Transit Reliability Improvement and Performance System (TRIPS)

System Engineering Management Plan

Concept of Operations (ConOps)

Final

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iteris

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Iteris Project 12610

TABLE OF CONTENTS

TABLES

FIGURES

ABBREVIATIONS

ATMS	Advanced Traffic Management System
AVL	Automated Vehicle Location
BSM	Basic Safety Message
CAD	Computer Aided Dispatch
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
CTA	Chicago Transit Authority
CV	Connected Vehicle
DSRC	Dedicated Short-Range Communications
DTGP	Decision to Grant Priority
DTRP	Decision to Request Priority
EVP	Emergency Vehicle Preemption
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMU	Field Monitoring Unit
GHz	Gigahertz
GTFS-S/RT	General Transit Feed Specification (S – static, RT – real time)
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISM	Industrial, Scientific, and Medial radio bands
ITS	Intelligent Transportation System(s)
IVN	Intelligent Vehicle Network
LRT	Light Rail Transit
MHz	Megahertz
MMITSS	Multi-Modal Intelligent Traffic Signal System
NEMA	National Electrical Manufacturers Association
NTCIP	National Transportation Communications for Intelligent Transportation System (ITS) Protocol
OBU	On-board Unit
PRG	Priority Request Generator
PRS	Priority Request Server
RF	Radio Frequency
RSU	Roadside Unit
RTA	Regional Transportation Authority (Chicago Metro area)
SAE	Formerly Society of Automotive Engineers, currently known as SAE International, a recognized standards organization in transportation industry
SIC	Signal Interconnect (copper)
SMART	Strengthening Mobility and Revolutionizing Transportation (Funding Grant)
SPaT	Signal Phasing and Timing
SRM	Signal Request Message
SSM	Signal Status Message
TMC	Traffic Management Center
TOC	Traffic Operations Center
TSP	Transit Signal Priority
USDOT	United States Department of Transportation
VTA	Santa Clara Valley Transit Authority
WLAN	Wireless Local Area Network

1.0 PURPOSE OF DOCUMENT

This document provides a rationale for the expected operations of a centralized Transit Signal Priority (TSP) system deployment along various corridors within Santa Clara County. It documents the outcome of stakeholder discussions and consensus building that has been undertaken to ensure the system implemented is operationally feasible and has stakeholder support. The intended audience of this document includes the system operators, administrators, decision-makers, nontechnical readers, and other participating stakeholders who will share the operation of the system or be affected by it.

2.0 SCOPE OF PROJECT

2.1 Project Background

VTA has secured federal funds under the Strengthening Mobility and Revolutionizing Transportation (SMART) grant program to improve transit performance and reliability by applying advanced technologies to provide priority treatment to its transit vehicles as they approach signalized intersections throughout Santa Clara County. The vision of the project is to deploy and utilize the technology in transit vehicles, at the central signal system of local agencies managing traffic signals, through a centralized TSP application platform, and at the roadside at traffic signals. This approach leverages the existing equipment on the transit vehicles (the existing CAD/AVL and communications equipment) and the existing traffic signal system infrastructure (existing communications between central traffic signal systems and traffic signal controllers at intersections) operated and maintained by the various municipal agencies throughout Santa Clara County. The envisioned system will allow VTA to expand TSP functionality to local cities throughout Santa Clara County where VTA provides transit service.

VTA will deploy the system initially on the Rapid and Frequent bus routes throughout Santa Clara County. VTA has plans to scale up the system(s) in the future to include local routes. An illustration of a VTA's route map showing the Rapid and Frequent bus network in the vicinity of the cities of Cupertino and Santa Clara is shown in **Figure 1**, with the full system map included in **Appendix A.** Throughout Santa Clara County, the Rapid and Frequent bus routes collectively cross through approximately 12 jurisdictions and a total of 871 signalized intersections. A summary of intersections on the Rapid and Frequent routes by jurisdiction is shown in **Table 1**.

Figure 1 – VTA Route Map Sample

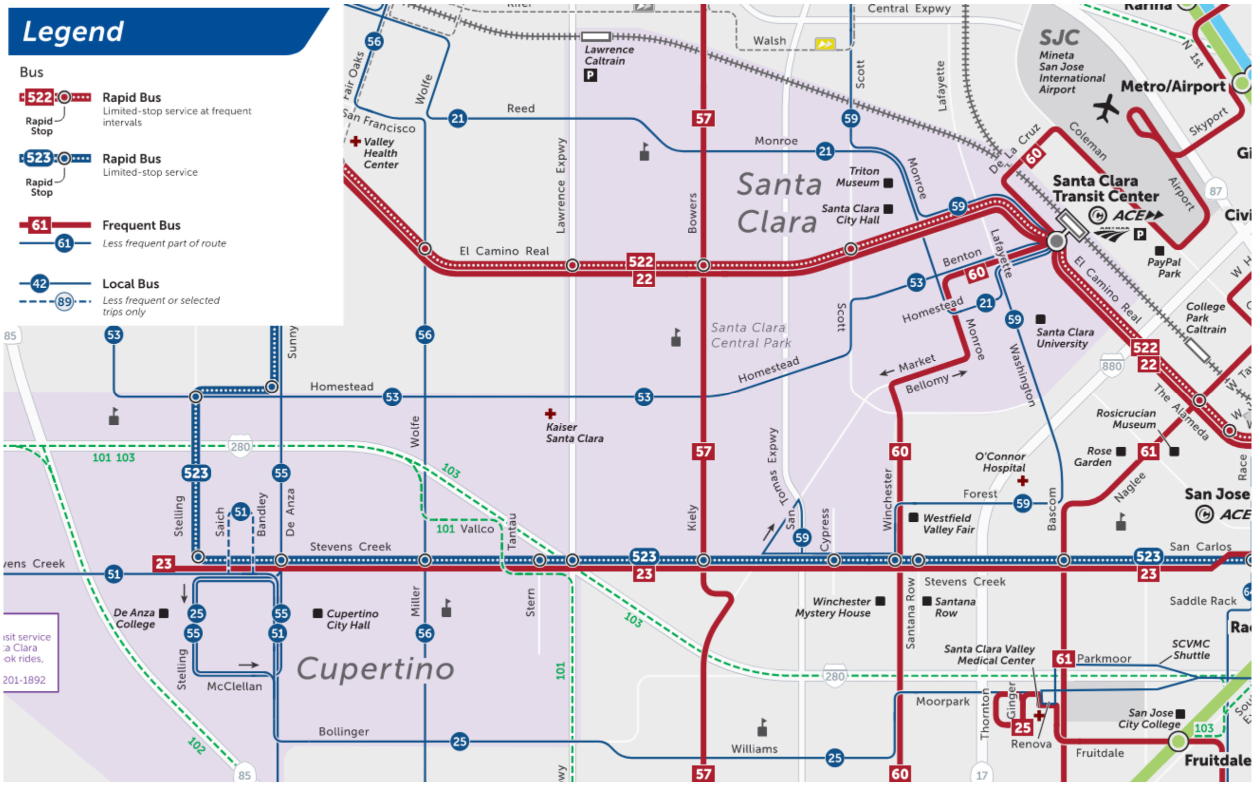


Table 1 – Project Stakeholder Signals on VTA Rapid and Frequent Routes

Stakeholder Agency	Number of Agency Signals on Rapid and Frequent Routes
Caltrans	68
Campbell	26
County of Santa Clara	54
Cupertino	19
Gilroy	10
Milpitas	20
Morgan Hill	20
Palo Alto	1
San Jose	568
Santa Clara (City)	48
Saratoga	7
Sunnyvale	30
Total Signals	**871**

2.2 Project Objectives

The goal of this project is to deploy TSP to keep VTA transit vehicles moving through intersections across multiple jurisdictions to make transit faster, more reliable, and an equitable mobility option so people have greater access to opportunities and to contribute to thriving communities.

The objectives for this project are to:

- Deploy a centralized TSP system(s) initially focused on the Rapid and Fast network, and that is easily scalable to the rest of VTA's transit network.
- Improve transit reliability and travel time along all VTA's service routes.
- Increase transit mode share (i.e., ridership and person throughput) and improve mobility for residents, employers, retailers and regional commuters.
- Reduce the fuel use and carbon footprint related to transit vehicle operations.

This project will deploy a centralized transit signal priority (TSP) system throughout Santa Clara County and is expected to transform the efficiencies and innovation in Santa Clara County's various transportation systems by improving transit performance metrics (e.g., travel time, reliability, etc.). This project builds upon a previous pilot project that tested a centralized TSP system that leveraged existing infrastructure resulting in minimal new infrastructure, using standardized communications protocols to connect to traffic signals, and taking advantage of modern-day broadband communications and edge-computing capabilities. The project will deploy a centralized application that provides TSP for VTA transit vehicles through integration between the existing transit system infrastructure and the local agency traffic signal system infrastructure. The goal is to provide TSP capabilities throughout Santa Clara County at all traffic signals that transit vehicles operate through, which are managed by multiple disparate traffic signal control systems and controllers.

The details of TSP operation (i.e., business rules) will be determined with the agency Stakeholders as part of the project, but in general the benefit to transit travel time will be dependent on: 1) the thresholds that will be established to allow a TSP request to be generated by the transit vehicle, and 2) the extent of priority that will be provided by parameters programmed in the traffic signal controller to either extend or provide an early green indication for the transit vehicle. It is also important to note that multiple TSP systems may need to be present to achieve the goals of the project.

3.0 REFERENCED DOCUMENTS

The following documents have been used in the preparation of this Concept of Operations (ConOps) document.

- "Systems Engineering Guidebook for ITS", California Department of Transportation, Division of Research & Innovation, Version 3.0, November 2009.
- "Systems Engineering Processes for Developing Traffic Signal Systems", National Cooperative Highway Research Program (NCHRP) Synthesis 307, Transportation Research Board, 2003.
- "Intelligent Transportation System Architecture and Standards; Final Rule, 23 CFR Parts 655 and 940", Department of Transportation, Federal Highway Administration, Federal Register, Vol. 66, No. 5, Monday, January 8, 2001.
- "Executive Summary of the Bay Area ITS Architecture", Metropolitan Transportation Commission, Updated April 2021.

4.0 EXISTING CONDITIONS

The purpose of this section is to summarize the existing conditions into which the proposed centralized TSP solution will need to be integrated. Organized by stakeholder, this section provides an overview of VTA's existing on-board equipment and the existing traffic signal system infrastructure of each local stakeholder agency as they relate to this project. Relevant existing facilities summarized in this section include the type(s) of controllers and controller cabinets utilized by the agency, whether or not the agency has any form of communications to the project intersections, whether or not the agency utilizes a centralized traffic signal management system (i.e., ATMS), and the number of intersections on the Rapid and Frequent routes as the initial focus of this project. The overview also notes if the agency currently operates TSP at their intersections and if Light Rail Transit (LRT) is present within the jurisdiction. The existing condition summary is based on meetings held with stakeholder agencies in the Fall of 2024 following the project kick-off, and a review of documentation provided by each local agency.

4.1 VTA

VTA owns and operates a fleet of approximately 670 transit vehicles (572 buses and 98 light rail vehicles), all of which are equipped with or supported by the following equipment.

4.1.1 Bus Operations

4.1.1.1 On-Board Equipment

The VTA buses are equipped with an on-board system to manage bus operations and management. The on-board equipment is housed in a secure cabinet on each bus. The main component of the system (the "brain") is the Clever Devices Intelligent Vehicle Network (IVN). The IVN connects to the CAD/AVL system but also integrates and controls many of the on-board services including closed caption television, public Wi-Fi. Communications for the CAD/AVL system is achieved via a Moovbox or Peplink cellular router and AT&T Firstnet service (which is uninterruptible).

4.1.1.2 Central CAD/AVL System

VTA utilizes a CleverCAD CAD/AVL system for trip updates and vehicle position tracking. Backend hardware for the CAD/AVL system is housed at VTA's offices. VTA's CleverCAD CAD/AVL also provides bus location and status information data feeds to third-party platforms including General Transit Feed Specification (GTFS) both Static and Realtime, and Swiftly. This data feed includes providing updated schedules and real-time information about vehicle positions, active trips, canceled trips, and occupancy (as available).

4.1.1.3 Existing TSP Systems

VTA has previously deployed Emtrac, a commercial off-the-shelf (COTS) radio frequency-based system, along Rapid routes 522 and 523 on El Camino Real for TSP operation. However, some of the Emtrac equipment is beginning to reach end of life and may not be operating reliably if at all.

