left-turn movements will no longer be prohibited so a protected only three-section signal head must be installed.</td>
</tr>
<tr>
<td>Broad Street and Robinson Street</td>
<td>This intersection will serve as one of the BRT median stations. Thus, the existing signal poles in the median would need to be removed and new signal poles installed curbside. In addition, since westbound left-turn movements will be prohibited at this intersection, the protected / permissive five-section signal head must be removed and left-turn restriction signs added.</td>
</tr>
<tr>
<td>Broad Street and Davis Street</td>
<td>Existing signal poles in the median would need to be removed and new signal poles installed curbside so this intersection can accommodate BRT median operations. Although eastbound left-turn movements are currently allowed at this intersection, the permissive three-section signal head must be replaced with a protected only three-section signal head.</td>
</tr>
<tr>
<td>Broad Street and DMV Drive</td>
<td>This intersection needs to accommodate BRT median operations for</td>
</tr>
</tbody>
</table>
### Signal Modifications

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Broad Street and Ryland Street</td>
<td>The existing mast arms are too short to accommodate transit signal heads. The eastbound protected/permissive five-section signal head must be replaced with a protected only three-section signal head.</td>
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</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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<tbody>
<tr>
<td>Broad Street and Roseneath Road</td>
<td>The intersection needs to accommodate BRT median operations for which transit signal heads will need to be installed. Existing mast arms are too short to accommodate transit signal heads. Since westbound left-turn movements will be prohibited at this intersection, the protected/permissive five-section signal head must be removed and left-turn restriction signs added.</td>
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<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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<tbody>
<tr>
<td>Broad Street and Terminal Place</td>
<td>The protected/permissive five-section signal head will be replaced by a protected only three-section signal head. Although eastbound left-turn movements are currently allowed at this intersection, the protected/permissive five-section signal head must be replaced with a protected only three-section signal head.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Broad Street and Hermitage Road</td>
<td>Westbound left-turn movements will no longer be prohibited so a protected-only three-section signal head must be installed. Although eastbound left-turn movements are currently allowed at this intersection, the protected/permissive five-section signal head must be replaced with a protected only three-section signal head.</td>
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<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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<tbody>
<tr>
<td>Broad Street and Allen Avenue</td>
<td>Although eastbound left-turn movements are currently allowed at this intersection, the protected/permissive five-section signal head must be replaced with a protected only three-section signal head.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Broad Street and Lombardy Street</td>
<td>Since westbound left-turn movements will be prohibited at this intersection, the protected/permissive five-section signal head must be replaced with a protected only three-section signal head. Left-turn restriction signs added.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Broad Street and Bowe Street</td>
<td>Although eastbound left-turn movements are currently allowed at this intersection, the protected/permissive five-section signal head must be replaced with a protected only three-section signal head.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Broad Street and Harrison Street</td>
<td>Although westbound left-turn movements are currently allowed at this intersection, the protected only three-section signal head must be replaced with a protected only three-section signal head.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Broad Street and Laurel Street</td>
<td>Since westbound left-turn movements will be prohibited at this intersection, the protected/permissive five-section signal head must be replaced with a protected only three-section signal head. Left-turn restriction signs added.</td>
</tr>
</tbody>
</table>

### New Signalized Intersections

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad Street and Byrd Avenue</td>
<td>This intersection will serve as a turn-around point at the western terminus of the BRT corridor. Signalization is required in order to provide priority to the BRT.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad Street and Monroe Street</td>
<td>This intersection will provide vehicular cross access. Signalization is required to safely move vehicles across the exclusive median BRT lanes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Street and Orleans Street</td>
<td>This intersection will serve as a turn-around point at the eastern terminus of the BRT corridor. Signalization is required in order to provide priority to the BRT.</td>
</tr>
</tbody>
</table>
**Figure 16 – Signalized Intersections for BRT Operations**

**Legend**

- Traffic Signal
- Median

**GRTC Bus Rapid Transit Project**

**Signalized Intersections for BRT Operations**

**Figure 16A**
Figure 16 – Signalized Intersections for BRT Operations

GRTC Bus Rapid Transit Project
Signalized Intersections for BRT Operations

Figure 16B
Figure 16 – Signalized Intersections for BRT Operations

GRTC Bus Rapid Transit Project
Signalized Intersections for BRT Operations
5.2. Controller and Cabinet Upgrades

In order to provide the functionality of transit queue jump phases at select intersections and TSP at all intersections along the corridor, it is necessary to upgrade some controllers (including firmware) and traffic signal cabinets. Transit queue jump phases are planned to be implemented at the intersections of Broad Street and Thompson Street and Broad Street and Foushee Street.

The Econolite controller firmware should support TSP. From conversations with Econolite, this will be accomplished through an upgrade of the firmware to version 2.63. The intersections of Broad Street and Willow Lawn Drive and Main Street and Williamsburg Road are currently operating with Eagle EPAC M40 controllers. Because the M40 series controllers cannot implement TSP, these existing controllers should be replaced with Econolite controllers to allow integration and full TSP functionality along the entire corridor. If VDOT prefers not to switch controller platforms from Eagle to Econolite at the intersection of Broad Street and Willow Lawn Drive, the Eagle EPAC M50 series controllers do have TSP capability as well.

It may be necessary to upgrade some traffic signal cabinets. The majority of the existing cabinets are NEMA TS-1. Where there are not enough available load switches to accommodate proposed transit queue jump phases or additional protected left-turn phases, the cabinets may need to be upgraded to NEMA TS-2 cabinets which can accommodate 16 load switches. Table 5.2 summarizes the existing signal inventory for the 52 signals along the proposed BRT alignment.

<table>
<thead>
<tr>
<th>Table 5.2</th>
<th>Summary of Existing Signal Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection</td>
<td>Maintaining Jurisdiction (City, County, or VDOT)</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Willow Lawn Drive and Markel Road</td>
<td>County</td>
</tr>
<tr>
<td>Broad Street and Willow Lawn Drive</td>
<td>VDOT</td>
</tr>
<tr>
<td>Broad Street and Staples Mill Road</td>
<td>City</td>
</tr>
<tr>
<td>Broad Street and Westmoreland Street</td>
<td>City</td>
</tr>
<tr>
<td>Broad Street and Commonwealth Avenue</td>
<td>City</td>
</tr>
<tr>
<td>Broad Street and Malvern Ave</td>
<td>City</td>
</tr>
<tr>
<td>Broad Street and Hamilton Street</td>
<td>City</td>
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<tr>
<td>Broad Street and Thompson Street</td>
<td>City</td>
</tr>
<tr>
<td>Broad Street and Roseneath Road</td>
<td>City</td>
</tr>
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<td>Broad Street and Cleveland Street</td>
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5.3. Vehicle Detection Upgrades

Intersection detection is typically used to alert the controller that a vehicle is present at a particular approach or movement. This allows the controller to operate the signal in actuated control and provides an ability to create a larger coordinated green band for the major street. For the BRT operation, vehicle detection is only needed for the side streets, if not currently available. A vehicle detection system also provides the capability to measure volumes, speed, occupancy, vehicle classification, and level of congestion on the corridor.

There are several different technologies that can be used to identify vehicles on the system. The conventional in-pavement loop detectors identify vehicles using an electrical current and sensing when an object breaks the magnetic field created by the electrical current. Non-Intrusive detectors are an alternative to the conventional loops. The most common non-intrusive detectors use either radar (MVDS – Microwave Vehicle Detection System), sound (PADs – Passive Acoustical Detectors), or video (VIDs – Video Image Detectors), to detect and classify vehicles. The technologies are continually being refined in an effort to provide more accurate and reliable data. Recent advances in non-intrusive detection equipment have resulted in technically sound and financially viable alternatives to conventional methods of in-pavement loop detection. Because of this, non-intrusive detection technology is often used for applications where inductive loop detectors are not feasible. Table 5.3 identifies the advantages and disadvantages of vehicle detection alternatives.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Inductive Loop</td>
<td>• Flexible design to satisfy large variety of applications.</td>
<td>• Installation requires pavement cut.</td>
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<td>• Mature, well understood technology.</td>
<td>• Decreases pavement life.</td>
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<td></td>
<td>• Large experience base.</td>
<td>• Installation and maintenance require lane closure.</td>
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<td></td>
<td>• Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap).</td>
<td>• Wire loops subject to stresses of traffic and temperature.</td>
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<td></td>
<td>• Insensitive to inclement weather such as rain, fog, and snow.</td>
<td>• Multiple detectors usually required to monitor a location.</td>
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<td></td>
<td>• Provides best accuracy for count data as compared with other commonly used techniques.</td>
<td>• Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.</td>
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<td></td>
<td>• Common standard for obtaining accurate occupancy measurements.</td>
<td>• Difficult to maintain / operate during intersection construction or repaving projects.</td>
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<td></td>
<td>• High frequency excitation models provide classification data</td>
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<tr>
<td>Magnetometer (Two-axis fluxgate magnetometer)</td>
<td>• Less susceptible than loops to stresses of traffic.</td>
<td>• Installation requires pavement cut.</td>
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<td></td>
<td>• Insensitive to inclement weather such as snow, rain, and fog.</td>
<td>• Decreases pavement life.</td>
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<tr>
<td></td>
<td>• Some models transmit data over wireless RF link.</td>
<td>• Installation and maintenance require lane closure.</td>
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<td>• Wireless RF models can be removed and reinstalled during repaving projects.</td>
<td>• Models with small detection zones require multiple units for full lane detection.</td>
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<td></td>
<td></td>
<td>• Difficult to maintain / operate during intersection construction or repaving projects.</td>
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<tr>
<td>System</td>
<td>Advantages</td>
<td>Disadvantages</td>
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<td>------------------------</td>
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| Magnetic (Induction or search coil magnetometer) | - Can be used where loops are not feasible (e.g., bridge decks).  
- Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required.  
- Insensitive to inclement weather such as snow, rain, and fog.  
- Less susceptible than loops to stresses of traffic. | - Installation requires pavement cut or boring under roadway.  
- Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.  
- Difficult to maintain / operate during intersection construction or repaving projects. |
| Microwave Radar        | - Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications.  
- Direct measurement of speed.  
- Multiple lane operation available.  
- Adaptable to intersection/pavement changes during reconstruction. | - CW Doppler sensors cannot detect stopped vehicles. |
| Active Infrared (Laser radar) | - Transmits multiple beams for accurate measurement of vehicle position, speed, and class.  
- Multiple lane operation available. | - Operation may be affected by fog when visibility is less than 20 feet (6 m) or blowing snow is present.  
- Installation and maintenance, including periodic lens cleaning, require lane closure. |
| Passive Infrared       | - Multizone passive sensors measure speed. | - Passive sensor may have reduced sensitivity to vehicles in heavy rain and snow and dense fog.  
- Some models not recommended for presence detection. |
| Ultrasonic             | - Multiple lane operation available.  
- Capable of overheight vehicle detection.  
- Large Japanese experience base. | - Environmental conditions such as temperature change and extreme air turbulence can affect performance.  
- Temperature compensation is built into some models.  
- Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds. |
| Acoustic               | - Passive detection.  
- Insensitive to precipitation.  
- Multiple lane operation available in some models.  
- Adaptable to intersection/pavement changes during reconstruction. | - Cold temperatures may affect vehicle count accuracy.  
- Specific models are not recommended with slow moving vehicles in stop-and-go traffic. |
The City of Richmond is moving towards nonintrusive detection technologies as they are easier to maintain; video detection is the City’s preferred option for this reason. Because agency preferences should be taken into account, it is recommended that video image processors be used for vehicle detection technology. This will allow the City of Richmond to maintain consistency with its existing detection devices for maintenance purposes.

### 5.4. Pedestrian Push Button Upgrades

Pedestrian push buttons are used to place a call to the controller for pedestrian crossings. In areas where the pedestrian levels are lower, pedestrian push buttons can be used to serve pedestrians only when there is demand. This helps to reduce the intersection delay by eliminating the need to include pedestrian walk and clearance time in every cycle. For BRT operations, additional pedestrian push buttons are only needed to cross the main street, if not available. The existing signalized intersections listed in **Table 5.4** below require the addition or upgrade of pedestrian push buttons. At intersections with proposed median running stations, pedestrian push buttons will need to be installed in the median in addition to the corners. Ramp conditions should be reviewed to comply with the Americans with Disabilities Act (ADA) requirements at locations where there will be a construction alternation to the existing pedestrian facilities.

Standard as well as audible and tactile pedestrian push buttons are available. Audible push buttons provide additional functionality for the visual impaired by playing a sound or message. A tactile pedestrian push button vibrates or includes a light indicator to assist the hearing impaired.
5.5. Recommendations

Traffic signal infrastructure improvements will be needed to accommodate GRTC BRT operations. In order for signal coordination to work effectively along the BRT corridor, all controller clocks must be synched to a common time source between the City of Richmond, Henrico County, and VDOT. Any new controllers installed within the City of Richmond or Henrico County should be Econolite ASC/3 with version 2.63 firmware capable of running Traffic Signal Priority. The new traffic controllers installed within VDOT jurisdiction (intersections of Broad Street and Willow Lawn Drive and Broad Street and Byrd Avenue) should either be an Econolite ASC/3 or an Eagle EPAC M50 depending on VDOT’s preference. If an Eagle EPAC M50 is installed, a GPS time source should also be installed to allow for coordination with adjacent intersections running Econolite controllers connected to the Centracs central system time source.

Any new traffic signal cabinets should be NEMA TS-2. A final decision on vehicle detection technology should be discussed with the City of Richmond, Henrico County, and VDOT as they will own and maintain installed detection equipment. GRTC and the City of Richmond should discuss whether audible pedestrian signals are needed, particularly for median station locations. Pedestrian countdown signal heads and push buttons should be installed for all intersections along the BRT corridor.

Table 5.4 – Necessary Pedestrian Push Button Additions / Upgrades

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<th>Intersection</th>
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<td>Main Street and Williamsburg Avenue</td>
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6. In-Vehicle Systems

The in-vehicle systems consist of the technology items that will interact with the BRT system. These include the following systems:

- Automatic Vehicle Location / Global Positioning System
- Automated Passenger Count (APC) System
- Automated Annunciation System (AAS)
- On-Board Closed Circuit Television (CCTV)
- Pedestrian Warning System
- On-Board Wi-Fi

Since GRTC has selected the GILLIG BRT Plus vehicles, the typical equipment that is installed should be compatible with the existing GRTC fleet. Therefore, this chapter does not provide technology evaluation, but identifies which of these technologies are capable of interfacing with the proposed BRT system. Equipment will most likely be ordered from the current system vendors and installed at the GRTC Transit Operations Center prior to project commissioning.

6.1. Automatic Vehicle Location (AVL) System

GRTC has implemented the Clever Devices AVL system for its current fleet. The proposed BRT system will also include the equipment and technology components that would be compatible with the current Clever Devices technology. Clever Devices system, also referred to as CleverCAD®, is a Computer Aided Dispatch (CAD) / AVL system which supports a number of technologies through mobile voice and data communications to provide information on the real-time bus location. The system includes the Intelligent Vehicle Network® (IVN®), which contains Vehicle Logic Unit (VLU) and Mobile Data Terminal (MDT). The vehicle location GPS data is transmitted by data radio once every thirty seconds from each vehicle to the servers located at the GRTC Transit Operations Center. The GRTC Transit Operations Center passes next stop information to the vehicle that requires it. In addition, the CAD / AVL system provides vehicle trip characteristics allowing GRTC to make informed decisions regarding operational issues improving response time to customers. The AVL / GPS unit can provide the position of the buses for TSP activation and interfaces with the traffic signal system; however, the frequency of vehicle location data would have to be increased to once per second.

6.2. Automated Passenger Count (APC) System

The Automated Passenger Count (APC) System, which is provided by the Clever Devices, is used to identify the people entering and exiting the bus to determine the bus ridership by time of day. The unit is known as CleverCount® APC unit. The APC does not necessarily interface with the BRT system, unless the TSP logic includes passenger loading as a criteria for TSP activation.

6.3. Automated Annunciation System (AAS)

The Automated Annunciation System (AAS) is integrated with the Clever Devices CAD / AVL system and provides the next-station announcement with corresponding LED signs. This feature consists of an audio and visual annunciation system consisting of LED next stop sign and public address (PA) components. The AAS system does not typically interface with other BRT components and is considered a customer amenity that enhances transit service.
6.4. **On-Board Closed Circuit Television (CCTV)**

To improve the ability to view the in-vehicle bus activities, an on-board security camera system is used on GRTC buses. Currently, GRTC uses the Apollo CCTVs and records the CCTV images for a period of seven days. For consistency, the same equipment should also be installed on the BRT vehicles. It is recommended that each BRT vehicle be equipped with at least five cameras to provide full coverage of the vehicle interior. A digital video recorder (DVR) on-board each BRT vehicle will be setup to loop the footage. Current procedures for record keeping are adequate for security purposes based on input from GRTC and the Richmond Police Department.

6.5. **On-Board Wi-Fi**

GRTC plans to provide on-board wireless local area network (WLAN) communications in the vehicles as an additional customer service. The service will be free, and it will be advertised to attract choice riders to use the system, allowing them to conduct business or check emails while on-board the vehicle. In addition, the WLAN will facilitate the CCTV and APC data upload and schedule and annunciator data downloads while the vehicle is in the GRTC Transit Operations Center. The WLAN is an additional router / integrated with the VLU as a part of the Clever Devices equipment. Bandwidth requirements will be reviewed by GRTC for appropriate service subscription.

6.6. **Pedestrian Warning**

A Pedestrian Warning System is a safety feature on-board buses that provides audio warning to pedestrians to stay clear of the bus and bus maneuvers in and out of the stations. Equipment will be provided by GRTC as they have developed the system in-house. This unit will have no interface with other BRT technology components.

6.7. **Recommendations**

GRTC has established equipment for all needed in-vehicle systems. For operational functionality with TSP, the vehicle location GPS data would need to be transmitted once a second from each vehicle to the servers located at the GRTC Transit Operations Center and/or the City of Richmond Traffic Operations Center. GRTC should ensure that current vendors meet established technical criteria and expected functionality during systems integration and testing for the subsystems provided.
7. Station Systems

Technology components at stations interface with the BRT vehicles, traffic signal systems, passengers, and other members of the public. These technologies include the following systems:

- Off-Board Fare Collection System (FCS)
- Real-time Transit Information System (RTIS)
- Closed Circuit Television Cameras
- Emergency Phones

Figure 17 shows the typical technology items at BRT transit stations. These units will have to interface with the equipment on-board the bus and other system components. In addition to technology components, other amenities are included in the transit stations such as benches, trash receptacles, transit service schedules, and wayfinding signs. Wayfinding maps provide information to the customers about the surrounding communities’ attractions, points of interest, and other service information.
7.1. Off-Board Fare Collection System (FCS)

GRTC’s primary goal with the BRT system is to implement a progressive Fare Collection System (FCS). GRTC is currently updating outdated fareboxes and backend systems for the fixed route buses under a separate procurement and would like the BRT FCS to follow suit.

GRTC will utilize an off-board Proof of Payment FCS where patrons purchase and / or validate fares prior to boarding the BRT bus, versus purchasing and / or validating fares on-board.

FULL FEATURE INTEGRATION WITH FIXED ROUTE BUS FARE COLLECTION SYSTEM

GRTC is looking to facilitate full feature integration between the fixed route and the BRT FCS. This includes:

- One back end FCS to operate and maintain for fixed route buses and BRT
- Seamless patron experience across fixed route buses and BRT
- Common fare media (smart cards) for patrons to use across fixed route buses and BRT
- Integrated fare policies (e.g. passes, transfers) across fixed route buses and BRT
- Simplified / unified financial reconciliation
- Simplified / unified customer service

PATRON CONSIDERATIONS

Of utmost importance for GRTC are considerations for its patrons who may use the BRT system, especially Title VI considerations. These considerations include, at a minimum:

- Fare policy that does not price riders out of the BRT system
- Usability and availability for core “cash” customers
- Equal access to service for all patrons
- Multi-lingual support (e.g. English and Spanish)

MODERN AND ADVANCED PAYMENT ALTERNATIVES

GRTC is looking to implement modern and advanced payment alternatives for the BRT, including:

- Full Feature Ticket Vending Machines (TVMs) - The addition of TVMs on the BRT platforms to enable patrons to purchase fares on fare media with cash, debit cards, and credit cards.
- Smartcards - The implementation of new Limited Use and Full Feature Smartcards, both of which are more durable than GRTC’s current magnetic tickets and support enhanced fare payments options (e.g. daily, weekly or monthly passes). This would ultimately reduce the cost of tickets as patrons are able to reuse the smartcards for much longer periods than the current magnetic tickets.
- Mobile Ticketing - BRT fare collection should be capable of supporting GRTC’s goal of implementing an integrated mobile ticketing application across the fixed route and BRT systems. A mobile ticketing application would enable patrons to use their smart phones to pay for, display, and activate fares for use on the fixed route and BRT buses. This would also eliminate the need for those patrons to purchase smartcards or interact with TVMs on the BRT platforms to purchase or validate fares prior to boarding.

MAINTAINABILITY

The BRT FCS needs to be a proven system that is low maintenance and highly reliable with a low breakdown rate. It needs to be configured such that the connectivity between the TVMs and the backend for transaction and payment processing is highly reliable.
SECURITY
The BRT FCS needs to be highly secure including:

- TVMs that are highly secure and not subject to theft or vandalism
- Payment Card Industry (PCI) compliant PIN Pads in the TVMs to protect patron credit and debit card information
- PCI compliant backend and communications infrastructure to protect patron personally identifiable information

7.1.1. SYSTEM CONFIGURATIONS
Following GRTC’s desire for an off-board Proof of Payment FCS, there are essentially two options for how the system can be configured:

- Gated platform
- Proof of Payment with Inspection

GATED PLATFORM
One system configuration is a gated platform BRT FCS, which would implement turnstiles on the BRT platform. Patrons would purchase or validate fares at a TVM or platform validator prior to entering the BRT platform. Patrons would present their fare media to the turnstile which would validate the patron's fare prior to allowing them entry to the platform.

Because GRTC’s BRT platforms are proposed as being street-side, a gated platform solution is not feasible, nor is it GRTC’s preference.

PROOF OF PAYMENT WITH INSPECTION
The alternate configuration is a Proof of Payment BRT FCS with inspection. There would not be a farebox on the BRT bus to validate patron fares. Patrons would purchase or validate fares at a TVM on the BRT platform prior to boarding. Upon boarding, there would not be a farebox on the bus, thereby allowing the patron to simply find a seat.