4.1.2 Light Rail Operations

VTA also operates three light rail lines throughout the County that also utilize either LRT priority or preemption. The LRT lines occasionally also intersect or interact with the Rapid and Frequent routes, as well as local routes throughout the county. The priority or preempt of LRT at intersections is largely dictated by the physical layout of the LRT crossing (e.g., within intersection or offset from intersection) and the type of traffic signal control the local jurisdiction utilizes. In general, the LRT runs parallel to the City streets along the street centerline in the cities of San Jose, Santa Clara, Sunnyvale, Milpitas, unincorporated County of Santa Clara. These intersection crossings generally utilize transit priority treatment. By contrast, within the cities of Mountain View and Campbell, the LRT runs adjacent to intersections or crosses roadways between signalized intersections. These crossings are controlled by gates and utilize separate preemption, functioning as traditional rail crossings. For the purpose of this ConOps, the focus is on the intersection crossings that interact directly with signalized intersections and may benefit from TSP.

4.2 Caltrans

The following table provides a summary of Caltrans' existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 2 – Caltrans Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Caltrans uses TSCP 2070 controllers at all project intersections.
Communications	Caltrans has communications available at 11 of 68 project traffic signals.
Advanced Traffic Management System (ATMS)	Caltrans utilizes a Parsons iNet ATMS system at their TMC, though there is no connection to the project intersections.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 68 Caltrans intersections.
Number of LRT Intersection Crossings	None.

All Caltrans project intersections operate with 2070 controllers running TSC 2.0 firmware in Model 332 controller cabinets. All of these controllers are capable of operating TSP.

4.3 City of Campbell

The following table provides a summary of the City of Campbell's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 3 – City of Campbell Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Campbell uses a combination of Trafficware (Cubic) 980, Trafficware (Cubic) 980 ATC, and Trafficware (Cubic) Commander controllers. The project intersections run a combination of version 61, version 76, and version 85 firmware.
Communications	Communications in Campbell is achieved utilizing a combination copper Signal Interconnect Cable (SIC) and fiber optic cable. 10 of 26 project intersections have communications. All communications to project intersections are Ethernet-based (IP).
Advanced Traffic Management System (ATMS)	Campbell utilizes the Cubic ATMS.now system to manage its signal network.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 26 Campbell intersections.
Number of LRT Intersection Crossings	None.

All Campbell project intersections operate with NEMA TS-1 controller cabinets. Campbell has no TSP operating currently.

4.4 County of Santa Clara

The following table provides a summary of the County's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 4 – County of Santa Clara Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	The County of Santa Clara uses Trafficware (Cubic) 980 ATC controllers with version 76 firmware.
Communications	The County has communications to all project intersections. The County utilizes various communications media including wireless, copper interconnect cable, and fiber optic cable. All communications to project intersections are Ethernet-based (IP).
Advanced Traffic Management System (ATMS)	The County utilizes the Cubic ATMS.now system to manage its signal network.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 54 County intersections.
Number of LRT Intersection Crossings	Two.

All County of Santa Clara County traffic signals operate with NEMA TS-2 controller cabinets. 8 of 54 project intersections are owned by the County but maintained by the City of San Jose.

4.5 City of Cupertino

The following table provides a summary of the City of Cupertino's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 5 – City of Cupertino Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Cupertino currently uses a combination of Trafficware (Cubic) 980, 980 ATC, and Commander controllers. The City's controllers use a combination of versions 76 and 85 firmware.
Communications	The City has communications to all project intersections. All traffic signal communications are via fiber optic cable and are Ethernet-based (IP). Signal communications terminate at City's TMC at the Corporation yard.
Advanced Traffic Management System (ATMS)	Cupertino uses Cubic's ATMS.now version 5.12.103.4 to manage its network.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 19 Cupertino intersections.
Number of LRT Intersection Crossings	None.

All Cupertino project intersections, but one, operate with NEMA TS-1 or TS-2 controller cabinets. The City has one Type 332 controller cabinet in the project. Cupertino has deployed TSP in the past, but all locations are currently deactivated.

4.6 City of Gilroy

The following table provides a summary of the City of Gilroy's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 6 – City of Gilroy Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Gilroy utilizes McCain (Swarco/BiTran) 170 and 2070 controllers running 233 and 2033 firmware respectively.
Communications	Gilroy does not currently have communications.
Advanced Traffic Management System (ATMS)	Gilroy does not currently have an ATMS.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 10 Gilroy intersections.
Number of LRT Intersection Crossings	None.

All of Gilroy's project intersections operate with Type 332 controller cabinets. Gilroy has no TSP operating currently.

4.7 City of Milpitas

The following table provides a summary of the City of Milpitas' existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 7 – City of Milpitas Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Milpitas utilizes Trafficware (Cubic) 980 controllers which run version 61 firmware.
Communications	Milpitas employs a combination of fiber optic cable and copper SIC for their Ethernet-based (IP) communications. 11 of 20 project intersections have communications.
Advanced Traffic Management System (ATMS)	Milpitas uses Cubic's ATMS.now to manage its network.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 20 City intersections.
Number of LRT Intersection Crossings	Four. These crossings are currently undergoing controller upgrades to Econolite EOS, expected to be completed and in operation by Spring 2025.

All City of Milpitas project intersections operate with NEMA TS-1 controller cabinets. Milpitas has no TSP operating currently.

4.8 City of Morgan Hill

The following table provides a summary of the City of Morgan Hill's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 8 – City of Morgan Hill Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Morgan Hill utilizes McCain (Swarco/BiTran) 170 and 2070 controllers running 233 and 2033 firmware respectively.
Communications	Morgan Hill does not currently have communications.
Advanced Traffic Management System (ATMS)	Morgan Hill does not currently have an ATMS.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 20 Morgan Hill intersections.
Number of LRT Intersection Crossings	None.

All Morgan Hill project intersections operate with Type 332 controller cabinets. Morgan Hill has no TSP operating currently.

4.9 City of Mountain View

The following table provides a summary of City of Mountain View's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 9 – City of Mountain View Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Mountain View has a mix of Econolite, Traconex, McCain, and Cubic controllers. The City recently standardized to 2070LX controllers.
Communications	Mountain View has copper signal interconnect on two corridors: Shoreline Boulevard and Grant Road. No traffic signals have communications back to City facilities.
Advanced Traffic Management System (ATMS)	Mountain View does not currently have an ATMS.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes do not currently pass through any Mountain View intersections.
Number of LRT Intersection Crossings	None.

Mountain View previously operated a Rhythm InSync adaptive system on Shoreline Blvd and Grant Road, but that system has been turned off and the City does not anticipate reutilizing it in the future.

4.10 City of Palo Alto

The following table provides a summary of the City of Palo Alto's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 10 – City of Palo Alto Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Palo Alto utilizes Trafficware (Cubic) 980 controllers running version 76 firmware.
Communications	Palo Alto achieves communications via fiber optic cable. All communications in Palo Alto are Ethernet-based (IP).
Advanced Traffic Management System (ATMS)	Palo Alto utilizes Cubic's ATMS.now system to manage its traffic signals.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 1 Palo Alto intersection.
Number of LRT Intersection Crossings	None.

Palo Alto's project intersection operates with a NEMA TS-1 controller cabinet. Palo Alto currently has GPS/radio-based TSP operating at the project intersection.

4.11 City of San Jose

The following table provides a summary of the City of San Jose's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 11 – City of San Jose Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	San Jose utilizes McCain and Econolite 2070 controllers with Fourth Dimension (D4) firmware.
Communications	San Jose uses a combination of fiber optics, copper SIC, and wireless radios for traffic signal communications. All communications are Ethernet-based (IP) and all City project intersections have communications.
Advanced Traffic Management System (ATMS)	San Jose currently utilizes Transcore's TransSuite ATMS.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 568 San Jose intersections.
Number of LRT Intersection Crossings	74.

In addition to the aforementioned equipment, San Jose has previously deployed and recently expanded a centralized cloud TSP system (LYT) in their City. San Jose also utilizes Transcore TCS for emergency vehicle preemption. San Jose is also working on deploying a shared LYT system with City of Santa Clara to provide TSP for Routes 22, 23, 522, 523 and 60 which move between both cities. Project intersections operate with a mix of NEMA TS-1, NEMA TS-2, and Type 332 controller cabinets.

4.12 City of Santa Clara

The following table provides a summary of the City of Santa Clara's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 12 – City of Santa Clara Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Santa Clara utilizes Cubic 2070 controllers running Fourth Dimension (D4) firmware.
Communications	Santa Clara uses a combination of fiber optic cable and copper SIC to communicate with its traffic signals. Santa Clara has Ethernet-based (IP) communications to all City project intersections.
Advanced Traffic Management System (ATMS)	Santa Clara currently utilizes Kimley-Horn's KITS ATMS to manage its traffic signals.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 48 Santa Clara intersections.
Number of LRT Intersection Crossings	Seven.

In addition to the aforementioned equipment, the City of Santa Clara has recently deployed the Kimley-Horn Traction centralized cloud TSP system at intersections along Line 57. Santa Clara is also collaborating with San Jose to deploy a second centralized cloud TSP system (LYT) on two corridors where they overlap with the City of San Jose: El Camino Real and Stevens Creek Boulevard (along VTA Routes 523 and 60). All City project intersections operate with NEMA TS-2 controller cabinets.

4.13 City of Saratoga

The following table provides a summary of the City of Saratoga's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 13 – City of Saratoga Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Saratoga utilizes Trafficware (Cubic) 2070 controllers with version 85.5 firmware.
Communications	Saratoga utilizes the Smart City Signals system's cellular network to communicate with all of its project traffic signals.
Advanced Traffic Management System (ATMS)	Saratoga utilizes Cubic's ATMS.now system, as well as the Smart City Signals system to manage its traffic signal network.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 7 Saratoga intersections.
Number of LRT Intersection Crossings	None.

The City's project intersections operate with Type 332 controller cabinets in addition to one NEMA TS-1 cabinet.

4.14 City of Sunnyvale

The following table provides a summary of the City of Sunnyvale's existing traffic signal infrastructure along the VTA bus routes, and specifically the Rapid and Frequent routes.

Table 14 – City of Sunnyvale Signal System Infrastructure

Category	Infrastructure Summary
Signal Controller(s)	Sunnyvale utilizes Econolite 2070 controllers with EOS firmware.
Communications	Sunnyvale uses a combination of fiber optic cable and copper SIC to achieve Ethernet-based (IP) communications to all of its project signals.
Advanced Traffic Management System (ATMS)	Sunnyvale manages its signal network utilizing Econolite's Centracs ATMS.
Number of Signals along VTA Rapid and Frequent Routes	The Rapid and Frequent routes pass through a total of 30 Sunnyvale intersections.
Number of LRT Intersection Crossings	10.

All Sunnyvale project intersections operate with Type 332/333 controller cabinets. Sunnyvale has no TSP operating currently on VTA's bus routes. Seven of the ten LRT intersections have Econolite Cobalt controllers, with the remaining three utilizing 2070C controllers operating with Econolite's EOS software.

4.15 All Other Stakeholders

There are several additional Cities in Santa Clara County that are not on the Rapid and Frequent routes but are served by other VTA transit service routes. These routes may be affected by future scaling of the system but not by this initial deployment. For that reason, detailed data collection for these agencies was not performed for this ConOps. However, future deployments and expansion of the system will require coordination and consideration with the following Stakeholder agencies:

- Town of Los Gatos
- City of Los Altos
- Town of Los Altos Hills
- City of Monte Sereno

5.0 PROPOSED APPROACH TO IMPROVING THE SYSTEM

5.1 Centralized TSP System(s)

VTA plans to improve transit performance and reliability by applying advanced technologies to provide priority treatment to transit vehicles as they approach signalized intersections. Because of the varying existing infrastructure throughout the jurisdictions where VTA's transit routes travel, the technology will facilitate communications directly from VTA transit vehicles to an intersection's traffic controller through a central/cloud-based application platform. This approach would leverage existing equipment on the transit vehicle (via the existing CAD/AVL system) and existing traffic signal system infrastructure (either via an existing communications connection between a central communications network with traffic signal controllers at intersections or via field interface units). While this project will initially focus on deploying TSP technology on VTA's Rapid and Frequent routes, the deployed technology will allow VTA and project stakeholders to scale and expand TSP functionality to other transit routes throughout Santa Clara County, assuming the TSP system can be integrated with those stakeholders' infrastructure. The use of a central/cloud-based application will also provide greater flexibility to prioritize competing TSP requests at an intersection as compared to traditional systems. For example, this would simplify configuration of TSP parameters from a centralized location.