Fare enforcement would be performed on-board via inspection. As visual inspection cannot be performed on-board since the “proof of payment" will be contained in the application on the chip of the fare media (paperless), fare inspectors would utilize handheld validation units on the bus to inspect patron fare media and validate fares. Fare inspectors could validate fare media for all patrons or a subset as directed by GRTC.

Frequency and visibility of fare inspection as well as level of fines and requirement of court appearance are typical drivers of reducing fare evasion in this configuration.

Benefits to Proof of Payment with inspection are:

- Eliminated fareboxes on the BRT buses
- Eliminated turnstiles on the BRT platforms
- Eliminated on-board patron fare purchase or validation
- Eliminated bus driver involvement in collecting or validating fares
- Reduced bus dwell times

The Proof of Payment with inspection configuration is desired by GRTC and, therefore, is what will be implemented for the BRT.
7.1.2. TECHNOLOGY OPTIONS

This section outlines the technology options and components for the BRT FCS.

FARE MEDIA

It is GRTC’s general desire to use smartcards and / or mobile ticketing application Quick Response (QR) Codes as much as possible, and eliminate the current magnetic stripe GoCard. Therefore the current magnetic stripe GoCard will not be included in the BRT FCS.

The BRT will implement ISO 14443-compliant smartcards; these reloadable smartcards contain an embedded chip with an application for storing the patron’s stored value, purchased pass products, and validated pass products. The smartcard application will be readable and writeable via the TVM and handheld validation units.

Short-term passes (e.g. day pass) will be issued by the TVM on less expensive, durable, but still reloadable, “limited use” smartcards meant to last a couple of months of normal use. Longer-term passes (e.g. week pass, month pass) will be issued on more durable reloadable smartcards meant to last years of normal use.

Once the GRTC mobile ticketing application is developed (under a separate project / procurement), BRT passes can be implemented using this application. This would eliminate the need for patrons to purchase smartcards and provide the ability to have the mobile ticketing pass validated either visually on the BRT system or via a QR Code read on the fixed route buses.

FARE POLICY

Fare policy for the BRT will be implemented to include the purchase and validation of passes. While passes can be either trip passes (e.g. 1-trip, 10-trip) or period passes (e.g. day, week, month), the preference is to implement period passes.

Passes can either be validated solely upon first use (and active for the duration of the pass), or validated prior to each boarding by the patron. It is GRTC’s preference to have patrons validate their passes prior to each boarding. This is driven primarily by the scenario where GRTC has to provide ridership reports to local agencies for reimbursement, thereby requiring each individual trip by the patron be recorded. Actual BRT fare policy (e.g. types of pass products, pricing, transfers with fixed route buses, etc.) will be developed as the project progresses.

CENTRAL (BACK OFFICE) SYSTEM

A Central (Back Office) System is used for the management and administration of fare policy, configuration of fare collection equipment, financial reporting and reconciliation, as well as customer service. For ease of interoperability and to reduce integration, implementation, operations, and maintenance costs and efforts, it is recommended that the BRT system leverage the new Central System that will be implemented for the fixed route FCS by adding the TVMs, Handheld Validation Units, and BRT fare policy to that system.

7.1.3. TICKET VENDING MACHINE

There are two types of TVMs available for GRTC’s BRT system:

- Cashless TVMs: Accept debit and credit cards only, but no cash
- Full Feature TVMs: Accept debit and credit cards as well as cash

PATRON CONVENIENCE

GRTC is looking to maximize patron convenience at the BRT TVMs by accepting debit and credit cards as well as cash, and by not adding additional steps for cash carrying riders. Therefore, full feature TVMs will be implemented. In addition, the TVMs will be installed in highly visible and easily accessible locations on the BRT platform.
CASH COLLECTION
TVM cash collection and security needs are to be considered; this should include the ability to implement bill and coin recyclers in the TVMs to reduce cash collection and restocking. Cash collection from the BRT TVMs will likely be performed by GRTC staff.

MAINTENANCE
TVMs need to be installed on the BRT platform such that GRTC maintenance personnel can easily access the TVMs for Preventative Maintenance (PM) and repair purposes. PM and repairs of the BRT TVMs will likely be performed by GRTC staff; timeliness of repairs and spare parts inventory will need to be considered by GRTC as no other alternative ticket purchasing mechanism will be available at the stations.

WARRANTY
Industry-standard warranties from the fare collection supplier will be included in procurement of equipment.

QUANTITIES TO BE PURCHASED
GRTC will be purchasing 30 full feature TVMs for the BRT system: 26 for station platforms, 3 for spare equipment, and 1 to be housed at the GRTC Transit Operations Center for testing / troubleshooting purposes. There will be one (1) installed at each station platform with two (2) end line stations being single platform stations. Additional TVMs may be considered in the future for higher volume stations or stations serving special events (e.g. Siegel Center) based on ridership.

7.1.4. PLATFORM VALIDATORS
Platform validators are simple pole-mounted validators on the station platform that allow patrons to validate or activate passes for riding the BRT. Platform validators drive patrons away from TVMs who do not need to purchase passes with cash, debit or credit cards, thus freeing up the TVMs for patrons who need to purchase fare media.

QUANTITIES TO BE PURCHASED
While no (0) platform validators will be purchased as a part of the initial BRT FCS rollout, platform validators may be considered as a future option for higher volume stations based on ridership.

Consideration should be given to setting up the station platform infrastructure to support future platform validators.

7.1.5. HANDHELD VALIDATION UNITS
Handheld validation units are portable units that are used on-board by fare inspectors to confirm if patrons have activated their pass. Handheld units are generally in one of two form factors:

- Custom built unit with a built in fare card and QR Code reader; or
- "Sled" with a fare card reader that attaches to a mobile phone (QR Code reading would be done via the phone camera and application on the phone).

The handheld validation units will connect to the Central System via a cellular carrier and / or via WiFi. The handheld validation unit cradle will be installed on each BRT bus for the purposes of charging and connectivity to the Central System.

QUANTITIES TO BE PURCHASED
GRTC will be purchasing 12 handheld validation units for the BRT system. One (1) unit will remain with each BRT bus at all times, plus two (2) additional spare units, which may also be used for supplemental fare inspection during special events.
7.1.6. MOBILE TICKETING

Mobile ticketing is a way to allow patrons to purchase and validate BRT fares on their mobile phones, thus eliminating the need for those patrons to utilize the BRT TVMs and / or purchase additional fare media. It is GRTC’s desire to use PayPal as a common payment source via the mobile ticketing application. This would reduce GRTC’s PCI exposure for this component of the FCS. GRTC is not interested in using Apple Pay or Google Wallet at this time.

As mentioned previously, GRTC is already working on a project to implement a mobile ticketing application, and the Central System being procured for the fixed route bus system will support mobile ticketing. Therefore, the BRT FCS will leverage the mobile ticketing implementation currently planned by GRTC.

GRTC’s current Mobile Application project has four (4) phases:

- Phase 1: Real-time bus arrival, route maps, and feedback forms
- Phase 2: Trip planning
- Phase 3: Cashless payment
- Phase 4: Addition of BRT support

While there may be some level of effort and cost associated with integrating the BRT with a mobile ticketing application, those costs are minimal yet still accounted for in the fare collection capital costs.

7.1.7. PASSENGER COUNTING

Important to any FCS is the ability to obtain a ridership count of passengers using the BRT. There are generally two automated methods that can be employed to accomplish this:

- Use of an APC system installed on the bus; and
- Requiring patrons to validate their passes prior to boarding every time.

While the BRT buses will have an APC installed, GRTC would also like to require patrons to validate their passes (e.g. at a TVM or via the mobile ticketing application) prior to boarding every time. The reason for this, as mentioned previously, is that GRTC needs to provide ridership reports to local agencies for the purpose of fare reimbursement. Therefore, the BRT FCS will require pass validation prior to boarding each time.

7.1.8. OPERATIONAL ENVIRONMENT AND ROLES / RESPONSIBILITIES

Fare collection operating environment and roles / responsibilities are outlined in Table 7.1.
Table 7.1 – Operational Environment Roles / Responsibilities

<table>
<thead>
<tr>
<th>Operational Environment</th>
<th>Role</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fare Collection System Operation</td>
<td>Operate the BRT Fare Collection System</td>
<td>GRTC</td>
</tr>
<tr>
<td>Fare Collection System Maintenance</td>
<td>Warranty Repairs</td>
<td>Supplier</td>
</tr>
<tr>
<td></td>
<td>Maintain the Fare Collection System and Equipment (e.g. Preventative Maintenance, Corrective Maintenance, and Bench Repairs)</td>
<td>GRTC</td>
</tr>
<tr>
<td>Revenue Collection</td>
<td>TVM revenue collection and servicing</td>
<td>GRTC</td>
</tr>
<tr>
<td>Enforcement</td>
<td>Fare inspection and enforcement</td>
<td>To be determined</td>
</tr>
</tbody>
</table>

### 7.1.9. FARE COLLECTION SYSTEM OPERATION
The BRT FCS will require operational support such as:

- Testing and implementing new Central System software
- Testing and implementing new fare policy changes
- Testing and implementing new fare collection equipment software and configurations
- Troubleshooting and resolving FCS problems that may arise
- System administration for the Central System applications, databases, servers, and connectivity

GRTC has budgeted for two additional employees to cover BRT FCS operations, in conjunction with their support of the new fixed route FCS.

### 7.1.10. MAINTENANCE
FCS maintenance includes:

- Periodic and ongoing PM performed on the equipment in the field
- Replacement of failed equipment parts in the field
- Repair of defective equipment parts returned from the field to the GRTC shop
- Preparation of defective parts for return to the FCS supplier for warranty repair or replacement

It is generally expected that PM will be performed on each TVM once per month, at 2.5 hours per TVM, plus 1.5 hours per instance to replace or repair failed equipment parts.

GRTC anticipates that it may need to add up to three (3) new technicians to meet the BRT FCS needs.

### 7.1.11. REVENUE COLLECTION
Cash (coins and bills) will periodically need to be collected from and / or added to the BRT TVMs. It is generally expected that each TVM will require revenue servicing twice per week, 45 minutes each (including travel time).

It is anticipated that existing GRTC revenue servicing staff and one (1) additional staff member can cover the work load added by the BRT revenue servicing needs.
7.1.12. ENFORCEMENT

Fare enforcement would be performed on-board via inspection. As visual inspection cannot be performed on board since the "proof of payment" will be contained in the application on the chip of the fare media (paperless), fare inspectors would utilize handheld validation units on the bus to inspect patron fare media and validate fares. Fare inspectors could validate fare media for all patrons or a subset as directed by GRTC. Frequency and visibility of fare inspection as well as level of fines and requirement of court appearance are typical drivers of reducing fare evasion in this configuration.

The fare evasion citation policy and fine structure will need to be determined, as well as who will be performing the actual on-board fare inspection.

FARE INSPECTOR OPTIONS

Options for consideration for fare inspectors include:

- GRTC staff
- City of Richmond Police Department
- City of Richmond Sheriff’s Office
- Henrico County Sheriff’s Office
- Virginia State Police
- Outsourced to a private firm

GRTC may choose to have fare inspectors ride certain BRT buses for an entire route, hop on and off BRT buses at certain stops, or choose a more random pattern for which BRT buses to inspect.

FARE EVASION CITATION / FINE OPTION EXAMPLES

Transit agencies across North America have chosen various options for fare evasion citations and fines, which GRTC may wish to consider when determining its policy. GRTC should coordinate with the City of Richmond so that existing laws / ordinances are complied with or changed as approved by the City of Richmond. This section cites some examples.

York Region Transit (North of Ontario)

York Region Transit has a two (2) zone fare system on their BRT system, with a fine of $155 for the following offenses:

- Travel without depositing fare
- Travel without Proof of Payment
- Fail to show Proof of payment
- Sell proof of payment without permission
- Unauthorized use of proof of payment
- Use of altered pass
- Use of counterfeit pass
- Produce altered pass
- Fail to have Proof of Payment for each zone

Proof of Payment for GO Transit Rail, which is the regional transit service for the Greater Toronto and Hamilton Area, provides one warning for fare evasion, with information taken down by the inspector and entered into a database. The second occurrence results in a fine. Note: This was waived during the rollout until the system was stable and customers got familiar with the new payment media. Inspection rates are generally low, which is commonly known by patrons.
LA Metro (Los Angeles)

Fines start at $75 and can go as high as $250 with 48 hours of community service. In early 2014, LA Metro started to increase enforcement on their Orange Line, and their numbers showed fare evasion was reduced from 22% to 7%.

Fines for fare evasion on LA Metro increase with each occurrence:

- First offense: Notice of violation ($75 fine); and ejection
- Second offense: Notice of violation ($75 fine); and ejection
- Third offense: Notice of violation ($75 fine); ejection; and exclusion for 30 days
- Fourth offense: Notice of violation ($75 fine); ejection; and exclusion for 60 days
- Fifth offense: Notice of violation ($75 fine); ejection; and exclusion for 90 days

GCRTA (Cleveland)

Cleveland does not issue citations. If a passenger is caught with no ticket on the appropriate service, then "You may have to pay a Violation Fare. This fare will cost you the price of a Monthly Pass or $85. If you get caught again, you are subject to criminal prosecution." (O.R.C. 2917.41) (Cleveland Ordinance 605.11) This puts the money collected in the coffers of the Regional Transit Authority (RTA) rather than the judicial system.

Originally, GCRTA envisioned citing non-paying riders and the City of Cleveland had agreed to process the citations and fine or prosecute. The City of Cleveland then decided not to prosecute non-paying riders cited by fare inspectors (RTA transit police and civilian employees) due to concerns about stereotyping. The agency implemented the violation fare as a means of offering a path to paying the fare (the monthly pass fare) without the need to forward a citation to the courts if that fare is paid within a certain period of time. This approach reduces the workload on the courts, offers the first-time (or infrequent) violator a lower cost alternative, and keeps the process and the fine (or violation fare) revenue within the agency.

This internal mechanism is similar to the adjudication processes that have been put in place by several other agencies to reduce the number of violations forwarded to the courts, keep more revenue, and lessen negative public perceptions of the agency.

Sound Transit (Seattle)

Sound Transit (Seattle) has Proof of Payment on its light rail and commuter rail systems; King County Metro implemented Proof of Payment on its Rapid Bus lines. Sound Transit inspects with teams of uniformed Securitas security civilians, sometimes escorted by a Deputy Sheriff assigned to the Transit Division. They inspect on average 13% of the total ridership.

Riders without Proof of Payment will be warned if it is a first offense and will be cited and fined for repeat offenses. Warnings are purged from the books after a certain time (e.g. 6 months). By observation, most citations occur when riders have not tagged their monthly pass before boarding, which is required by Sound Transit.

7.1.13. RECOMMENDATIONS

In order to reduce cost, effort, schedule and risk, it is recommended that GRTC look to procure BRT fare collection equipment that natively integrates with the new fixed route FCS.
7.2. Real-Time Transit Information Systems (RTIS)

The Real-Time Transit Information System (RTIS) provides up-to-date information to the transit user. At BRT stations, a message board displays the anticipated arrival time of the next BRT vehicle. Push button activated or regularly scheduled audio announcements can indicate arrival times to the visually impaired transit user. A RTIS is dependent on a BRT system with AVL in the transit vehicles and a reliable communications network to the message boards at the stations. A ruggedized display monitor, push button actuators, and loudspeaker assembly at BRT stations are recommended. All of the information on the display is communicated audibly when the push-button is pressed, starting with the time of day and then going through the individual routes displayed.

The communications connection to the RTIS signs will be provided through the fiber optic communication network that will be shared with the City of Richmond’s traffic signal system. If for any reason, either cost or physical constraints, a wireless communication can also provide connectivity to the RTIS signs as the bandwidth is limited for the RTIS signs. Where used, a wireless communication will typically entail a leased digital option.

At select facilities along the BRT route including City Hall, the Science Museum of Virginia, and Stone Brewing Co., RTIS signs may also be deployed.

7.3. Closed-Circuit Television Cameras

CCTV camera systems provide the required level of security and means to prevent and / or apprehend individuals who cause vandalism, as well as monitor general conditions of the BRT stations so that service adjustments can be made based on congestion. Also, liability claims / fraudulent claims may be verified using CCTV camera systems. With this system in place, agency staff can determine the appropriate action needed to mitigate impacts when an incident occurs as well as provide information to the appropriate emergency service providers and other agencies.

7.3.1. FUNCTIONAL REQUIREMENTS

As a starting point for the development of the technology alternatives, an initial set of functional requirements is presented in order to identify requirements for the video cameras and to evaluate various technologies. These recommended functional requirements are as follows:

- Security cameras shall provide views of the station areas to effectively monitor activities of individuals in and around the station.
- Video shall be of a resolution and quality to adequately identify individuals. Video cameras shall provide unobstructed views of the TVMs.
- Video cameras should be visible as deterrence. Warning signs should also be installed as an additional deterrent to inform the patrons that the area is under monitored surveillance.
- Video shall be able to be recorded at the highest resolution for a user defined period, either locally (at the shelter) or remotely (at the GRTC Transit Operations Center or City of Richmond Police Department facility).
- The video camera system at the shelters shall be able to be powered by the same power source for the bus shelter.
- Video images should be transmitted to the GRTC Transit Operations Center and can be transmitted to the City of Richmond Police Department.

In addition to the above functional requirements, the proposed video security system would have the following recommendations:

- Install the security cameras outside of the shelter at a height to provide full coverage of the shelter area.
- Install a minimum of one camera or preferably two cameras, depending on the budget for full coverage.
- Use an Internet Protocol (IP) dome type of camera with smoked color dome to keep the camera invisible and protected from environmental factors.
- Utilize the shared fiber optic communications for connectivity to the cameras and video feeds.
- In the event that fiber optic communications is not available at a particular station, due to cost or other physical constraints, use a wireless option, such as microwave or WiMax/Wi-Fi option.
- Install video recording equipment locally (i.e., at the bus shelters) or at the GRTC facility, depending on the cost and other design reasons.

Installing the cameras outside of the bus shelters provides the ability to view individuals and their movements approaching and/or driving by the bus shelter for situational awareness. It also provides more visibility for the cameras to the public acting as a deterrent. Warning signs can also be installed as an additional deterrent to inform the patrons that the area is under monitored surveillance.

7.3.2. CAMERA TYPE

The use of CCTV monitoring systems is generally limited to two different system installation paradigms, fixed or dynamic as described in Table 7.2. The use of fixed cameras typically requires several cameras to cover the same viewing area as a single dynamic camera that has Pan, Tilt, and Zoom (PTZ) capabilities.

<table>
<thead>
<tr>
<th>Camera Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Fixed       | - Permits simultaneous viewing of multiple directions and consistent recordings.  
- Does not require manual operation to see all approaches.  
- Does not require a communication data link from a central control station to the camera.  
- Relatively easy to mount to a luminaire or traffic signal mast arm.  
- Fixed cameras eliminate the control issue between the agencies and the video images can be easily shared with the public. | - View is static and cannot be changed remotely.  
- Requires multiple cameras to provide coverage in multiple directions |
| Dynamic     | - One camera can provide coverage for multiple directions  
- View can be changed remotely within PTZ coverage area | - Provides footage of only one direction at a given time. Inconsistent video recordings based on roving camera direction.  
- A PTZ camera is a mechanical device that typically needs servicing more often than a fixed camera.  
- The cost of a camera with a PTZ and the associated communications data channel exceeds the cost of a fixed camera |

A PTZ dome type of camera provides the greatest flexibility for project application. However GRTC’s initial preference is to install fixed position cameras.
7.3.3. CCTV CAMERA PLACEMENT

A security risk assessment for assets at each transit facility will identify the CCTV camera coverage needs of the BRT system. The American Public Transportation Association (APTA) guidelines identify CCTV camera coverage and field of view considerations as shown in Table 7.3.

<table>
<thead>
<tr>
<th>Transit Facility</th>
<th>CCTV Location</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td>§ Entrances / exits</td>
<td>§ View of both pedestrian and vehicle entrances and exits</td>
</tr>
<tr>
<td></td>
<td>§ Ticket sales</td>
<td>§ View of individuals at ticket booths and ticket vending machines</td>
</tr>
<tr>
<td></td>
<td>§ Elevator</td>
<td>§ Maximum field of view of the elevator interior and entrance</td>
</tr>
<tr>
<td></td>
<td>§ Platforms</td>
<td>§ View of the entire length and width of the platform</td>
</tr>
<tr>
<td></td>
<td>§ Pedestrian passageways</td>
<td>§ View of entrances, exits, and entire length of passageway</td>
</tr>
<tr>
<td></td>
<td>§ Restricted Areas</td>
<td>§ View of restricted access points</td>
</tr>
<tr>
<td>Parking</td>
<td>§ Entrances / exits</td>
<td>§ View of both pedestrian and vehicle entrances and exits</td>
</tr>
<tr>
<td></td>
<td>§ Overview</td>
<td>§ Overview of parking areas for general situational observation</td>
</tr>
<tr>
<td></td>
<td>§ Revenue</td>
<td>§ View of individuals at ticket booths and ticket vending machines</td>
</tr>
<tr>
<td></td>
<td>collection sites</td>
<td>§ Maximum field of view of the elevator interior and entrance</td>
</tr>
<tr>
<td></td>
<td>§ Elevator</td>
<td></td>
</tr>
</tbody>
</table>

Source: Recommended Practice for CCTV Camera Coverage and Field of View Criteria for Passenger Facilities, APTA (2008)

For this project, cameras are recommended for the station areas only. Security at any future park and ride locations would need to be discussed with the appropriate property owners.

7.3.4. RECOMMENDATIONS

CCTV cameras are recommended at each transit station in order to monitor the TVM as well as activities in and around the station. It is recommended that a minimum of one CCTV camera be placed at each station; however, two cameras would be preferable to provide additional coverage particularly with fixed position cameras. The final number of cameras is dependent on the budget and station architecture.

A network video recorder (NVR) is recommended at the GRTC Transit Operations Center. The NVR receives video inputs directly from the CCTV cameras and encodes and stores the data. The NVR should loop seven days’ worth of footage for each camera at each station. It is important that the video resolution and quality be sufficient to adequately identify individuals in both day and night conditions (with proper lighting).

7.4. Emergency Telephone

An emergency telephone is recommended at each transit station. The telephone line will connect directly with 9-1-1 dispatch.

7.5. Wireless Internet Access

Wireless internet access is not recommended for transit stations. An unsecured internet connection at the stations will attract the presence of non-transit users and potentially create a disturbance to transit users.
8. Communication Systems

The City of Richmond Department of Public Works Transportation Engineering Division currently manages an extensive communications network which provides connectivity to approximately 300 of the City’s 469 signalized intersections. In March 2015, construction will begin to incorporate an additional 100 signalized intersections south of the James River. Construction for this second phase of the Richmond Signal System is expected to be complete in Fall 2016.