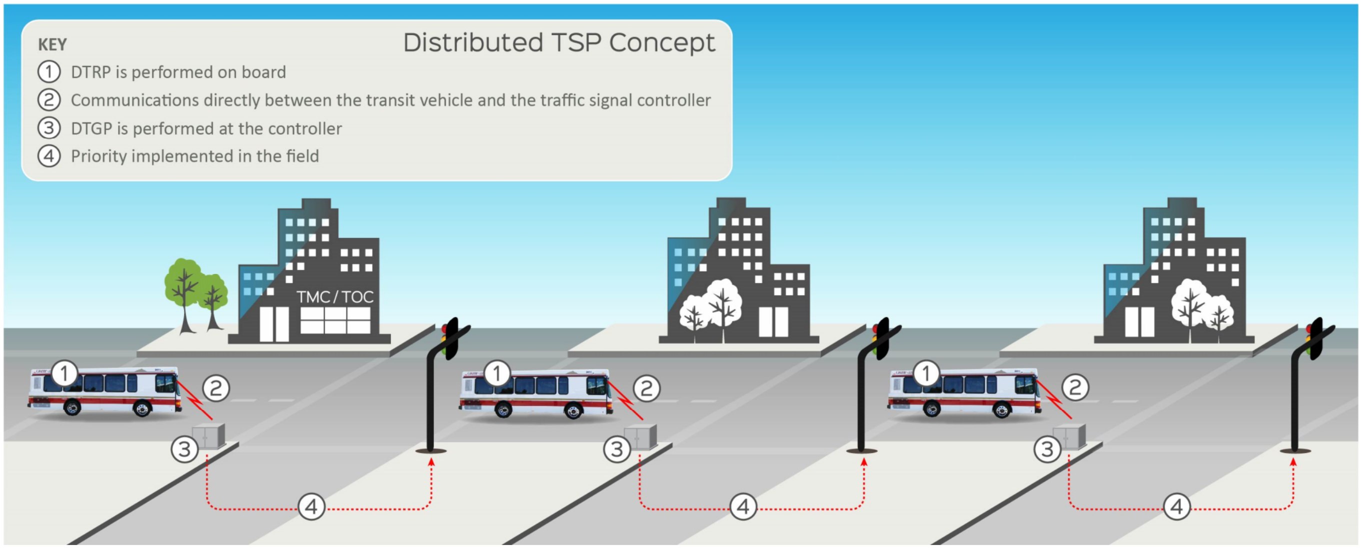
6.0 CONCEPTS FOR THE PROPOSED SYSTEM

This section describes the concept exploration. It provides a summary description of the alternative concepts examined and an evaluation and assessment of each alternative. This leads to the rationale for the selected approach.

6.1 Distributed TSP System Concept

A distributed TSP concept is one where the Decision to Request Priority (DTRP) is made entirely by the transit vehicle through a Priority Request Generator (PRG), and the Decision to Grant Priority (DTGP) is made locally at the signalized intersection, typically by the traffic signal controller. In this concept, the Transit Vehicle Requests Priority (DTRP), and the vehicle communicates that request wirelessly to the controller. The traffic control unit at the signalized intersection then decides to grant priority based on pre-established parameters (i.e., rules) programmed in the control unit. **Figure 2** is a high-level depiction of a Distributed TSP Concept implementation.

Figure 2 – Distributed TSP Concept



A distributed TSP system is suitable when there are long distances between traffic signals, and the distance between the transit vehicle and the target intersection at the time the priority request is generated and sent to the intersection is sufficiently long that the signal at the target intersection has adequate time to react and provide the desired priority.

For unconditional TSP operation, the PRG will always request priority as a transit vehicle approaches a signalized intersection. Unconditional TSP is common approach to simplify TSP deployment (i.e., no need to integrate the PRG with another system such as a CAD/AVL) or when there is no other system to integrate with. For conditional TSP operation, the PRG will only request priority when certain predefined conditions are met, such as schedule adherence and passenger load. For conditional TSP, the PRG typically needs to be integrated with the transit vehicle's CAD/AVL system to extract the information needed to determine the need for priority. VTA transit vehicles do not currently contain the required on-board infrastructure to enable the conditional TSP described here, thus creating a roadblock for this type of operation.

6.1.1 Commercial-off-the-Shelf (COTS) Systems

The following provide an overview of "off the shelf" offerings that generally fit the criteria discussed in the above text. The systems are vendor specific. There are other vendors that provide similar offerings but those, outlined as follows, are known to be the primary offerings in the TSP space in California:

- **Optical Based**: Optical technology has been widely used for decades in the Bay Area, as well as California and North America in general, for emergency vehicle preemption. The same technology has also been used for TSP, in most instances resulting in a single system being used for both Emergency Vehicle Preemption (EVP) and TSP. The optical TSP technology typically uses an infrared strobe emitter installed at the front end of the transit vehicle, an infrared receiver installed at the intersection (typically, multiple receivers), and an interface unit that takes the signal from the transit vehicle and provides it to the traffic signal controller in a format it can understand, and to which the controller can provide an appropriate response. The optical emitter uses varying frequency rates to distinguish priority requests, primarily between emergency vehicles and transit vehicles. Frequency rates can also be varied to distinguish between transit service types or transit vehicle types, which may factor into the decision to request and be granted priority.

Optical system equipment must be mounted and aimed so there is an unobstructed line-of-sight view between the transit vehicle and the intersection. For TSP where requests for priority may be initiated at 600-800 feet from the intersection typically from the curb traffic lane, the need for an unobstructed line of sight can limit the effectiveness of the optical technology for TSP. If there are obstructions that cannot be removed, additional receivers may need to be installed although this is rarely done. Receivers can be mounted upright on mast arms, signal head assemblies, traffic signal poles, or other appropriate locations. They can also be inverted and suspended from a span wire over the intersection. Of note, this technology type can be deployed in a distributed manner, meaning it does not require a connection to a centralized traffic control or TSP system to implement.

- **Radio Frequency Based**: This TSP solution most typically utilizes on-vehicle GPS units that track vehicle location together with Radio Frequency (RF) transceivers installed on the transit vehicles that broadcast vehicle location and status data to RF receivers mounted at signalized intersections. The GPS unit denotes the vehicle location relative to the intersection, which is provided to the intersection equipment. This technology solution is used for TSP, as well as emergency vehicle preemption. It is generally considered to be an evolution of the optical technologies described above. The Industry, Scientific and Medical (ISM) radio bands are defined as the unlicensed frequencies of 902-928 MHz (referred to as 900 MHz) typically used for low bandwidth, long range applications; 2.4-2.4835 GHz typically used for applications in dedicated wireless local area Ethernet networks; and 5.725-5.850 GHz typically employed for higher power, greater bandwidth dedicated wireless Ethernet network applications, respectively. Within the license-free ISM bands, these three frequency ranges are authorized by the FCC and are widely used today for wireless devices and networks.

  Use of RF technology is not dependent on line of sight, as compared to optical emitters. The optical emitter technology typically requires multiple receivers at the intersection to cover a typical four approach intersection. In contrast, RF technology typically requires only one receiver at the intersection, using the on-board GPS function to indicate the approach direction. The RF receiver is typically placed on the signal pole closest to the controller cabinet, minimizing conduit fill at the intersection for the TSP deployment.

Typical Commercially Available Systems: GTT Opticom (Optical), Novax Bus Plus (Optical), GTT Opticom (GPS/RF), Emtrac (GPS/RF)

Recommendation: These COTS systems are well-established technology in current use. However, they do not fit into VTA's program to minimize cost with minimal hardware procurement due to the various Stakeholders involved. Thus, the use of COTS distributed systems for TSP are not recommended for further consideration.

6.1.2 Tailored Wi-Fi and Network-based Systems

This family of TSP solutions typically utilizes on-vehicle GPS-based AVL systems to track vehicle location and schedule status in real time. The transit vehicle also carries Wireless Local Area Network (WLAN) equipment, which is used to communicate requests for priority to the signalized intersections. While operating along a transit route that has been equipped with WLAN equipment, the on-vehicle WLAN equipment will associate with the roadside transit route WLAN. As a transit vehicle approaches a signalized intersection where priority is available and reaches a user-defined distance or time from the intersection, an on-vehicle logic unit will initiate an IP-based request for priority message on the WLAN addressed to the traffic controller at the target intersection, where priority is being requested.

The WLAN TSP solution may be implemented as a standalone solution or integrated with already-installed CAD/AVL transit management systems. It can also utilize already-installed bulk data transfer WLAN equipment. The basic operating concept and equipment suite are relatively common across multiple platforms, in some cases using different wireless communications media, including Wi-Fi and other spread spectrum radio frequencies. The primary operating example of this type of system is the Metro Countywide TSP System. The Metro Countywide TSP System has been developed by the Los Angeles County Metropolitan Transportation Authority (Metro) working with a technical advisory committee consisting of representatives from local traffic engineering agencies and municipal transit operators in Los Angeles County. It is presently operational for seven LA Metro Rapid transit lines operated by Metro with deployments for Torrance Transit, Foothill Transit and projects in development for Culver City Bus. LA Metro, however, is currently in the process of revising this program and deploying a centralized cloud-based system to simplify operations.

The Metro Countywide TSP System includes an on-vehicle system incorporating GPS-based AVL, a vehicle logic unit that supports the decision making for conditional priority based on user-specified conditions and initiates requests for priority, and an IEEE 802.11b/g compliant wireless network client that forwards the requests for priority to a transit route communications network. The roadside transit vehicle route communications network consists of a series of wireless communications access points that are typically situated at every third or fourth intersection along the length of the transit route. This roadside communications system provides end-to-end communications coverage along the length of the transit route, permitting request for priority data to be sent from the transit vehicles, or mobile clients, to the intersection traffic controllers, or intersection clients.

A second notable example is Pace's regional TSP program in the Chicago metropolitan area. Pace initially deployed a demonstration Wi-fi-based TSP system in 2010 as part of its Pace TSP Initiative to measure effectiveness in an effort to improve transit performance against current and future demands, to attract ridership, and increase transit rider satisfaction. Pace's system includes outfitting key intersections with PRS units and outfitting transit vehicles with PRG units. The system also included a TSP Central Management System which was installed at Pace Headquarters in Arlington Heights, IL. The entire system was further supported by a robust communications system consisting of both fiber optic and wireless media which allowed Pace to monitor system performance. Pace's system relied on custom integration with Pace's Intelligent Bus System (the agency's existing AVL system) to manage priority requests under specific schedule adherence conditions (typically if transit vehicle was over 1 minute behind schedule), as well as with consideration to several onboard triggers such as next stop pulls and door status to ensure that priority was not given if the transit vehicle would not utilize it. Since this initial deployment, Pace has gone on to expand the program, most recently deploying on its Pulse Milwaukee and Pulse Dempster bus rapid transit lines with plans to expand to five additional corridors in the future. Pace has also gone on to partner with the Regional Transportation Authority (RTA), Chicago Transit Authority (CTA), Illinois Department of Transportation, and Chicago Department of Transportation to coordinate and deploy a regionally interoperable TSP system in the Chicago region. RTA continues to oversee this Regional Transit Signal Priority Implementation Program (RTSPIP) which establishes common standards and protocols, as well as performance metrics.

Known Available Systems: LA Metro, Chicago Pace

Recommendation: These systems are typically highly tailored, and designed and deployed by a systems integrator for a specific client need. There are also standard-based technologies now available that offer a similar approach. For this reason, this TSP solution is not being recommended for further consideration.

6.1.3 Connected Vehicle (CV) Application

A more recent technology that has been developed is the use of CV-based applications. This technology utilizes industry adopted standards for the communications medium as well as the communications message format. CV-based applications utilize the message format established by the Society of Automotive Engineers (SAE), such as the most prevalent SAE J2735. For wireless communications, a common medium is the use of a 5.9 GHz radio frequency spectrum conforming to IEEE 802.11p and 1609, known as Dedicated Short-Range Communications (DSRC), that has been allocated to Intelligent Transportation Systems (ITS) vehicle safety and mobility applications such as TSP. DSRC had been gaining traction for various CV applications prior to 2020 primarily due to support from the USDOT through various CV test beds, CV Pooled Fund Studies, CV Pilot Deployments, and the Signal Phasing and Timing (SPaT) Challenge. However, outside of these USDOT sponsored initiatives, there has been less activity in the emergency response and transit sectors to adopt CV-based applications due to the stability and maturity of V2I communications and availability of commercial EVP/TSP applications.

The CV approach utilizes an On-Board Unit (OBU) located on the transit vehicle with GPS to track location status such as location, direction of travel, speed, etc. CV-based applications, such as TSP, reside on the OBU. The OBU is also equipped with a DSRC radio that is used to wirelessly broadcast the vehicle's location status and a request for priority to the signalized intersections. While operating along a transit route that has been equipped with Road-Side Units (RSU), the on-vehicle OBU equipment will communicate with the RSU to exchange information. The transit vehicle will communicate its location status via the broadcast of a basic safety Message (BSM) and a Signal Request Message (SRM) when it needs to request priority. The signalized intersection will communicate its traffic signal status via the broadcast of SPaT messages, its geometric layout via the broadcast of a Map message, and the status of a priority request via the broadcast of a Signal Status Message (SSM).