North of the James River, the communications system consists of approximately 6.5 miles of single-mode fiber-optic cable. The system makes a direct connection to the Traffic Operations Center located in City Hall and the backup Traffic Operations Center located at the Transportation Engineering Division Shop on Hermitage Road. Redundancy is an integral part of the network design, although funding was not available to provide redundancy along or adjacent to Broad Street between Hermitage Road and Boulevard. Additionally the City operates Ethernet over agency-owned twisted pair copper to provide additional connectivity to traffic signals and CCTV cameras within the Downtown, The Fan, Museum District, and Near West End.

The Richmond Signal System north of the James River encompasses the GRTC BRT corridor except for two segments: the 2.0 mile segment from the proposed Willow Lawn Station to the intersection of Broad Street and Boulevard and the 2.0 mile segment from the intersection of Main Street and 14th Street to the proposed Rocketts Landing Station.

South of the James River, approximately 39 miles of single-mode fiber-optic cable will be installed within existing and proposed conduit owned by the City. There will be a direct fiber-optic cable connection to the relocated backup Traffic Operations Center near the intersection of Hopkins Road and DPW Drive.

The proposed BRT system communications schematic is shown in Figure 18.

Figure 18 – Communications Schematic
8.1. Communication Media Alternatives

The purpose of this section is to present various communication options for the ITS elements. This communication technology assessment outlines the various communication alternatives applicable in the corridor. The intent of this section is to give information used to later make recommendations for communication connections. The communication technology assessment includes both the station to Transit Operations Center and Transit Operations Center to Traffic Operations Center/ Emergency Operations Center communication.

8.1.1. FIBER OPTIC

Fiber optic communication relies on the propagation of light through glass strands or plastics. Fiber optic cable coupled with fiber optic transceivers provides high-speed capability for the transmission of voice, data, and video. Optical fiber has a number of advantages over copper wire. For example, optical fiber, being made of glass (or sometimes plastic), is immune to electromagnetic interference, such as is caused by thunderstorms or copper wires that may share the same conduit. Also, because light has a much higher frequency than any radio signal, fiber has a wider bandwidth and can therefore carry more information.

There are two types of fiber optic cables generally used for ITS applications: single-mode and multi-mode. Single mode fiber is typically recommended for ITS applications as it is two to five times less expensive compared to multimode fiber and has significantly less optical attenuation resulting in longer transmission distances.

8.1.2. DIGITAL SUBSCRIBER LINE (DSL)

DSL is a technology that utilizes the twisted pair including the existing telephone infrastructure for the transport of data. It operates in higher frequencies compared to voice modulated frequencies for the plain old telephone system, and thus both voice and data transport is possible. DSL can achieve effective throughputs of up to 52 Mbps. There are multiple types of DSL services, ranging in speeds from 16 Kbps to 52 Mbps. DSL connections are point-to-point open, dedicated circuits that are always connected (there is no dial-up needed), which means that the line is a direct connection into the carrier’s frame relay, ATM, or other Internet connection system. A DSL modem / router is required at the customer site, and at the carrier’s premises a DSL Access Multiplexer is used to gather multiple DSL lines and route them accordingly. Services are available in two major categories of either symmetrical (SDSL, traffic flows at the same speed in both directions), or asymmetrical (ADSL, the downstream capacity is higher than the upstream capacity). ADSL service is the most widely used DSL technology and is offered by the major telecommunication providers at very competitive rates to compete in the home or small business internet connectivity market. Public agencies can also deploy this technology over their own properly conditioned twisted-pair cabling.

8.1.3. WIRELESS

Wireless communication enables devices to be connected to the Transit Operations Center without extending wireline infrastructure. There are many different types of wireless technologies, many of them proprietary. The most popular for transportation applications are those technologies that operate in the unlicensed Industrial, Scientific and Medical (ISM) bands and utilize spread spectrum techniques for secure and reliable data transport. For the purpose of this document, the most feasible wireless technologies for the Broad Street BRT corridor are discussed below, which include Spread Spectrum (proprietary) and IEEE 802.11 (Wi-Fi).

SPREAD SPECTRUM (PROPRIETARY)

There are many manufacturers who have developed wireless systems for use within the unlicensed 900 MHz, 2.4 GHz, and 5.8 GHz ISM bands. These systems use either Frequency Hopping Spread Spectrum or Direct Sequence Spread Spectrum to provide secure and reliable data transport. This is because this spectrum is open for anyone to use, and thus can be very crowded with wireless transmissions from different systems. Spread
spectrum systems are typically point-to-multipoint systems where one central location talks with multiple other locations. Data throughput for these systems are limited (typically less than 512 Kbps for a two-way link). However, due to the use of spread spectrum, there is a high level of security and reliability.

**IEEE 802.11 (WI-FI)**
The Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard is for wireless local area networks. More commonly referred to as “Wi-Fi” (Wireless Fidelity), it is a wireless standard intended for indoor and short range applications. It utilizes Ethernet for data transport (packet-switched), and the network access is based on contention, i.e., first-come, first-served basis. It operates in half-duplex mode (sends or receives, not both at the same time).

**NETWORK DESIGN**
The use of wireless networks offers the benefit of avoiding expensive communications infrastructure. When designing such a network, the following activities should be considered:

- Conduct a detailed propagation analysis.
- Conduct a detailed line-of-sight and path analysis to determine if any obstructions exist for antenna communications.
- Conduct a frequency survey using a frequency spectrometer to determine the “noise floor” of the project area and to verify that the desired radio spectrum is not saturated by other users.
- Prepare a link-by-link bandwidth analysis to ensure that the highest utilized link is not overburdened.
- Utilize encryption to ensure the information is received only by authorized users.

Different applications to be operated over the wireless network must be tested to determine if higher latencies can be tolerated, especially when transmitting long NTCIP frames or video images. Wireless links should be connected or aggregated at a wireline link, which will require a wireless router to be connected to an Ethernet switch, as an example. Depending on the wireless standard utilized, ITS designers may have to deal with the Federal Communications Commission for any licensing issues including base station design and the effective radiated power emitted from each station.

**8.2. Recommendations**
The preferred communications infrastructure to be installed on the GRTC BRT Project is underground single-mode fiber-optic cable. It is anticipated that four miles of fiber optic cable would need to be installed along Broad Street and Main Street to provide full coverage of the proposed BRT alignment. In order for GRTC to monitor the BRT system, a new connection must be made to the GRTC Transit Operations Center located south of the James River on Belt Boulevard. This connection will require approximately 500 feet of conduit installation beginning at the City of Richmond’s network junction box on Belt Boulevard near Lordley Lane and ending at the Transit Operations Center. Single-mode fiber-optic cable may then be spliced with the City of Richmond’s cable and routed through the conduit to the GRTC Operations Center. Additionally, a connection is need to the City’s Emergency Operations Center to allow the City to view GRTC station video feeds. The City’s Emergency Operations Center is located off Hopkins Road and would require a fiber extension of approximately 1100 feet from the intersection of Hopkins Road and DPW Drive.

**Figure 19** (included as 24 x 36 plan sheet at the end of the SEMP) shows the existing and proposed communications system.
9. Procurement Options

There are various procurement options, types, and techniques available for the acquisition of ITS or technology items for the GRTC BRT Project. The following contracting practices are permissible within FTA guidelines. In addition, since GRTC has decided to use the Construction Manager at Risk (CMAR) for the construction phase of the project, the CMAR may present other options that should be considered.

9.1. Types of Contracts

The following is a description of the primary types of contracts that can fit within the CMAR process for the ITS procurement and installation. There are basically two types of contracting that can fit within the CMAR, which includes the systems integrator or the installation contractor (traditional construction) approach. The ITS components of the project can be lumped together for contracting for the systems manager or the equipment can be procured separately and be provided to the installation contractor as “an agency furnished” item. The following provides a general description of these two options.

9.1.1. SYSTEMS INTEGRATOR APPROACH

Under this contracting approach, the systems integrator is selected using conventional consultant procurement processes. The systems integrator will be responsible for hardware procurement, installation, software development if needed, integration, testing, and overall quality control. Systems integrators are selected based on a combination of qualifications, approach, and price. In a systems integrator approach, the risks are all transferred to one entity for system performance.

9.1.2. INSTALLATION CONTRACTOR APPROACH

Under this contracting approach, the equipment is procured separately under various methods that will be described later, and the equipment is then furnished to an installation contractor who will install the equipment, test, and integrate the system. The installation contractor will be also responsible for training. The original equipment vendor will be responsible for the equipment performance and GRTC and CMAR will share some of the responsibility for systems integration and coordination.

9.2. Equipment Procurement Options

The following is a description of the primary types of equipment procurement for the technology components.

9.2.1. SEALED LOW BID

Sealed low bid is perhaps the most common method of award for contracting and requires that contracts be awarded only on a lowest cost, responsible and responsive bidder basis. This approach tends to maximize the number of private firms competing against each other solely on the basis of price, thereby giving the procuring agency the “best buy.” The sealed bid process is easy to defend in protests due to its objectivity. Sealed bidding works best when the agency can develop a complete, adequate, and realistic set of specifications; there are two or more responsible bidders willing to compete; the procurement lends itself to a firm, fixed price contract, and the selection itself can be made on price alone.

In the ITS context however, sealed bidding presents some significant disadvantages. Detractors of sealed bidding argue that detailed specifications may not be available for emerging technology, sealed bidding inhibits innovation, it precludes the public sector from considering anything but price in its selection, and it limits opportunities for the public and private sector to engage in meaningful dialogue to find the most appropriate solution to the agency’s needs.
To mitigate some of these disadvantages, many public agencies have adopted prequalification procedures to ensure that low bidders have the requisite skills and competencies to successfully execute the work. This is particularly important in the ITS environment.

Lifecycle contracting is another approach agencies have employed to ensure that they receive both low cost and good value in their procurements. Lifecycle contracting is a competitive procurement process, which results in the selection of the bid with the lowest lifecycle costs or that increases the weight given to lifecycle cost considerations.

9.2.2. TWO STAGE BID PROCESS

This approach allows the procuring agency to gain the advantages of a sealed bid approach when it lacks adequate specifications for a project. The process starts with a solicitation from the public agency that sets forth its technical needs and requirements. Proposers make technical proposals based on the solicitation, without discussing price. Those firms submitting technically acceptable proposals in step one would be invited to submit sealed fixed price bids based on their proposals.

9.2.3. COMPETITIVE PROPOSALS

This approach uses Requests for Proposals (RFPs) and Requests for Qualifications (RFQs) to select contractors when price and other considerations must be weighed. This method is also known as Value Procurement. This approach is usually employed when there is more than one source capable of providing the services. While there is some subjectivity involved in selecting a contractor under this method, the process is sufficiently objective to allow for courts to review decisions, if a proposer issues a protest. Competitive proposals encourage innovation, but if the solicitation is too loosely defined, proposers may submit bids that the public agency does not consider to be responsive. The process also does not allow for bidders to clarify their bids in such circumstances as a Best and Final Offer.

9.2.4. COMPETITIVE NEGOTIATION

Competitive negotiations use an RFP / RFQ process to identify one or more firms with which to conduct negotiations. This allows the agency to negotiate different contract terms than those used as the basis for the bid. Among the criteria to be considered in determining whether competitive negotiations are appropriate are whether there are significant variations in how the services to be procured can be provided, whether attributes other than price are to be considered, and whether there is a need for bidders to revise their work plans after the initial evaluation of the proposals. This process is commonly referred to as an "Invitation to Negotiate" or ITN. The process is very well adapted to ITS, and has been used successfully in several states, especially for software procurement or integration services. The ITN tends to be superior for software, because the proposer can modify, add, or delete requirements to match their lowest cost alternative. The agency can then weigh the decision as to whether or not to require custom modules that require development and additional costs. The ITN process can save both time and money, as schedules can be negotiated in addition to costs and terms.

9.2.5. SOLE SOURCE

Sole source contracting is allowed in only very limited circumstances. This approach involves the selection of a contractor for negotiations based on the firm’s reputation or its prior relationship with the owner; it should be used only when the supplies or services to be procured are available from only one source. However, for this project, there are a number of existing systems that cannot be feasibly changed and use of the existing system and vendors is preferred.
9.3. Recommendations
For the GRTC BRT Project, either the Systems Integrator or the Installation Contractor approach can be used based on the CMAR recommendations. For either option, the following equipment should be procured using the sole-source approach due to compatibility issues:

- Off-Board Fare Collection Equipment
- Real-Time Transit Information System
- On-Board Vehicle Equipment
- Econolite Controllers / Firmware

All other equipment is recommended to be acquired using the competitive proposal / Value Procurement method.
10. Configuration Management

10.1. Introduction
In the systems engineering process, the Configuration Management Plan (CMP) is defined as a management process for establishing and maintaining consistency of a product’s performance, functional and physical attributes with its requirements, design, and operational information throughout its life. This process is intended to ensure that the system performs as intended and is documented to a level of detail sufficient to meet needs for operation, maintenance, repair, and replacement.

10.2. Purpose of Configuration Management Plan
The primary purpose of the CMP is to establish and maintain the integrity and control of hardware and software products supplied by the vendors, system integrator, or installation contractor during the life cycle of the project. This will involve two main stages:

- Configuration management led by A&E firm during system development
- Configuration management led by CMAR / systems integrator / installation contractor during the implementation phase

The CMP will address the management and control of content, change, or status of shared information within BRT development and implementation phases for the technology items. This will include performance requirements, functional and physical requirements, and design and operation information. This CMP identifies both technical and administrative direction for the control of change and integrity of the BRT technology system product data and documentation. The CMP should identify the configuration of the software and hardware (e.g., software work products) at given points in time, systematically controlling changes to the configuration, and maintaining the integrity and traceability of the configuration throughout the project’s life cycle. At the conclusion of the contract, administration of the CMP will be taken over by GRTC and revised and configured for application during the remainder of the system’s life cycle.

10.3. Roles and Responsibilities

10.3.1. GRTC
The configuration management process is under the ultimate control of GRTC. The responsibility for controlling the process and final approval of configuration baselines and changes will be delegated to a Configuration Management Board (CMB).

The CMP for the project implementation stage shall follow configuration management guidelines established by GRTC. The CMP will be developed by the A&E firm and transitioned to the CMAR firm during the latter part of the system design phase.

10.3.2. CONFIGURATION MANAGEMENT BOARD
The CMB will be appointed by GRTC and may include representatives from the City of Richmond and Henrico County, as appropriate.
10.4. Configuration Management Components
The Software / Hardware CMP for the project shall identify the following integrated activities:

- Configuration identification of work products that would be used or developed by the A&E firm
- Configuration change control of information, including the impact of changes to application development tasks, management schedules, budgets, technical or assurance activities, testing or retest requirements, and project status reporting mechanisms
- Status accounting of work products used by the integrator during the development, release, and maintenance of the system
- Develop configuration reviews and audits that assess the status and acceptability of products controlled or released by the integrator
- Develop interface control process to manage all external interface integrity and control procedures
- Develop application system delivery and release management procedures to monitor the status of integrator

10.5. Configuration Identification
The CMP shall record the items to be controlled, the project Configurable Items (CIs), and their definitions as they evolve or are selected. The CMP shall also describe how the list of items and the structures are to be maintained for the project. At a minimum, all CIs that are to be delivered shall be listed. Appropriate baselines shall be defined at control points within the project life cycle in terms of the following:

- The event that creates the baseline
- The items that are to be controlled in the baseline
- The procedures used to establish and change the baseline
- The authority required to approve changes to the approved baseline documents

10.6. Naming Configuration Items
The CMP shall specify an identification system to assign unique identifiers to each item to be controlled. It shall also specify how different versions of each are to be uniquely identified. Identification methods shall include naming conventions and version numbers and letters.

The CMP shall describe the methods for naming controlled items for purposes of storage, retrieval, tracking, reproduction, and distribution. Activities may include version marking, labeling of documentation and executable software, serialization, and altered item marking for executable code. Hardware, Commercial-off-the-shelf (COTS) software, vendor proprietary software, and support software may require special identification schemes and labeling.

10.7. Acquiring Configuration Items
The CMP for the project shall identify the controlled software libraries for the project and describe how the code, documentation, and data of the identified baselines are to be physically placed under control in the appropriate library. For each library, the format, location, documentation requirements, receiving and inspection requirements, and access control procedures may be specified.

The CMP may specify procedures for the actual storage of documents and magnetic media, including the identification of software / hardware items. Data retention periods and disaster prevention and recovery procedures shall also be described.

Procedures shall describe how to retrieve and reproduce controlled items from library storage. These activities include verification of labeling, tracking of controlled copies, and protection of proprietary and security information.
The CMAR / systems integrator / installation contractor must ensure that the CMP includes the establishment of a Software Development Library that maintains the integrity of the work products that are placed under configuration management control, to ensure repeatability of the products and a proper baseline.

10.8. Configuration Control
The CMP shall define the configuration control process and procedures designating the level of control through which each software / hardware work product must pass (e.g., author control, project-level control, or acquirer control); identifying the persons or groups with authority to authorize changes and to make changes at each level (e.g., the programmer / analyst, the software / hardware lead, the project manager, the acquirer); and the steps to be followed to obtain required authorization for changes, to process change requests, to track changes, to distribute changes, and to maintain past versions.

Change control provides the mechanism to build the software / hardware system for tests that have a known configuration and can be exactly reproduced. For identification of interface requirements, establishment of both internal and external interface agreement processes and procedures will be required.

For each project software / hardware component of the system, the CMP shall describe the change controls imposed on the baseline CIs. The CMP shall identify the following sequence of specific steps:

- Identification and documentation of the need for a change
- Analysis and evaluation of a change request
- Approval or disapproval of a request
- Verification, implementation, and release of a change

The CMP shall identify the records to be used for tracking and documenting this sequence of steps for each change. Any differences in handling changes based on the origin of the request shall be explicitly documented.

10.9. Requesting Changes
The CMP shall specify the procedures for requesting a change to a baseline CI and the information to be documented for the request. At a minimum, the information recorded for a proposed change shall contain the following:

- The name(s) and version(s) of the CIs for which a change is proposed
- Originator’s name and organization
- Date of request
- Indication of urgency
- The need for the change
- Description of the requested change

Additional information, such as priority or classification, must be included to clarify the significance of the request and to assist in its analysis and evaluation. Other information, such as change request number, status, and disposition, shall be recorded for change tracking.

10.10. Evaluating Changes
The CMP shall specify the analysis required to determine the impact of the proposed change and the procedures for reviewing the results of the analysis. Changes should be evaluated according to their effect on the deliverable, their impact on project resources, and impact on project schedule.
10.11. Approving or Disapproving Changes
The CMP shall identify each Configuration Control Authority (CCA) and its level of authority for approving proposed changes. A CCA may contain individuals in the CMB. The CMB shall approve in writing, any changes on the CMAR / systems integrator / installation contractor contract, regardless of whether it does or does not impact the budget or schedule of the project. The CMP shall specify how the proper level is determined for a change request, including any variations during the project life cycle.

10.12. Implementing Changes
The CMP shall specify the activities for verifying and implementing an approved change. The information recorded for the completion of a change must contain the following:

- The change request(s)
- The names and versions of the affected items
- Verification date and responsible party
- Release or installation date and responsible party
- The identification of the new version

Additional information, such as software fault metrics or identification of the supporting software used to implement the change, may be included. The CMP may also specify activities for release planning and control, for example coordinating multiple changes, reconfiguring the CIs, and delivering a new baseline.

10.13. Status Account
The CMP shall define status accounting activities which record and report the status of the system CIs. The plan must include the following information:

- What data elements are to be tracked and reported for baselines and changes
- What types of status accounting reports are to be generated and their frequency
- How information is to be collected, stored, processed, and reported
- How access to the status data is to be controlled
- What function the automated system performs for status accounting activity, if there is an automated system

The CMP shall identify the system implementation configuration audits that shall determine to what extent, the actual software / hardware configuration items reflect the required physical and functional characteristics. Configuration reviews are management tools for establishing a baseline.

The CMP shall identify the configuration audits and reviews to be conducted on the project. At a minimum, a configuration audit shall be performed on all the software / hardware configuration items prior to its release.

For each planned configuration audit or review, the CMP shall define the following:

- The objective of the audit
- The software / hardware CIs under audit or review
- The schedule of audit or review tasks
- The procedures for conducting the audit or review
- The audit participants by job title
- The documentation required to be available for review or to support the audit or review
- The procedure for recording any discrepancies and reporting of corrective actions
- The approval criteria and the specific action(s) to occur upon approval
10.15. **Interface Controls (IC)**

The CMP shall identify the Interface Control (IC) activities to support external interfaces to other entities within the system for end to end solution. The IC activities shall coordinate changes to the interfacing items outside the scope of the system CIs. Hardware, system software, support software, as well as other components and deliverables, should be examined for potential interfacing effects on the overall project.

The CMP shall identify the external items to which the project software / hardware interfaces. For each interface the CMP shall define, as a minimum, the following:

- The nature of the interface
- The affected organizations
- How the interface code, documentation, and data are to be controlled
- How the interface control documents are approved and released into a specified baseline

10.16. **CMAR / Systems Integrator / Installation Contractor Management**

CMAR / Systems integrator / installation contractor control activities incorporate items developed for the system project environment. Included are software and hardware that is developed by the CMAR / system integrator / installation contractor and software that is acquired (i.e. COTS) in its fully completed form. Special attention should be directed to these integrator activities due to the various system maintenance and warranty issues that inherently come along with the acquisition of COTS hardware or software.
11. Systems Integration, Testing, Validation, Documentation and Training

These requirements will serve as a guide during the implementation phase of this project for systems integration, testing, validation, and documentation training for the BRT system, especially the technology components and systems. During the final design phase of this project, specifications produced based on this document will be written for project activities covered in this section and will govern project deliverables provided during the implementation phase of the project. The following project activities should be addressed:

- Installation, interconnection, and integration of all equipment
- Testing of software and hardware within the City of Richmond Traffic Operations Center and the GRTC Transit Operations Center
- Testing of software and hardware within each legacy system
- Testing of firmware and hardware within the field devices, controllers, and cabinets
- Testing of the TSP equipment, off-board FCS, RTIS, and all other technology equipment
- System verification and validation
- Training of system administrators, operators, supervisors, engineers, and technicians
- All system documentation including project, technical, user, testing, and maintenance

11.1. Software Supplier
Any software supplied by any of the vendors, including the TSP software, or other software for other systems, such as CCTV control system.