As a transit vehicle approaches a signalized intersection and enters the intersection's DSRC broadcast zone, it will receive the intersection's SPaT and Map messages while at the same time sending BSM's to the intersection. When priority is needed, the transit vehicle will additionally send an SRM to the intersection to request priority. The signalized intersection, having received the SRM will then additionally broadcast a SSM in response to the SRM to indicate the status of the priority request to the transit vehicle.

There are no known commercially available CV-based TSP applications at this time. The first known CV TSP application, known as the Multi-Modal Intelligent Traffic Signal System (MMITSS), was developed jointly by the University of Arizona (UA) and the California Department of Transportation (Caltrans) through the Connected Vehicles Pooled-Fund Study. The TSP application is one of a number of CV applications that are part of the MMITSS suite of applications. Under the MMITSS program, two versions of MMITSS were developed: one version by UA (MMITSS-AZ) and one version by Caltrans (MMITSS-CA). Each had a slightly different approach to the application architecture as well as the controller communications protocol used (NTCIP for Arizona, and AB3418 for Caltrans). The MMITSS application source code is available as a free download from the Federal Highway Administration's (FHWA) Open Source Application Development Portal (OSADP).

Subsequently, the Utah Department of Transportation (UDOT) was also interested in deploying DSRC for CV applications. UDOT looked to TSP as a viable application and saw MMITSS-AZ as a feasible option. UDOT made some structural changes to the MMITSS architecture by both removing and adding additional features to integrate it with the Utah Transit Authority's (UTA) CAD/AVL system to provide conditional priority functionality. UDOT's approach used only the TSP feature of MMITSS-AZ and also used the application to serve as a PRG and a priority request server (PRS) to place a priority request (call) to the traffic signal controller. UDOT did not use the optimization solver logic or the priority hierarchy and controls that are part of MMITSS-AZ for signal operations. The UDOT version of MMITSS is owned by Utah and can be made available to other public agencies.

As part of the CV Pilots sponsored by the USDOT, the Tampa CV Pilot also deployed a CV TSP application as part of their overall project. The Tampa Hillsborough Expressway Authority (THEA) also began with the MMITSS-AZ application and made some structural changes to the application architecture in order to meet the needs of that project. Some of the changes include the addition of conditional priority and the routing of the SRM to a central "master" server to process the request, makes the decision to grant the request, and then sends out the priority request to the intersection, if granted. The MMITSS THEA application source code was recently made available as a free download from the FHWA's Open Source Application Development Portal (OSADP).

It should be noted that on February 6, 2020, the FCC released a Notice of Proposed Rulemaking (NPRM) that reallocated most of the 5.9GHz spectrum to other wireless communications technologies. The Second Report and Order, adopted in November 2024, resulted in a much smaller allocation (30 megahertz) of the spectrum to be used for ITS applications as well as removed the use of DSRC technology to be replaced by cellular-vehicle-to-everything (C-V2X) technology.

Known Available Applications: MMITSS-AZ, MMITSS-CA, MMITSS UDOT, MMITSS THEA

Recommendations: The use of a CV-based application for TSP does not fit into VTA's program to minimize cost with minimal hardware procurement due to the various stakeholders involved. In addition, the use of CV-based applications for TSP is not recommended for further consideration given the uncertainty of the reduced bandwidth available within the 5.9GHz spectrum to support ITS applications and the C-V2X technology that will be utilized.

6.2 Centralized TSP System Concept

In a centralized TSP concept, many of the TSP functions are, or can be, performed by a computer that is located in a central location, such as a Traffic Management Center (TMC), a Transit Operations Center (TOC), or other off-site facility. That computer serves as the PRG. Centralized TSP architectures are typically implemented where on-board systems are full-featured, and communications infrastructure between the transit vehicle and the TOC, and between the intersection and the TMC are most robust. There is currently no communications infrastructure in place between the VTA transit vehicles and the various stakeholder central traffic signal control systems located along the Rapid and Frequent Routes.

In the centralized concept, the TSP operation still begins on the transit vehicle. The transit vehicle reports its location, and possibly its schedule status (early, on time, or late) to the priority request generator at the TMC/TOC. Schedule status could also be determined on the priority request generator at the TMC/TOC, rather than on the transit vehicle. The DTRP is made on the priority request generator at the TMC/TOC. The priority request is then typically sent to the controller at the intersection by the PRG at the TMC/TOC.

Figure 3 is a depiction of a common centrally based TSP concept. **Figure 4** provides a similar approach, with variations on the communications path(s) for communications between the transit vehicle and the priority request generator.

Figure 3 – Typical Centrally Based TSP Concept

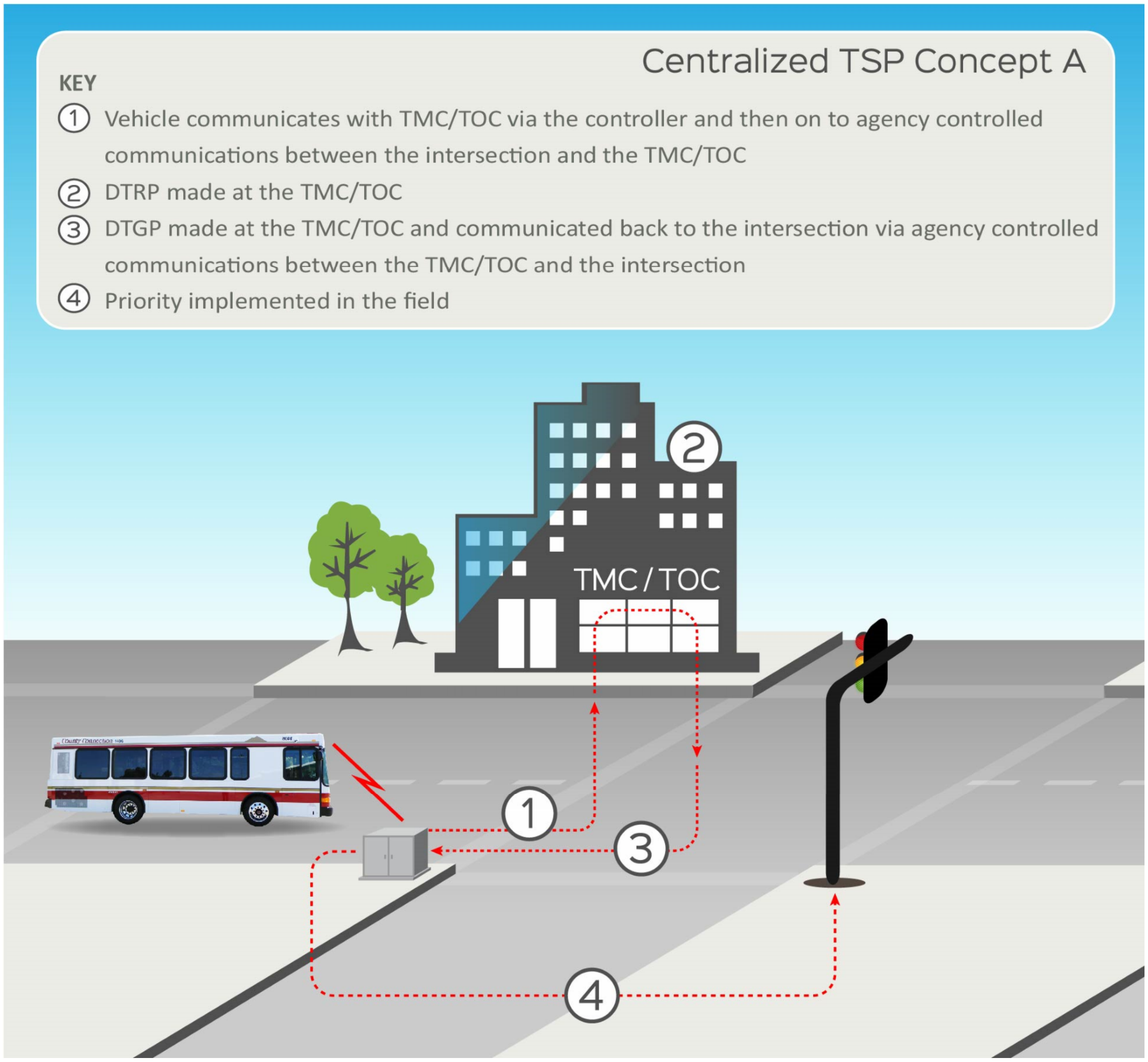
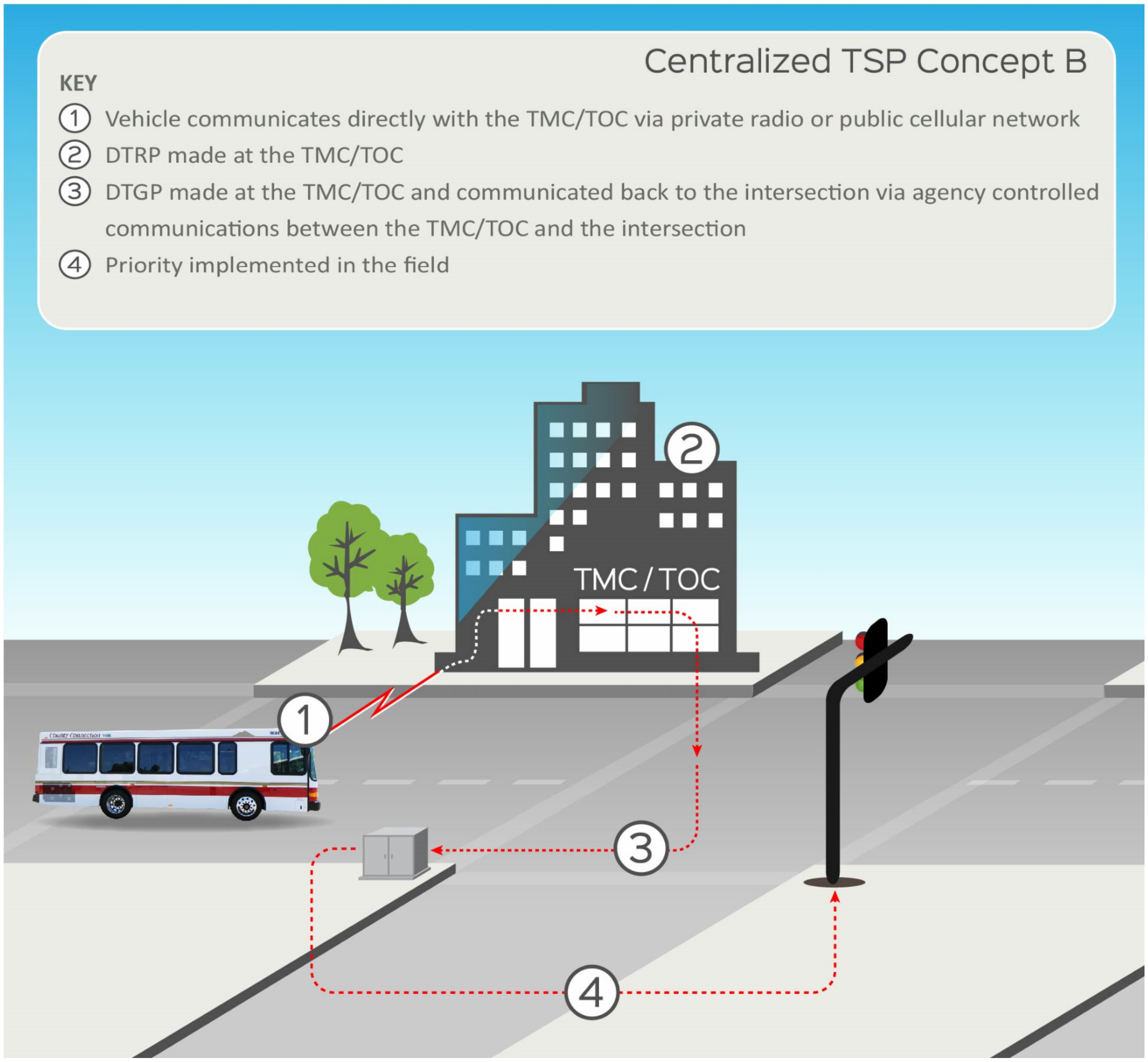


Figure 4 – Centrally Based TSP Concept (Alternative Communications Path)



There are a few variations in the communications path between transit vehicle and the priority request generator at the TMC/TOC. The most common path is from the transit vehicle to the controller at the intersection, then on to agency-controlled communications infrastructure, most typically copper wire or fiber optic cable, to the priority request generator at the TMC/TOC. There are also instances where the transit vehicle communicates with the priority request generator more directly via wireless technology, either a terrestrial radio system, or a commercial cellular data carrier. Typically, the PRG is a function built into the transit Automated Vehicle Location (AVL) system. Most of the vendors selling commercially available AVL systems have some version of a PRG available, including Clever Devices.