11.2. CMAR / Systems Integrator / Installation Contractor
The project contractors (CMAR, systems integrator, and installation contractors) will be responsible for all system construction, integration, and testing. The scope of the contractor’s work will be based on the final detailed design. The following are the expected services:

- Furnishing field devices and related hardware
- Installing field devices and related hardware
- Configuring field devices and related hardware
- Interconnecting and integrating field devices and related hardware
- Documenting field devices and related hardware
- Testing all SI furnished items
- Computer and communication hardware installation, interconnection, configuration, and testing
- Systems verification and validation

11.3. CMAR
The CMAR firm will provide oversight services system integration services as required for the installation, configuration and integration of system elements during the enhancement of the legacy Advanced Traffic Management System (ATMS). CMAR will be an agent for GRTC during the integration phase of the project. SI services include oversight services, testing, review of the acceptance plan and training in coordination with the A&E firm.
11.4. Documentation Requirements

The software and hardware suppliers and CMAR will provide documentation appropriate for the project. Two major categories of documentation are to be supplied: a) Project Documentation and b) Operations and Maintenance Documentation.

- Project Documentation - Includes schedules, meeting minutes, work plans, formal problem reports, value-added proposals, change order request backup and project status / progress reports. It also includes technical documentation such "as-built" drawings, interconnect diagrams, etc. that document the as-delivered system.
- Operations and Maintenance Documentation - Includes documentation that will be used to understand, operate, modify, and maintain the system once it is accepted.

11.4.1. SOFTWARE DEVELOPMENT PLAN

A Software Development Plan should be developed for any new customized software development by the supplier to guide the software development process. The Software Development Plan will describe the software development approach and process, and document the hardware, software, and human resources required for the successful completion of the development, testing, and integration of the required system.

The Software Development Plan shall include, at a minimum, the following:

- Software Configuration Plan and Process
- Software development staffing requirements, to include approximate number of development staff, roles, and expected staff utilization
- Development hardware requirements (developer workstation, development servers, testing equipment, etc.)
- Development software environment requirements (operating systems, COTS software, programming language compilers, software development suites, web development software, database management software, configuration management software, etc.)
- Schedule for development to include development milestones, integration timeframe, and targeted tests and testing deadlines

The Software Development Plan shall include a description of the development process including tasks and administrative requirements (i.e., code review process, quality control / quality assurance review plan and procedures, etc.). The software supplier shall be responsible for preparing and delivering to GRTC the following documentation:

- Software Design Document – To reflect the software in its delivered state, after the central application software is completed, any software design documents developed and submitted during the design phase will be updated. The updated software design document shall be an “as-built” or “as-delivered” description of the software for the proposed system. This document shall be designed to acquaint users with how the application software accomplishes the functions of the system. The manual shall be written for hands-on users of the system and / or those who will be responsible for interfacing with the developers of the application software. It shall be delivered in paper format and a searchable electronic format.
- User Manual – The system shall be designed to be extremely user friendly so that its users can become productive in a very short time. A user manual will be written to acquaint the reader with the components of system and with the various functions that can perform. The topic of operational procedures is addressed in the operator manual. This manual is intended for everyone interested in knowing what comprises the system, and would include new or experienced operators, technicians, programmer / analysts, system engineers, and transit management personnel. This manual shall contain brief descriptions of each of the major hardware, software and functional components of the system.
Operator Manual – A detailed manual for operators and other users of the system to assist with using the various functional components of the system on a day-to-day basis. This manual shall describe operator as well as supervisory functions and tasks. A table of contents and an index shall be included for ease of reference. It shall be delivered in paper format as well as a searchable html version. Snapshots of the user interface screens, system icons, maps, and other graphics shall be used as appropriate to pictorially describe the operator and supervisor tasks. This manual shall also cover security log-on procedures.

Maintenance Manual – A detailed manual describing how to maintain the various components of the system. Its focus is on maintaining all hardware and software components from a configuration standpoint. The maintenance manual shall outline types of maintenance (routine back-ups, preventive, system recovery, etc.), as well as a schedule and procedures for performing system maintenance. Warranty information, service numbers, and other information shall be provided for trouble-shooting maintenance activities if necessary. This manual is intended for those who will be responsible for reconfiguring the system (when necessary). Staff responsible for interfacing with any contracted maintainers of the system hardware and software.

Software Manual – A high-level description of the software. It shall describe how the software accomplishes the functions of the system. This manual is intended for hands-on users of the system and / or those who will be responsible for interfacing with the developers of the application software.

11.4.2. TECHNICAL DOCUMENTATION

The software supplier shall deliver to GRTC, the following technical documentation:

- Program Source Libraries and Source Code – The actual source code along with all source libraries and associated documentation shall be delivered in electronic form for any customized developed software.
- Functional Decomposition Diagrams and Module Descriptions – All diagrams and descriptions shall be delivered to GRTC upon delivery of the software.
- Database Definitions and File Structures – Outlines and documents the database contents, table contents, table sizes, database organization, and other components of the overall database layout
- Field Device Communications Protocols and Formats – All as-built communication protocols for each device type. Message structures and wrappers will be provided along with detailed message formats and message content descriptions

11.4.3. CONTRACTOR TECHNICAL DOCUMENTATION

CMAR / Systems integrator / installation contractor shall provide documentation for all project elements furnished to the project. This documentation will be furnished to GRTC for approval prior to initiation of the system acceptance test.

Drawings and diagrams to be submitted as part of the as-built documentation shall include but not be limited to the following:

- Cabinet and rack wiring diagrams
- Electrical schematic and wiring diagrams
- System connection diagrams
- Fiber optic splices and splice closures
- Software documentation

As a minimum, and where applicable, the following manuals shall be provided:

- Installation manuals
- User manuals
11.4.4. OPERATIONS AND MAINTENANCE DOCUMENTATION

The hardware / software suppliers shall submit to GRTC outlines and drafts of each manual (both paper and HTML versions as required) prior to development of the materials. Following the development of each manual, a draft will be submitted to GRTC / A&E firm for review and comment. Comments from GRTC / A&E firm shall be incorporated and final versions of the manuals shall be delivered.

11.4.5. COMMERCIAL-OFF-THE-SHELF (COTS) APPLICATION DOCUMENTATION

It will be the responsibility of the CMAR to organize and catalog all documentation supplied by the vendors for each COTS application used for any components of the project. In addition, all documentation specified above for COTS shall be provided, with the exception of the source codes.

11.5. Testing Requirements

As indicated above, the Software Development Plan described above will include a testing and acceptance plan that provides for software testing at the following levels:

- Module level testing
- Subsystem level testing
- Software acceptance testing

The hardware / software suppliers shall conduct informal module level tests to validate the operation of the software components in conjunction with the central computer hardware and equipment designated for field installation. These tests shall be designed to “prove out” the system software at incremental stages of system integration.

These informal tests shall (at a minimum):

- Demonstrate all key functions of the applications software
- Perform database access, modification, storage, and retrieval (if applicable)
- Perform internal status checking of program processes and functions

Formal system testing and acceptance activities will be conducted by the hardware / software suppliers per the A&E / GRTC approved test procedures. Testing and acceptance procedures to be used during these activities shall be developed by the hardware / software supplier and submitted to the GRTC / A&E firm for review and approval. These formal tests will include system level software testing. The hardware / software supplier shall fully test and validate the central application software against the actual field device controllers and firmware deployed within the project scope.

The systems integrator / installation contractor shall conduct on-site subsystem and system testing of the software to verify that it functions properly prior to placing it in continuous service in the presence of CMAR / A&E firm and GRTC.


CMAR will provide an oversight of the testing by the systems integrator / installation contractor / hardware / software supplier and others to verify the system acceptance. All tests must be conducted in the presence of the
CMAR / A&E firm and GRTC using approved test procedures, and test results submitted to the Engineer must be with approved test data forms (see below). If the equipment or systems fail any part of the test, the systems integrator / installation contractor or the hardware / software supplier will be responsible for making the necessary corrections and repeating the entire test.

CMAR and A&E firm will be reviewing the following tests that will be performed by the hardware / software supplier and the Contractor as applicable:

- Factory Demonstration Test (FDT) (when required)
- Factory Acceptance Test (FAT) (when required)
- Stand-Alone Test
- Subsystem Test (SST)
- System Acceptance Test (SAT)

FDTs are performed on a production unit and verify that the equipment meets the functional requirements. FATs verify that each unit of equipment as it comes off the production line operates as specified. Stand-alone tests verify that after installation but prior to interconnection, the equipment operates as specified. SSTs verify that units forming a subsystem continue to operate as specified when they are interconnected. The SAT verifies that all interconnected subsystems operate together as one system. Upon successful completion and acceptance of the SAT, the project will advance to the Operational Support Period.

The hardware / software supplier and Contractors will be required to conduct SSTs for the field equipment and related equipment at the hubs and software once they are completely installed and integrated.

The hardware / software supplier and Contractors will be responsible for submitting Test Procedures and data forms. Test procedures will need to be prepared for all required FDT, FAT, stand-alone, SST, and SAT tests.

At a minimum, the SI will review the test procedures and data forms that include the following:

- A step-by-step outline of the test sequence to be followed, showing a test of every function of the equipment or system to be tested
- A description of the expected operation, pass / fail criteria, and test results
- A data form to record all data and quantitative results obtained during the test
- A description of any special equipment, setup, manpower, or conditions required for the test

11.7. Systems Interface Specifications

A system interface is defined in terms of the protocols and formats used to establish communication between software elements provided by one entity that must talk to elements provided by others. These software elements can be represented as functional subsystems, software processes (tasks), or software modules (subroutines or functions).

The scope of the document shall define the detailed requirements for all such interfaces. The specifications shall define the principal interface that lies between and directly couples any two communicating systems. The document shall describe the hardware and software interfaces, the physical properties, and the nature and behavior of the interface. Every message that goes across the interface shall be described to the bit level. Any particular protocol handshaking shall be described. Voltage levels, bit patterns, and data-rates shall also be defined as applicable.

The document will include an overview of the interfaces, the interface protocols and formats for each interface link, the database usage as a means of passing information between software elements, the graphical user interface specifications, and the system facilities used to implement communication interfaces. All interfaces must meet the approved NTCIP standards.
11.8. Training Requirements
Training the users and administrators who will be using the system and its various components every day is a key element of the overall system implementation effort. The hardware / software supplier and the CMAR / systems integrator / installation contractor respectively, will provide portions of the required training. Training to be provided generally will be comprised of classroom style workshops / presentations to operators, system administrators, engineers and technicians. Hands-on training also will be provided as appropriate. Classroom training should be videotaped for future use by GRTC or other stakeholders, such as the City of Richmond, Henrico County, or VDOT.

11.9. Supplier Training Requirements
The hardware / software supplier will provide training sessions that will involve workshops / presentations to operators and supervisors, hands-on training at the operator and supervisor workstations using the online menus and help facilities of the user interface, as well as operator and maintenance manuals. The supplier shall provide training for the following key roles:

- Systems Operator – Overall system functionality
- Systems Maintenance – Routine back-ups, preventive maintenance, and troubleshooting
- Systems Administrator – Configuration and security
12. Operational Environment and Roles / Responsibilities

The BRT project has a number of system components that are interconnected both physically and operationally. Hence there will be multiple agencies that would have ownership and operational responsibility for the system components. However, in order for the system to work in an optimum manner, all of the agencies must collaborate with each other and share responsibility for system maintenance and operations. These roles and responsibilities will be documented in the Ownership, Operations and Maintenance Agreement that needs to be approved and executed by all participating agencies.