6.2.1 Cloud-Based TSP Systems

Cloud-based TSP systems are a version of centrally based systems which take advantage of technological advancements and easy access to the cloud computing platforms. This concept takes advantage of existing but separate control and monitoring systems on the transit side and on the traffic signal control side and connects the two systems over a cloud-hosted application. This concept relies on existing infrastructure on the transit side with vehicles equipped and connected back to the transit agency's CAD/AVL system and on the local agency side with traffic signals equipped and connected back to the local agency's central traffic signal management system. In the absence of the connection back to a central traffic signal system, transit vehicles may still be able to communicate to traffic signal infrastructure via field interface units at the intersection level.

The cloud-hosted application would interface with a transit agency's CAD/AVL system (through a secured internet connection), or with the transit vehicle's on-board system, or a third-party platform to obtain transit vehicle location, heading, status, etc. and with a local agency's traffic signal system (also through a secured internet connection) to send priority requests. The application then functions as an intermediary between the transit vehicle (either through a central CAD/AVL system or directly with the transit vehicle's on-board system) and the traffic signal systems. For each connected transit vehicle , the application would function to make the decision to request priority, and if so, also functions as the priority request generator for the transit vehicle. The application would then send the priority request to the appropriate traffic signal through its connection with the traffic signal system.

This concept has the advantage of a widespread deployment with potentially lower capital costs as it relies on connecting existing infrastructure that is already well equipped. However, this approach does involve a high degree of systems integration as the application must be configured to work with both the transit agency's particular CAD/AVL and the local agency's particular central signal system. This approach also heavily relies on both the transit agency and local agency having an existing robust communications system as the system only works if transit vehicles are communicating back to a central CAD/AVL system and traffic signals are communicating back to a central TMC. Some systems may, however, still require new equipment (i.e., Applied Information requires a field monitoring unit, FMU, in the cabinet) to be installed at the intersection. This concept also highlights the concept of TSP as a service as a trade-off is made to lower upfront capital cost for deployment in exchange for ongoing service cost.

Potential Available Central/Cloud Systems: Applied Information, Connected Signals, Cubic, Econolite, Emtrac, Kimley-Horn, LYT, Miovision (GTT), Tenco, and ThruGreen.

Recommendation: Cloud-based systems and TSP as a service continues to grow in the market and has matured into a commercially viable and proven solution. Many transit agencies and local municipalities have successfully deployed and integrated cloud-based systems, as centralized cloud-based TSP systems have become a top option for new or replacement TSP systems. Thus, the Cloud-Based TSP approach is recommended for further consideration.

7.0 USER-ORIENTED OPERATIONAL DESCRIPTION

7.1 Goals & Objectives

The goal of this project is to keep transit vehicles moving through intersections across multiple jurisdictions to make transit faster, more reliable, and an equitable mobility option so people have greater access to opportunities and to contribute to thriving communities.

The objectives for this project are to:

- Deploy a centralized TSP system initially focused on the Rapid and Fast network, and that is easily scalable to the rest of VTA's transit network.
- Improve transit reliability and travel time along VTA's various routes throughout Santa Clara County.
- Increase transit mode share (i.e., ridership and person throughput), improve mobility for residents, employers, retailers and regional commuters, and increase ridership.
- Reduce the fuel use and carbon footprint related to transit operations.

This project will implement TSP for the first time in many stakeholder Cities and supplement existing TSP in others. The project will deploy a system that provides TSP for VTA transit vehicles initially focused on the Rapid and Frequent routes, with the ability to easily scale to other service routes. The transit vehicles on these routes will be able to request priority at each of these signals, and each local agency's traffic signal will grant priority based on a mutually agreed-upon set of rules. The details of TSP operation will be determined within the project, but in general the benefit to transit travel time will be primarily dependent on the extent of priority that will be provided by parameters programmed in the traffic signal controller to either extend or provide an early green indication for the transit approach phase.

7.2 Stakeholders

The stakeholders and their roles in this project are summarized in **Table 15**.

Table 15 – Project Stakeholders & Roles

Stakeholder	Role(s)
VTA	Current Role: Operates and maintains transit service in the project area. Project sponsor and initial recipient of SMART grant funds. Funding agency, program manager, systems engineering contract manager, and overall systems engineering project oversight. Future Role: Lead, and/or support, the procurement and deployment of the centralized TSP system(s)and associated improvements for use on its network.
Cities/Towns of San Jose, Campbell, Milpitas, Santa Clara, Sunnyvale, Cupertino, Mountain View, Palo Alto, Los Gatos, Gilroy, Morgan Hill, Saratoga, Los Altos, Los Altos Hills, Monte Sereno; County of Santa Clara; and Caltrans	*Current Role*: Owns, operates and maintains the traffic signals in their respective jurisdictions that are travelled by VTA's transit routes. Responsible for review and acceptance of the proposed TSP system concept and requirements. *Future Role*: Support and/or lead the procurement and deployment of the centralized TSP system and associated improvements for use within its agency. Will own, operate, and maintain any TSP-related roadside hardware implemented by this project (e.g., controllers) within their jurisdiction. Lead and/or support the procurement and deployment of traffic signal hardware or infrastructure improvements (as needed), and for any City-owned systems which may integrate with the centralized TSP system. Procurement and deployment responsibility and funding will vary by project and available funding sources and would be documented in a Memorandum of Understanding between VTA and stakeholder agency(ies).
System Engineer (Iteris)	Perform system engineering tasks and provide support during TSP system selection and deployment.
System Vendor(s)	Furnish, install, and deploy the centralized TSP system. More than one TSP system may be utilized, which may require more than one TSP system vendor.
Design Engineer(s)	Perform design (PS&E) for physical improvements (i.e., traffic signal communication upgrades) in support of one or more project elements, if needed.
Construction Contractor(s)	Construct and install field elements such as communications, controllers, and TSP devices, if needed.
Construction Manager(s)	Provide construction administration and oversight of all field elements, if needed.
System Evaluation Consultant(s)	Develop the validation and evaluation plan for the deployed TSP system including performance of a before and after study, if needed.

7.3 Constraints

This project will involve multiple jurisdictions where traffic signals are under the individual control of each individual agency. Thus, the usual technical challenges that come with a multi-jurisdictional project are not avoided here. Depending on each agency, the robustness of the existing traffic signal infrastructure to support the TSP deployment varies and may limit the type of system(s) or operational strategies which may be deployed. Additionally, some technical challenges for this project may relate to the ease of integration of the cloud-based application vendors with existing infrastructure and the potential of multiple stakeholders who may have different operational strategies or policies for TSP. As a result, the technical challenges may include the following:

- Any given stakeholder may have a TSP operating strategy or policies (i.e., what and how conditional rules are defined) that would differ from VTA or adjacent Stakeholders agencies. Given that the same TSP system(s) will be utilized across the County, the TSP system must be able to accommodate varying TSP operating strategies or policies, or the stakeholders must agree upon a common approach.
- A centralized TSP system heavily relies on solid communications between project components. In particular, a functional and reliable communications link between each city's central signal system and each intersection traffic signal controller will be crucial.
- The TSP system and its various components and integrations will need to meet industry standards (i.e., NTCIP 1202 and 1211).
- Within some centralized systems, conditional TSP as a cloud-based application may still be relatively new. While TSP functionality is available as a cloud-based application, features for conditional priority may still need to be developed. Software development for conditional applications on a commercial basis is also relatively new and there may be few vendors in the market.
- Stakeholders have expressed a need to send transit priority request messages and receive signal status messages through the local agency's central signal system (ATMS), which may likely require integration of the two systems.
- Several stakeholder agencies lack the basic traffic signal system infrastructure (i.e., updated controllers that support TSP functionality and centralized communications to the traffic signals) to easily support a centralized cloud TSP system deployment. An alternative centralized TSP architecture would need to be provided for these local agencies.
- Security of data transmission between the transit vehicle and the traffic signal may need to be addressed. Other means of addressing transmission security may need to be identified. This may include consideration of stakeholder agency security preferences or requirements.
- This project does not include the relocation of near-side bus stops to the far side. As a result, locations with near-side stops will not be able to take full advantage of the efficiency gained by implementing TSP. TSP functionality would also need to account for situations where buses dwelling at near-side stops for passenger boarding/alighting would not generate an unnecessary TSP request.
- Providing agency staff with the necessary skill set for continued operations and maintenance of the TSP system including field infrastructure and on-board equipment.

7.4 Current Method of Accomplishing Goals and Objectives

Many of the stakeholder agencies have never previously implemented TSP and this will be a new technical endeavor. To the extent possible, current available methods of improving transit operations have relied on implementing well-coordinated signal timing plans along the project arterials in order to provide smooth traffic flow, minimize delay, and minimize congestion. Since transit vehicles travel along with the general mixed traffic, they also benefit from a corridor with traffic signals that have optimized timing plans and are well coordinated.

There are several stakeholder agencies which have already implemented some form of TSP to various degrees of success, whether it be hardware-based systems in the field, or more current centralized cloud-based solutions. This VTA project will implement TSP throughout the County where it doesn't currently exist, as well as integrate with existing cloud-based deployments as possible, and is expected to have a direct benefit to transit travel time and reliability to help meet the project goals and objectives.

8.0 OPERATIONAL NEEDS

This section describes the user needs identified by the stakeholders related to the operations of the TSP system. Each section below describes something that the system needs to be able to accomplish. Each of these needs, preceded by a ConOps reference number as shown, will be satisfied by compliance with a set of system requirements that will be developed in a subsequent document.

8.1 Operational Needs

[8.1-01] The TSP system needs to improve transit vehicle on-time performance reliability and reduce running time delay.

[8.1-02] The TSP system needs to increase ridership by making the transit service more attractive via improved performance reliability and reduced travel time.

[8.1-03] The TSP system needs to interface with VTA's existing central CAD/AVL system, on-board CAD/AVL system, or a third-party platform that has already established an interface with the existing CAD/AVL system.

[8.1-04] The system needs to provide early green and green extension for transit priority.

[8.1-05] The TSP operation should not compromise pedestrian crossings at signals.

[8.1-06] The TSP operation should not significantly increase side street traffic delay.

[8.1-07] The TSP system needs to operate under various modes of signal operations including Free and coordinated operation.

[8.1-08] The TSP system shall operate in conjunction with any existing adaptive signal control technology and not interfere with the adaptive system operation.

[8.1-09] The TSP system needs to operate under various street network topography such as a downtown grid (i.e., multiple crossing corridors with typically short blocks) and along arterials (i.e., single corridor with typically long blocks).

[8.1-10] The time interval and distance for sending the initial check-in message shall be user-configurable to accommodate varying street traffic conditions and characteristics.

[8.1-11] The system shall support implementation of preemption and/or priority for LRT and emergency vehicles.

8.2 Monitoring Needs

[8.2-01] The system needs to provide centralized monitoring of TSP activity and system performance to VTA and all project stakeholders.

[8.2-02] Project stakeholders need to have appropriate access (i.e., control vs. read-only) to real-time corridor signal operation information, including the current state of the signal and TSP operation.

8.3 Reporting and Documentation Needs

[8.3-01] For TSP operation, the following data needs to be reported by the system for each TSP request:

- Date
- Intersection ID
- Transit Vehicle ID
- Transit Vehicle travel direction
- TSP request
- TSP request granted/not granted
- Start time and end time of granted priority
- Type of priority granted (i.e., early green, green extension)
- State of signal when TSP is granted/not granted
- Health of the TSP system

[8.3-02] The system needs to provide measures of performance; real-time logging of status, events, and operation; and storage of logs for all events and operations.

8.4 Architecture Needs

[8.4-01] The system needs to be a centralized system where the transit vehicle reports its location and status in the cloud-based application to manage and generate the TSP request that will be sent directly to the local controller. The decision to grant the TSP request will then be determined by the local controller.

[8.4-02] The system needs to be a centralized system where the transit vehicle reports its location and status in the cloud-based application to manage and generate the TSP request. The TSP request will then be relayed to a central traffic signal system (ATMS) which will then process and send messages to the local controller.

[8.4-03] The system needs to be compatible and integrated with VTA's existing CAD/AVL, or other third-party platforms, in order to retrieve vehicle information collected and generated by the on-board CAD/AVL system.

[8.4-04] The system needs to be able to integrate with the various types of traffic signals within each jurisdiction, including having the ability to work across multiple controller brands/firmware.

[8.4-05] Regional interoperability of the TSP system is desired to maximize flexibility in the vehicle fleet deployment such that any vehicle assigned to any route would maintain TSP functionality.

[8.4-06] Regional interoperability of the TSP system would ensure the TSP can operate along entire routes that traverse multiple jurisdictions. This will improve reliability and reduce travel time along the entire route and not limit the benefit to within certain jurisdiction(s) along the route.