12.1. GRTC

GRTC will be responsible for the transit system operation, including customer service, bus operations, fare collection, RTIS, operation and maintenance of the CCTV at the stations, and maintenance and operation of the Wi-Fi on-board the vehicles.

GRTC will be also responsible for the operations and maintenance of all of the vehicle equipment, including the AVL system and GPS system, which are required for the system to be functional. GRTC will also partner with the City of Richmond, Henrico County, and VDOT for setting the parameters and reviewing the performance of the TSP system.

GRTC will be responsible for the fare collection equipment maintenance, collection of the cash, and fare enforcement. In addition, GRTC needs to collaborate with the City of Richmond Police Department and Sheriff’s office for the safety and security and emergency response on the buses and at the stations, in accordance with GRTC’s current safety procedures.

12.2. City of Richmond

The City of Richmond is currently responsible for the roadway and traffic signal maintenance within the City of Richmond jurisdiction. This responsibility will continue in the future, in addition to the maintenance of the transit stations and exclusive transitways, in accordance with a project’s Operations and Maintenance (O&M) agreement. In addition, as a result of the project, the City of Richmond will share new and existing communication infrastructure with GRTC for stations and for the TSP communication system, potentially including the short segment that extends into Henrico County.

The City of Richmond will be responsible for the maintenance of the communication system in an optimal manner, so that the system can be functional at all times. In addition, the City of Richmond will be responsible for the operations and maintenance of the TSP system. As a part of the operations of the TSP system, the City of Richmond will periodically meet with GRTC to review the system performance and recommend any modifications or enhancements to the TSP operations. The City will consult GRTC before making any modifications to the TSP system that could affect the transit operations. In the event of additional traffic signals in the BRT operational segment, the City of Richmond agrees to install compatible technology for the TSP or bus operations as applicable. The City of Richmond’s Police Department will support GRTC with safety and security at the transit stations and on the BRT buses in accordance with the currently established procedures.

12.3. Henrico County / VDOT

Henrico County and VDOT are responsible for the roadway and traffic signal maintenance within the Henrico County jurisdiction. This responsibility will continue in the future, in addition to the maintenance of the Willow Lawn transit station, in accordance with a new O&M agreement.

Henrico County / VDOT will be responsible for the operations and maintenance of the TSP system in their jurisdiction. As a part of the operations of the TSP system, Henrico County / VDOT will periodically meet with GRTC
and the City of Richmond to review the system performance and recommend any modifications or enhancements to the TSP operations. Henrico County / VDOT will consult GRTC and the City of Richmond before any modifications to the TSP system that could affect the transit operations. In the event of additional traffic signals within the BRT operational segment, Henrico County / VDOT agrees to install compatible technology for the TSP or bus operations as applicable. The Sheriff Department will support GRTC with safety and security at the transit stations and on the BRT buses in accordance with the currently established procedures.

12.4. Existing and Proposed Roles and Responsibilities

Currently, the City of Richmond and Henrico County / VDOT are responsible for the signal operations, signal timing, and maintenance of the communications system and associated devices. Similarly, GRTC is responsible for the transit operations and maintenance of all of the equipment of the bus, including the AVL system and bus arrival information signing.

As this project advances, a more formalized agreement for funding, construction, maintenance and operations of the BRT components will be developed. This agreement would define all shared responsibilities, including the stations and transitway maintenance as well as the TSP and technology components at the transit stations. The agreement would expand to include all of the BRT components, such as the stations, RTIS, FCS, bus stop security system, landscaping, trash collection, advertisements, and others as deemed appropriate.

For the TSP system to operate, continuous planning and consultation among the agencies is needed. This is typically accomplished through a Technical Advisory Committee (TAC). It is recommended that the existing TAC continue to provide technical guidance for this project. The TAC would consist of staff members from GRTC, the City of Richmond, Henrico County, VDOT, and others as deemed necessary. The TAC will be responsible for providing advice on maintenance and operation of TSP and communications systems. Other ITS and technology components can be included in this responsibility as well. It is the responsibility of each agency represented on the TAC to ensure that the appropriate staff persons who can address the specific issues on the agenda attend the TAC meetings. Issues that are not resolved may be referred to the Policy Advisory Committee (PAC). The TAC will meet on an as-needed basis to fulfill its responsibilities.

12.4.1. PROPOSED ROLES AND RESPONSIBILITIES

Since City of Richmond and Henrico County / VDOT operate and maintain the traffic signal system and communications system, the recommended roles and responsibilities of localities for this project are to:

- Review and approve the TSP concept of operations and subsequent changes during design and project implementation.
- Review infrastructure improvements.
- Operate and maintain the traffic system and central control system.
- Review signal timing plans and participate in signal timing plan development.
- Manage construction (when applicable).
- Cooperate with all participating agencies to develop traffic operations strategies to efficiently move traffic and transit vehicles in the corridors.
- Implement signal timing plans and TSP operational parameters, and periodically review changes when updates are made.
- Fund and maintain all of the traffic signal system and TSP equipment, including the central system.
- Share the use of the communications system and communications equipment with participating agencies to provide cost-effective communications.
- Notify other participating agencies when service interruptions occur that could affect system operations.
- Respond to emergency traffic conditions.
Since GRTC operates and maintains the transit system in the corridor, the recommended roles and responsibilities of GRTC for this project are to:

- Review and approve the TSP concept of operations and subsequent changes during design and project implementation.
- Design and perform an engineering review of infrastructure improvements.
- Install TSP units / GPS units on the fleet operating in the corridor.
- Implement and maintain the AVL system of the fleet.
- Integrate the TSP / GPS with the AVL system for recommended TSP operations.
- Implement and maintain transit information systems and share information with all participating agencies.
- Implement real time transit, fare collection, and CCTVs at the stations.
- Operate and maintain the system, including real time transit, fare collection, CCTVs and emergency telephone systems.
- Fund and maintain all of the TSP and AVL related equipment on the buses and other technology components at the stations.
- Cooperate with all participating agencies in developing operational strategies to efficiently move transit in the corridor.
- Respond to emergency conditions.

It is also expected that GRTC will act as the lead agency for the future phases of project implementation, in coordination with partner agencies, and will perform the following additional responsibilities:

- Grant management
- Partnership agreement development
- Managing the delivery of capital project elements of the program
- Program administration and management
- Overall design, engineering, contract management
- Coordination of the TAC meetings

### 12.5. Agreements

GRTC is currently developing both funding and O&M agreements for the project. The agreements will finalize the roles and responsibilities of each of the agencies participating in the development, implementation, and maintenance of the technology components of the project.
Figure 19 – BRT Communications Map
Appendix A – List of Acronyms
Appendix A - List of Acronyms:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAS</td>
<td>Automated Annunciation System</td>
</tr>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>ADA</td>
<td>Americans with Disabilities Act</td>
</tr>
<tr>
<td>ADSL</td>
<td>Asymmetrical Digital Subscriber Line</td>
</tr>
<tr>
<td>APC</td>
<td>Automated Passenger Count</td>
</tr>
<tr>
<td>APTA</td>
<td>American Public Transportation Association</td>
</tr>
<tr>
<td>APTS</td>
<td>Advanced Public Transportation Systems</td>
</tr>
<tr>
<td>AVI</td>
<td>Automatic Vehicle Identification</td>
</tr>
<tr>
<td>AVL</td>
<td>Automatic Vehicle Location</td>
</tr>
<tr>
<td>BRT</td>
<td>Bus Rapid Transit</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Dispatch</td>
</tr>
<tr>
<td>CCA</td>
<td>Configuration Control Authority</td>
</tr>
<tr>
<td>CCTV</td>
<td>Closed Circuit Television</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulation</td>
</tr>
<tr>
<td>CI</td>
<td>Configurable Item</td>
</tr>
<tr>
<td>CMAR</td>
<td>Construction Manager at Risk</td>
</tr>
<tr>
<td>CMB</td>
<td>Configuration Management Board</td>
</tr>
<tr>
<td>CMP</td>
<td>Configuration Management Plan</td>
</tr>
<tr>
<td>CMS</td>
<td>Central Management Software</td>
</tr>
<tr>
<td>CMU</td>
<td>Central Monitoring Unit</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial-off-the-shelf</td>
</tr>
<tr>
<td>DRPT</td>
<td>Department of Rail and Public Transportation</td>
</tr>
<tr>
<td>DSL</td>
<td>Digital Subscriber Line</td>
</tr>
<tr>
<td>DVR</td>
<td>Digital Video Recorder</td>
</tr>
<tr>
<td>EVP</td>
<td>Emergency Vehicle Preemption</td>
</tr>
<tr>
<td>FAT</td>
<td>Factory Acceptance Test</td>
</tr>
<tr>
<td>FCS</td>
<td>Fare Collection System</td>
</tr>
<tr>
<td>FDT</td>
<td>Factory Demonstration Test</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>FTA</td>
<td>Federal Transit Administration</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GRTC</td>
<td>Greater Richmond Transit Company</td>
</tr>
<tr>
<td>GTT</td>
<td>Global Traffic Technologies</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IC</td>
<td>Interface Control</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial, Scientific, and Medical</td>
</tr>
<tr>
<td>ITE</td>
<td>Institute of Transportation Engineers</td>
</tr>
<tr>
<td>ITN</td>
<td>Invitation to Negotiate</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td>LOS</td>
<td>Level of Service</td>
</tr>
<tr>
<td>MIB</td>
<td>Management Information Base</td>
</tr>
<tr>
<td>MDT</td>
<td>Mobile Data Terminal</td>
</tr>
<tr>
<td>MVDS</td>
<td>Microwave Vehicle Detection System</td>
</tr>
<tr>
<td>NEMS</td>
<td>Novax Elements Management System</td>
</tr>
<tr>
<td>NEPA</td>
<td>National Environmental Protection Act</td>
</tr>
<tr>
<td>NTCIP</td>
<td>National Transportation Communications for ITS Protocol</td>
</tr>
<tr>
<td>NVR</td>
<td>Network Video Recorder</td>
</tr>
<tr>
<td>O &amp; M</td>
<td>Operations and Maintenance</td>
</tr>
<tr>
<td>PAC</td>
<td>Policy Advisory Committee</td>
</tr>
</tbody>
</table>
Appendix A - List of Acronyms (Cont’d.)

PM          Preventative Maintenance
PRG         Priority Request Generator
PRS         Priority Request Server
PTV         Public Transit Vehicle
PTZ         Pan, Tilt, Zoom
QJ          Queue Jump
QR          Quick Response
RF          Radio Frequency
RFP         Request for Proposals
RFQ         Request for Qualifications
RTA         Regional Transit Authority
RTIS        Real-time Transit Information System
SAT         System Acceptance Test
SCP         Signal Control and Prioritization
SDSL        Symmetrical Digital Subscriber Line
SEMP        Systems Engineering Management Plan
SST         Subsystem Test
TAC         Technical Advisory Committee
TIGER       Transportation Investment Generating Economic Recovery
TCIP        Transit Communications Interface Profiles
TSP         Transit Signal Priority
TVM         Ticket Vending Machine
USDOT       United States Department of Transportation
VCU         Virginia Commonwealth University
VDOT        Virginia Department of Transportation
VID         Video Image Detector
VLU         Vehicle Logic Unit
WLAN        Wireless Local Area Network