[8.4-07] The system shall be easily scalable by adding, reassigning, or removing intersections at any time.

8.5 Maintenance Needs

[8.5-01] The central TSP system needs to operate without the interaction, management, or control of the operator.

[8.5-02] Comprehensive training needs to be provided to VTA and Stakeholder staff (hardware and software) for set-up, configuration, and maintenance.

9.0 ENVISIONED SYSTEM OVERVIEW

It is suggested that the centralized concept be the preferred approach, as opposed to the distributed concept, for this project. The foundation for deployment of TSP for this project is a centralized TSP application utilizing existing on-vehicle communications technology and traffic controller message format standards (i.e., NTCIP 1211) that have been developed and adopted. The project concept is based on the premise of a transit vehicle equipped with an AVL system and cellular radio that is able to identify and broadcast its current location and determine, utilizing a centralized TSP system, if and when to request priority from upcoming traffic signals using the cloud-based application to send and receive messages to an agency's central signal system or communications network infrastructure, and then sending the TSP request to one or more traffic signal controller(s) via an existing communications link.

Based on available cloud-based TSP systems, and depending on the solution selected, it is envisioned that some level of software development may need to be performed in order to meet the project's operational needs. For example, some level of software development may be needed to integrate the TSP application with a stakeholder's existing central signal system, if the priority request message generated by the TSP system needs to go through the central signal system before being sent to the local traffic signal controller.

9.1 TSP Process

The overall TSP process can be broken into four basic steps as depicted in **Figure 5** and summarized as follows:

Figure 5 – Overall TSP Process

- First, a VTA transit vehicle enters the zone of an intersection defined by the cloud-based TSP application and is identified as being in a location where priority is required, that is, when the transit vehicle is approaching an intersection where priority may be granted for the transit vehicle.
- Second, a decision is made whether request priority (either conditional or unconditional priority).
- Third, a decision is made whether to grant priority, based on another set of established criteria, such as time of day and minimum time intervals between successive priority implementations (such as not granting priority on back-to-back cycles).
- Finally, if priority is granted for the transit vehicle, the priority implementation stage is initiated and executed by firmware in the traffic signal controller.

To implement this process for the TSP system, the following components are required:

- On-vehicle computer system, currently provided by Clever Devices, on VTA transit vehicles to determine and provide real-time location information to a centralized system;
- Vehicle location and status data provided to centralized TSP application communications, using the communications equipment already installed on VTA transit vehicles, the central CAD/AVL system, or third-party platforms;
- Centralized cloud-based TSP application to central signal system communications network, with the necessary communications equipment at the central communications network to connect to the internet; and
- Central communications network to intersection traffic signal controllers to exchange priority requests and priority request status messages. The traffic signal controller will provide signal timing information to the centralized TSP application, receive the priority request message from the centralized TSP application, and implement priority for the requesting transit vehicles.

If a central communications network for traffic signals is not available, the centralized cloud-based TSP application may directly communicate with the traffic signal controllers via a field interface unit to exchange priority requests and priority request status messages, in order to implement priority for the transit vehicles.

Figure 6 illustrates how each of the four main system components relate to the TSP process when a central signal system is available. **Figure 7** depicts the same but with communications directly to the traffic signal controllers. Each of the components shown are discussed in more detail in the following sections.

Figure 6 – TSP Process Components – Via Central Signal System

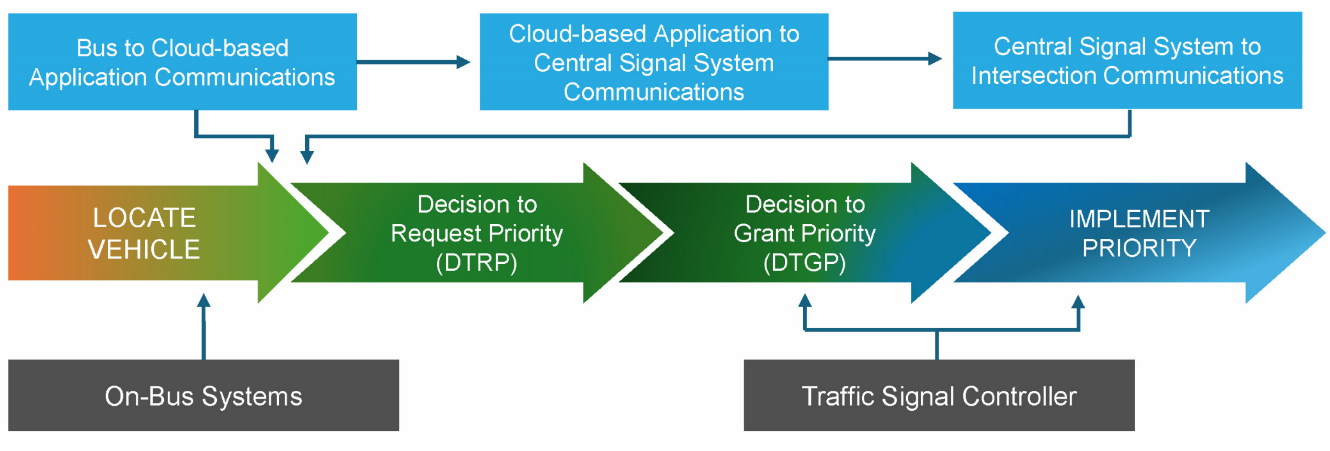
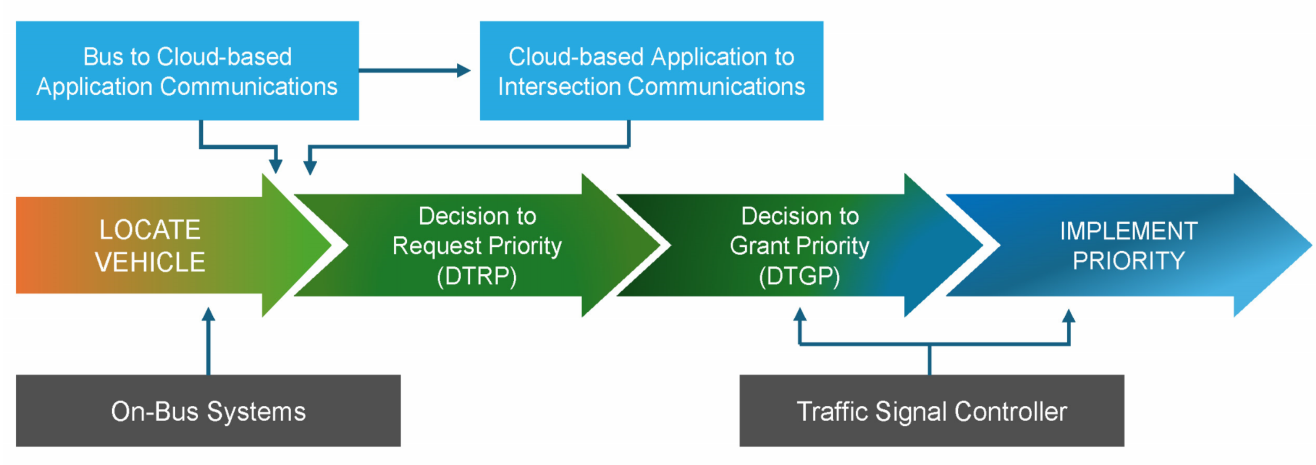


Figure 7 – TSP Process Components – Direct to Controller



9.2 On-Vehicle System

VTA transit vehicles are currently equipped with Clever Devices' IVN on-board CAD/AVL system and with Moovbox or Peplink cellular router capable of identifying the vehicle's current status and location data that are transmitted back to the CleverCAD central CAD/AVL system. Transit vehicle status and location information is also provided to third-party feeds including GTFS-Static, GTFS-RT, and Swiftly. A TSP application will be able to interface with either the on-board CAD/AVL system, the central CAD/AVL system, or the third-party data feed to obtain that vehicle location relative to upcoming signalized intersections. Based on the information provided by any of these means, the TSP application will have the necessary logic to request priority from the upcoming traffic signals

9.3 Transit Vehicle to Cloud-based TSP Application Communications

The cloud-based TSP application will obtain the location, heading, speed, and any other relevant geo-locational data of the transit vehicle to determine the need for priority. Multiple messages are transmitted for each priority request that include check-in messages and the check-out message. The messages generally include:

- Initial Check-In. The TSP application sends a “check-in” priority request to the intersection where priority is being requested. The message is sent when the TSP application has identified that a transit vehicle has entered a pre-defined zone of the intersection or is within a specified estimated time of arrival interval. This distance or ETA are configurable depending on intersection spacing and roadway configuration. The time interval for sending the initial check-in message may be user configurable to accommodate varying street traffic conditions and characteristics.
- Continued Check-In. Update messages are continuously sent as the transit vehicle approaches the intersection. This is done to ensure that the request for priority is received by the intersection and to update the estimated time of arrival accounting for any traffic conditions that the transit vehicle experiences as it approaches the intersection.
- Check-Out. Finally, as the transit vehicle enters the intersection, a “check-out” message is sent allowing the intersection controller to terminate the priority request.

9.4 Cloud-based TSP Application to Intersection Communications

This TSP system is envisioned to utilize an internet connection for communications between the TSP cloud application to each local agency’s traffic signal system, and to utilize existing communications between central systems and intersections where available. Depending on the robustness of the stakeholder agency’s communications network and the agency’s preferences relating to VTA access to their systems and infrastructure, there are three ways the cloud-based TSP system may reach an intersection traffic signal controller to make a request for priority:

1. Communicating directly with intersection controllers via the agency’s existing communication network;
2. Communicating with the agency’s central signal system which will relay the messages to the intersection controllers; or
3. Communicating with vendor field interface units via cellular communications to be installed at each intersection signal cabinet and connected to the controller.

In all three cases, the TSP application, having obtained information about the transit vehicle (such as its location, heading, and speed) and will determine if there is a need for priority as it approaches a signalized intersection. Which case that would be most appropriate is determined by the intersection agency’s existing infrastructure (i.e., central system, communications, controllers, and controller firmware).

In cases 1 and 2 above, the cloud-based TSP application will interface with the local agency’s existing central traffic communications network through an internet connection. Based on information provided by the transit vehicle, the cloud-based TSP application will determine the specific traffic signal(s), the approach direction and corresponding signal phase(s) where a priority request is needed and communicate this information directly to the traffic signal controller(s), or via the central signal system. For case 2, when a priority request is generated by the cloud-based TSP application, the central signal system will then generate a priority request to the affected traffic signal controller(s) and for the specific approach phase(s) in the field, as indicated by the cloud-based TSP application.

In case 3, the TSP application does not have an existing communications connection to an agency central communications network or to the signal controllers in the field. Instead, the centralized TSP system will communicate directly with the intersection infrastructure. Like cases 1 and 2, based on information provided by the transit vehicle, the cloud-based TSP application will determine the specific traffic signal(s), the approach direction and corresponding signal phase(s) where a priority request is needed, and communicate this information via cellular communications directly to a field interface unit to be installed in the intersection cabinets. When a priority request is generated by the cloud-based TSP application, it is sent to the affected field interface unit(s) which will generate the priority request to the traffic signal controller connected to that unit and for the specific approach phase(s) in the field, as indicated by the cloud-based TSP application.

9.5 Intersection Traffic Controllers

The intersection traffic signal controllers function to:

- receive the TSP request message generated by the centralized cloud TSP system, the central signal system, or the field interface unit;
- provide priority status message to the centralized cloud TSP system; and
- make the decision to grant priority and implement priority at the intersections.

The intersection controllers will accept the check-in, position update, and check-out messages and then act to modify the signal timing according to the local agency established parameters (i.e., green time extension or early return to green). Typically, the controller can be configured so there are limits placed on the amount of change invoked by priority and the frequency that priority is allowed. Some of the available TSP applications are also capable of limiting priority frequency. Typical industry practice includes up to 10 percent of the cycle time for early green/green extension; no priority granted on consecutive cycles, and prohibiting the skipping of vehicular and pedestrian phases. This functionality allows the local agencies with operational responsibility of their traffic signals the flexibility to develop these details in accordance with local policies.

Depending on the type of traffic signal controllers at the stakeholder intersections, the controllers will communicate with the central signal system or field interface units using existing infrastructure and protocols. The software on these controllers will need to be capable of TSP functionality.

9.6 Overview of Operations

To summarize the previous discussion, the following figures provide an overview of the three envisioned TSP operational concepts which may initially be implemented along the Rapid and Frequent routes throughout the various jurisdictions in Santa Clara County.

Figure 8 – Overview of TSP Operation Concept 1: Direct to Controller

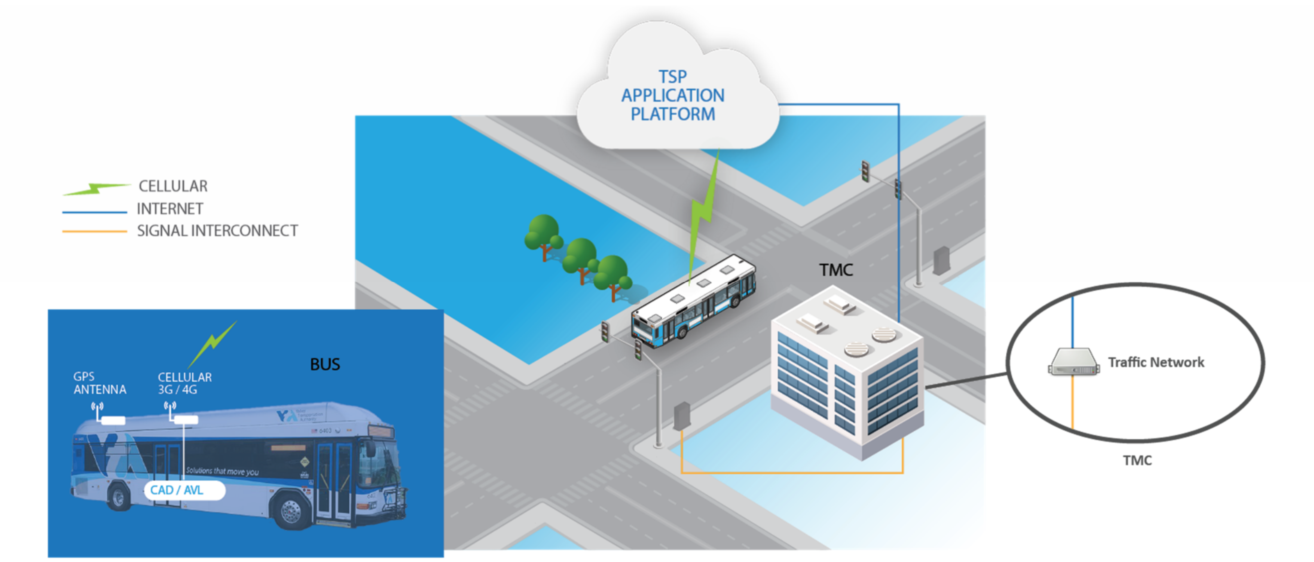


Figure 9 – Overview of TSP Operation Concept 2: Via Central Signal System

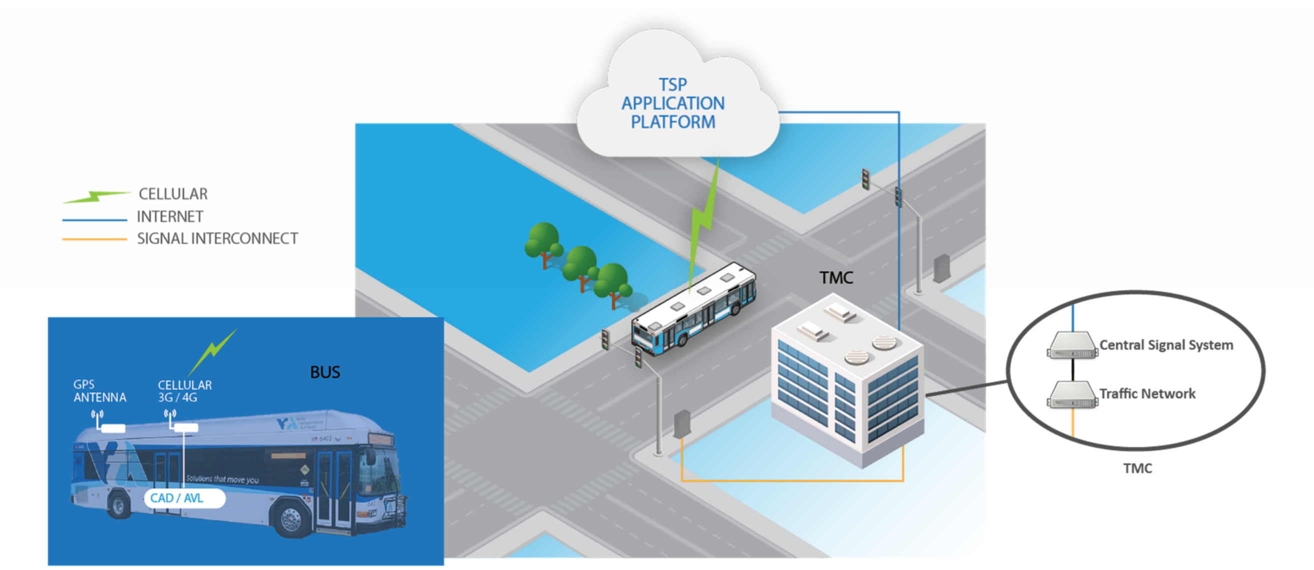
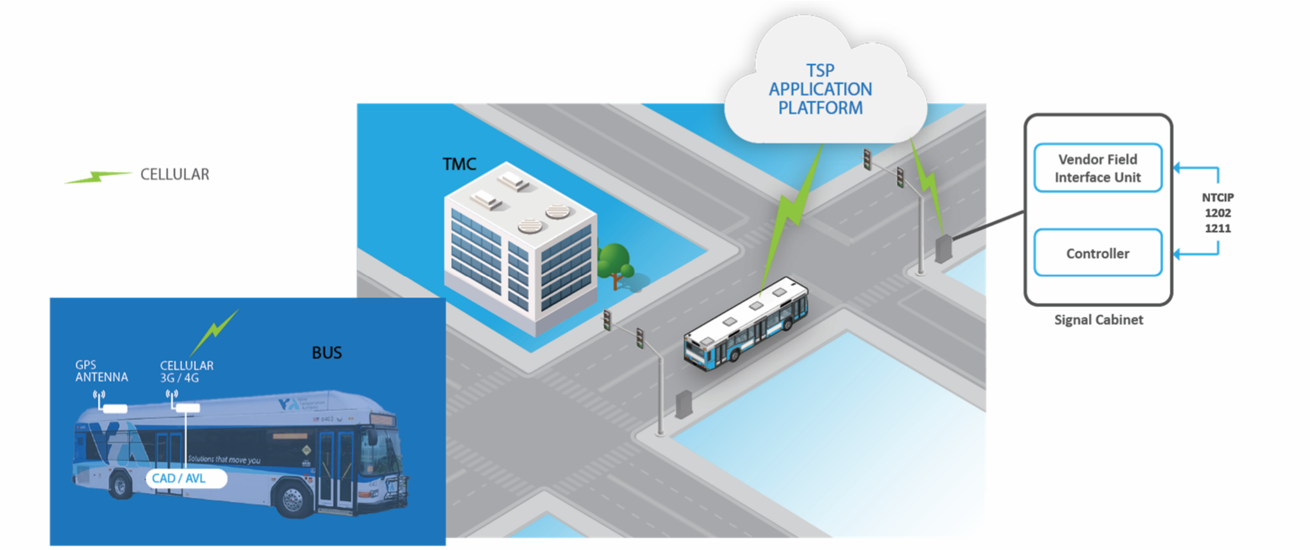


Figure 10 – Overview of TSP Operation Concept 3: Via Vendor Field Interface Unit



At a high level in each concept, VTA transit vehicles will communicate with a centralized cloud-hosted TSP application platform to request priority as it approaches a traffic signal. The cloud-hosed TSP application will either be connected to the jurisdictional agency's central communications network using an internet connection (Concepts 1 and 2) or a vendor field interface unit in the intersection cabinet using a cellular connection (Concept 3). Via those connections, the TSP application will send the priority request directly to the intersection signal controller, through the central signal system, or interface unit(s), respectively. The central signal system or interface units will then send the priority request to the affected traffic signal controller(s) for a response. The intersection traffic signal controllers will then implement priority for the transit vehicles.

The following is a detailed breakdown of how the TSP application will provide priority:

1. As a VTA transit vehicle approaches a signalized intersection, it enters the virtual detection zone of the intersection. The centralized TSP application will make a decision to request or not request priority at the signalized intersection.
2. If a decision to request priority is made by the centralized TSP application, the distance from the intersection where request for priority messages is initiated will depend on intersection characteristics but, typically, will be at a distance that corresponds to 10-30 seconds from the intersection, depending on intersection spacing and roadway characteristics.
3. Having made the decision to request priority, the centralized TSP application will initiate the request to the traffic signal controller. This is done in one of two ways, depending on the concept implemented:
    - Concepts 1 & 2: The message is sent using an internet connection between the centralized TSP application and the local agency's central traffic communications network; or
    - Concept 3: The message is sent via a cellular connection between the centralized TSP application and a field interface unit installed at the intersection cabinet.
4. Having received the priority request, the traffic controller directly (or via the central signal system or field interface unit) initiates the priority request at the intersection. The traffic controller then provides a status of the priority request to the central signal system or interface unit (as applicable).

5. The signal controller will modify the signal timing in anticipation of the transit vehicle (having requested priority) arriving at the intersection based on the data received in the request for priority messages being sent by the centralized TSP application. Possible actions taken by the controller in response to a request for priority from approaching transit vehicles include:
    - Priority is granted for the approaching transit vehicle (green extension or early green);
    - Priority is not needed for the approaching transit vehicle (signal indication is already green); and
    - Priority is denied. Priority may be denied for a number of reasons, such as priority being locked out for a user-specified number of cycles or seconds to avoid priority on back-to-back cycles or the controller locking out requests for priority during certain user-specified time periods.
6. The TSP activity is monitored and logged with access provided through a central interface with the centralized TSP application. In particular, priority requests and priority granted/not granted will be tracked to provide status of TSP activity. The priority request activity will provide an indication of when and where priority requests are made by the transit vehicle. The priority granted/not granted activity will indicate what action was taken by the controller in response to the request for priority sent by the transit vehicle. In addition, the jurisdictional agencies will be able to monitor TSP activity and performance measure from the centralized TSP application and their central signal system through event logs from their traffic signal controllers as applicable.

10.0 OPERATIONAL ENVIRONMENT

The system will be operated by VTA with shared access with the stakeholder agencies. In cases where the centralized TSP system is connected to an agency's central traffic communications network, the agency's central signal system will be able to monitor TSP operation through both this connection and the existing communications with the traffic signal controller. The TSP system will also have a central interface to monitor and log TSP activity. Since this is a cloud-hosted platform, all project partners could have access to the platform to monitor TSP activity and retrieve activity logs. The TSP activity will be logged to show priority requests and priority status activity which will inform when and where priority requests were made by a transit vehicle, with the traffic signal controller logs showing how the traffic signal controller responded to the requests.
The stakeholder agencies will maintain control of all local signal timing parameters for the traffic signals that they operate and maintain. This includes timing parameters such as minimum green, clearance, pedestrian walk and clearance, coordination timing plans, and preemption. When the signals are operating to serve a TSP request, allowable timing parameters (i.e., green extension, early green, lock-out time between priority requests) will be determined in consultation with project stakeholders. VTA will coordinate to determine system-wide parameters such as the days of TSP operation (i.e., weekday only, weekends) and hours of operation. All system-wide parameters will be determined by the stakeholder agencies and will be implemented by each for their respective traffic signals.

It is expected that the stakeholder agencies' transportation/traffic engineering staff are experienced in setting up, operating, and managing their existing signal systems and associated infrastructure. Day-to-day operations and management of the centralized TSP system will be the responsibility of the TSP system owner. In some cases, this may be the stakeholder agency themselves or VTA, depending on who leads the procurement process, the funding source(s), and terms of any inter-agency agreements for the procurement. The operating agency will require training specific to the TSP system to set up, fine-tune, and operate all aspects of the system. Maintenance of any equipment deployed at stakeholder agency's facility and/or intersections as part of the TSP system, along with all other existing traffic signal infrastructure, will be performed by each stakeholder agency's signal maintenance staff or contractor.

VTA expects to operate the centralized TSP system for a period of ten years, assuming system performance continues to meet the agency's needs. VTA will seek technical support from the system vendor in using the TSP system software for three years in which the vendor will provide support via a combination of phone, on-site visits, and remote log-in. VTA expects warranty and maintenance of any vendor-supplied software, parts, and equipment (including software updates, patches, iterative revisions, and new versions) for a minimum of three years will be included in the purchase price and include options to extend in one-year increments at VTA's discretion.

11.0 SUPPORT ENVIRONMENT

This section describes the support environment for the TSP system. Key elements include identifying institutions and stakeholders, facilities, system architecture constraints, utilities, equipment, computing hardware and software, personnel, and other support needs for the project.

As this project has a number of agency stakeholders, it is expected that each individual stakeholder agency will be the host site of any equipment to be deployed in support of the TSP system and will be responsible for operation, management, and maintenance of their own field system. VTA is responsible for operations, management, and maintenance of the on-board systems, central CAD/AVL system, and any third-party data feeds. Each stakeholder agency's signal operations staff will have operational oversight for their own agency's signals operating with the TSP system. VTA is the funding agency and program manager of this initiative and is responsible for overall program oversight to ensure project delivery and success.

The Stakeholder agencies have existing facilities in agency buildings where transportation staff are located. In many cases, these facilities currently house the existing central signal system and are equipped with equipment racks, servers, networking equipment, workstations, and video equipment. If needed, any TSP system field equipment will primarily be housed in the field at traffic signals and within the existing controller cabinet. Within the central signal system for each stakeholder agency, it is anticipated that new TSP platform hardware and/or software interface with the central signal system will be needed, along with the module to be added to the signal system to provide additional TSP functionality between the central signal system and the field controllers.

If needed, though not anticipated, VTA has existing facilities within their transit vehicle fleet to house the TSP system. Each VTA bus has a secure equipment cabinet that currently houses on-board equipment such as the CAD/AVL system, communications equipment, and other equipment for bus operation. It is anticipated that any TSP equipment needed can be housed in this equipment cabinet.

Any additional test equipment required to support the TSP system will be determined by the centralized TSP system vendor. The vendor will specify any hardware and software needed to support the TSP system as well as any field modifications needed. The vendor will be responsible for identifying any hardware needed to support the TSP system. It is anticipated that existing equipment in the Stakeholder agencies' facilities will be utilized to support the TSP system (i.e., network switch, workstations, monitors, printers, equipment racks, and power supply). Maintenance and repair of the computing equipment is the responsibility of each stakeholder agency's staff. Any additional support provided by each stakeholder agency's IT staff will be specific to each agency's business practice.

While it is anticipated that the TSP system will be operated by VTA, each stakeholder agency has staff dedicated to signal operations (or at a minimum, oversight of signal operations) and no additional staff is anticipated to be required to operate the TSP system. If needed, these staff are available during normal business hours, with after-hours support provided by each stakeholder agency's signal maintenance staff or contractor. Training of the stakeholder agency staff, the stakeholder agency's signal maintenance staff/contractor, and VTA staff will be required to be provided by the system vendor during and after the installation of the TSP system. To ensure optimal operation of the system, the system vendor will also provide on-going support and maintenance. The scope and duration of on-going support will be determined during procurement of the centralized TSP system.

12.0 OPERATIONAL SCENARIOS

This section presents a number of operational scenarios to describe how the TSP system is expected to operate to meet user needs. It is not intended to cover all the situations that may occur, but to present how the system will operate under some common situations such as:

- Typical Priority Requests;
- Conflicting Priority Requests; and
- Multiple Priority Requests.

12.1 Typical Priority Requests

As a VTA transit vehicle approaches a signalized intersection, it enters the virtual detection zone of the intersection operating under the cloud-hosted TSP application platform.

A decision to request priority is made by the cloud-hosted TSP application. Having made the decision to request priority, the cloud-hosted TSP application sends the request message to the traffic signal controller (or via the central signal system or field interface unit which then sends the message to the traffic signal controller) at the intersection. The message is sent and received using a combination of cellular radio, internet connection, and local agency-owned communications infrastructure between the central signal system and the traffic signal controllers in the field. The priority request message is received by the traffic signal controller at the intersection. The traffic controller then provides a status of the priority request by sending a status message back to the centralized TSP application and central signal system (if applicable).

The signal controller will then evaluate the needed modifications to the signal timing in anticipation of the transit vehicle arriving at the intersection. Based on the current operations of the traffic signal controller, the controller will attempt to provide a green signal for the transit vehicle by:

- Holding the green indication longer, if it would have otherwise terminated earlier, so that the transit vehicle can proceed through the intersection;
- Initiate the green indication earlier, if it would have otherwise started later, so that the transit vehicle can proceed through the intersection; or
- Take no action as the signal is already green and would normally remain green by the time the transit vehicle reaches the intersection.

12.2 Conflicting Priority Requests

In a scenario where two or more transit vehicles approach from conflicting directions (i.e., one northbound and one westbound), with both transit vehicles requesting priority with each sending a priority request for the intersection, the intersection will receive both priority requests. The traffic signal controller will contain rules related to receiving multiple priority requests and the order in which each request is granted. Such a rule may be a first-come-first-serve basis, such that if the northbound transit vehicle requests priority before the westbound transit vehicle does, the controller will provide priority to the northbound transit vehicle first. Then depending on other rules within the controller, it may or may not grant priority to the westbound transit vehicle after completing the priority service for the northbound transit vehicle.

Another such rule may be that east-west traveling routes have preference over north-south traveling routes. In this same scenario, although the northbound transit vehicle requests priority first, once the controller receives the westbound priority request, the controller will place the westbound priority ahead of the northbound and serve the westbound priority first. Then depending on other rules within the controller, it may or may not grant priority to the northbound transit vehicle after completing the priority service for the westbound transit vehicle.

12.3 Multiple Priority Requests

Similar to above scenario, there may be cases where priority requests occur in back-to-back cycles or within a short duration of each other. For example, this may occur if just having served a priority request for a westbound transit vehicle, the controller receives a new priority request by an eastbound transit vehicle. The traffic signal controller will contain rules related to receiving multiple priority requests and the minimum time duration (measured in the number of signal cycles or number of seconds) that must have elapsed before another request is granted.

Such a rule may be that after having served a priority request, a new priority request will not be granted until two full signal cycles have elapsed with no priority service. In this scenario, the eastbound transit vehicle would not be granted priority since the request was made just after a previous request was completed.

13.0 SUMMARY OF OPERATIONAL IMPACT

This section provides an evaluation of the proposed system and the impact on each of the stakeholders. It is presented from the viewpoint of each, so that they can readily understand and validate how the proposed system will impact their operations.

13.1 Stakeholders

The stakeholders of the project must fully commit to active involvement with the TSP systems. The technology that will be deployed will not achieve the goals of the project unless they are actively used and properly maintained. In order to have the system operate efficiently, stakeholders must collectively commit to maintaining the infrastructure that supports the TSP system. These responsibilities would be documented as part of a Memorandum of Understanding between VTA and the stakeholder agencies. The following **Table 16** provides a summary of the potential impact(s) on each individual stakeholder agency.

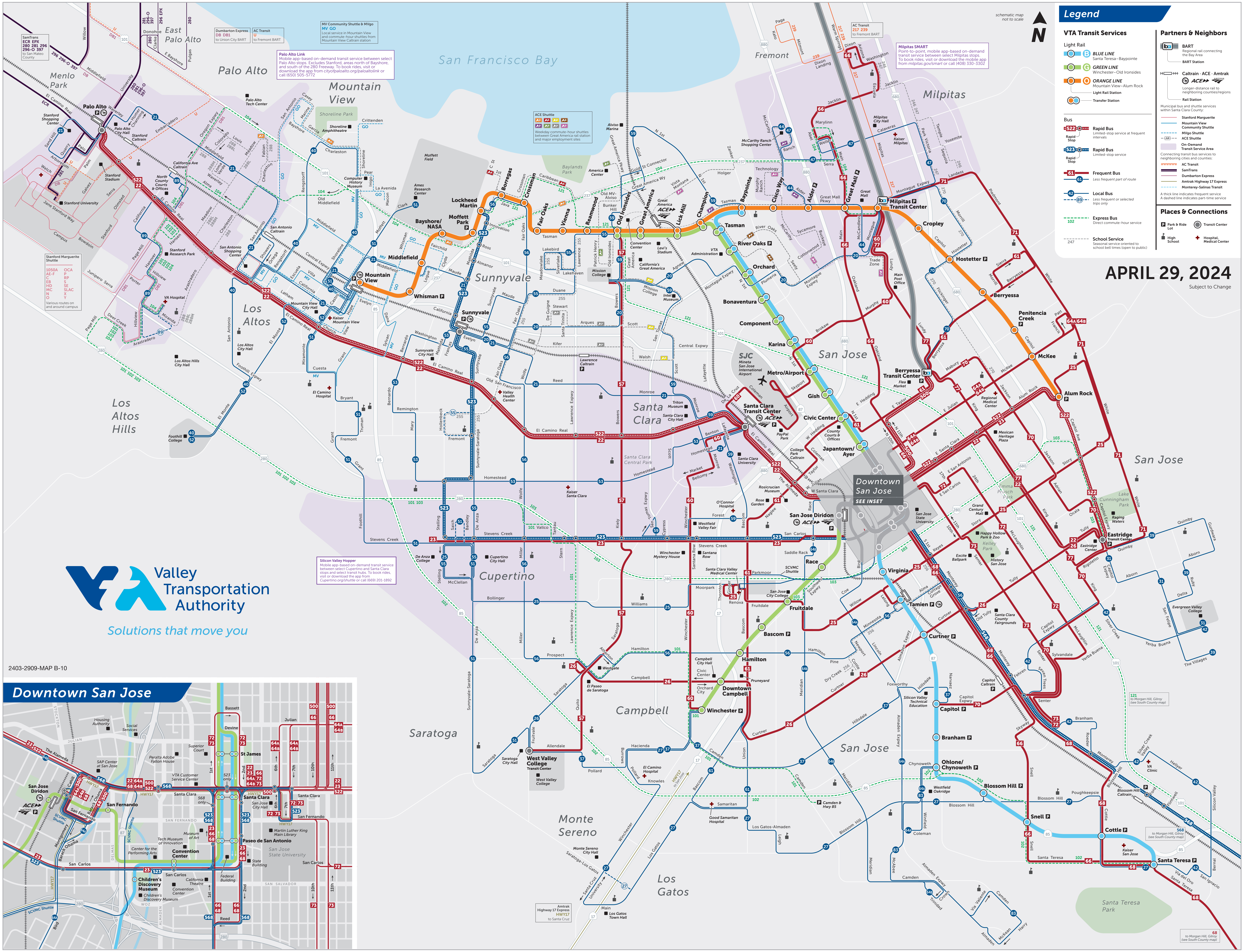
Table 16 – Project Stakeholders & Operational Impacts

Stakeholder	Operational Impacts
VTA	This project will provide VTA with a centralized cloud-based system to operate and maintain. Equipment included that is under VTA's control includes any system(s) that is required to support the TSP system (e.g., CAD/AVL hardware/software, server hardware), all of which would be located at VTA facilities. In addition to hardware, VTA will also be responsible for overall performance measurement of the system(s) and is responsible for implementing institutional agreements between VTA and the various other stakeholders for the operation of the system. VTA is also responsible for overseeing the procurement and deployment of the TSP system software throughout the County and will also be responsible for the ongoing Operation and Maintenance of the system, including funding.
Cities/Towns of San Jose, Campbell, Milpitas, Santa Clara, Sunnyvale, Cupertino, Mountain View, Palo Alto, Los Gatos, Gilroy, Morgan Hill, Saratoga, Los Altos, Los Altos Hills, Monte Sereno; County of Santa Clara; and Caltrans	Depending on the existing conditions of each agency's signal equipment, this project may result in providing agencies with new equipment to operate and maintain. Equipment under each agency's control may include: • Controllers with updated software for TSP; • Upgraded traffic controller hardware; • Communications equipment; and/or • Field interface units.
The Public (transit-riders)	Transit riders within Santa Clara County will experience an improved level of service throughout the County on VTA's fast and frequent routes.
The Public (all other modes)	Drivers, bicyclists, and pedestrians may experience temporary, but negligible delay as a result of granted transit priority.

13.2 System Constraints

The TSP system must be developed within the time and budget dictated by the terms and conditions of VTA's SMART grant program funds. The project should leverage existing infrastructure as much as feasible.

APPENDIX A – VTA TRANSIT ROUTE MAPS



APRIL 29, 2024
Subject to Change
Legend
VTA Transit Services
Light Rail
BLUE LINE
Santa Teresa–Baypointe
GREEN LINE
Winchester–Old Ironsides
ORANGE LINE
Mountain View–Alum Rock
Light Rail Station
Transfer Station
Bus
Rapid Bus
Rapid Stop
Frequent Bus
Local Bus
Express Bus
School Service
Partners & Neighbors
BART
Caltrain · ACE · Amtrak
Places & Connections
Valley Transportation Authority
Solutions that move you
2403-2909-MAP B-10
Downtown San Jose
San Francisco Bay
Palo Alto
East Palo Alto
Menlo Park
Mountain View
Los Altos
Los Altos Hills
Sunnyvale
Santa Clara
Cupertino
Saratoga
Campbell
Monte Sereno
Los Gatos
San Jose
Milpitas
Fremont
Downtown San Jose SEE INSET
Palo Alto Link
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Silicon Valley Hopper
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