

Washtenaw BRT Refinement Study

Transit Signal Priority (TSP)
Evaluation & Recommendations

September 27, 2018 **DRAFT**



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1. Introduction

This memorandum is intended to summarize the various options for Transit Signal Priority (TSP) technology and features relative to a future Washtenaw/M-17 corridor, provide specific recommendations and define an implementation plan. The memorandum includes a review of several TSP technologies and functionalities in detail based upon previous studies and several literature reviews. References for past studies and literature are provided should the reader desire further background, information and pertinent details.

1.1 Background on TSP Systems

TSP systems are a combination of traffic signal technologies and control strategies that adjust traffic signal timings in favor of transit vehicles by giving them a higher priority to traverse signalized intersections within a corridor. TSP systems typically target improved on-time performance and the reduction in delays experienced by transit vehicles, while seeking to minimize the net impact to other non-transit traffic. The primary objective and purpose for an agency to deploy TSP systems is to improve transit system operational performance by reducing delay and increasing reliability. Depending on the application, TSP can also be utilized to increase transit travel speeds in a corridor as well.

a. TSP System Architecture

Typical TSP systems take advantage of ITS technologies and functionalities to integrate transit systems and arterial traffic management systems (ATMS) together. Major components of TSP systems include:

- **Transit Vehicles** – TSP systems must at minimum understand the physical location of a singular transit vehicle relative to traffic signals. Transit vehicle location information can be provided through onboard vehicle systems such as GPS, AVL, wireless communication, Advanced People Count (APC) systems, or TSP-specific system modules. Advanced transit dispatching systems that already provide advanced transit vehicle location information can also be used in place of TSP-specific onboard equipment.
- **Traffic Signal System** – This could refer to distributed traffic signal systems comprised of individual on-street traffic signal controllers and/or a centralized traffic signal operations systems capable of receiving and prioritizing the broadcasted service needs of a transit vehicle.

- **Backend Systems** – Transit dispatching/fleet management system and the arterial traffic management system are typically housed in each of the partner agencies’ respective operations centers. The two operation centers used in most TSP solutions are commonly referred as:
 - Transit Dispatching Center – Housing the transit dispatching/fleet management systems
 - Traffic Management Center – Housing the arterial traffic management center systems

TSP systems are typically comprised of three key functional requirements and associated system components as follows:

- **Transit Vehicle Detection System** - Traditional TSP systems may use onboard vehicle location beacons on each transit vehicle, while modern TSP solutions may utilize existing GPS/AVL system data from the transit dispatching/fleet management systems. Regardless of the vehicle detection and location system utilized, the vehicle location data set is necessary to trigger basic TSP functions with traffic signal controllers.
- **Priority Request Generation (PRG) Module** – The PRG is the functional component of the TSP system that generates the priority service request to the arterial traffic management system that triggers the appropriate TSP operation.
- **Priority Requesting Processing/Decision Making (PRPDM) Module** – The PRPDM is the “Centralized” TSP functional component that determines if a priority request as received will be granted. The PRPDM is typically configured such that both transit system and traffic signal system service needs are balanced based upon agreed-to operational concepts between the transit agency and the traffic signal system agency.

These key functional requirements and system components may reside in different locations of a TSP system based upon the technology options available or chosen to implement the final TSP solution. Most notably, the location of the PRG and PRPDM modules defines the broader TSP system architecture as it relates to where the TSP service request originates. These TSP request points are defined as either “Decentralized” or “Centralized”.

TSP Request Point: “Decentralized” vs. “Centralized”

The “Decentralized” TSP priority request point is a system whereby the TSP request is sent directly by the transit vehicle to the local traffic signal controller.

The “Centralized” TSP priority request point is a system whereby the TSP request is generated either by the transit dispatching center, the traffic management center directly or without involving transit vehicles.

TSP Decision Making Point: “Distributed” vs. “Centralized”

The location of the TSP decision making point within the TSP system architecture can also vary based upon the technologies utilized and existing transit and traffic signal systems leveraged. These TSP decision making point locations are referred to as “Distributed” and “Centralized” and they are described as follows:

A “Distributed” TSP system does not require any centralized decision making solution to trigger the TSP operations, whereby TSP requests are generated directly by the transit vehicles and communicated to the local traffic signal controller at the intersection. The local traffic signal controller’s TSP-related settings will then determine whether it will grant or deny the TSP request. Once granted, the traffic signal controller would then implement the corresponding traffic signal timing adjustments. In general, a “Distributed” TSP system is easier to implement when compared to a “Centralized” TSP system. The following are some of the key system components for deployment of a “Distributed” TSP solution:

- Transit vehicle detection system
- Traffic signal controller w/firmware supportive of TSP functions
- Communication link between transit vehicles and the local traffic signal controller to deliver the TSP request.

A “Centralized” TSP system is typically structured around Traffic Management Center and/or Transit Dispatching Center based technologies that Determines whether requests should be granted or denied regardless of where the individual TSP requests are generated. If granted, the TSP functionality is triggered to be implemented at the local intersection by the PRPDM server located at the “Center”. There a few advantages to deploying a “Centralized” TSP system such as:

- Business rules can be built into the decision making logic based upon predefined conditions where requests are granted or denied, such as schedule adherence, headways, conflicting calls, ridership, etc.
- Flexibility in scaling and operating TSP relative to variations in treatments, operations, and business rules as they relate to different corridors and/or local jurisdictions
- Direct communication at the street level between transit vehicles and traffic signal controllers may not be necessary

The followings are some of the key system components for deployment of a “Centralized” TSP solution:

- Transit dispatching/fleet management system with AVL/GPS technologies
- Reliable real-time communication systems between the transit dispatching center and the traffic management center (Center-to-Center communications)
- Traffic signal controller w/firmware supportive of TSP functions

- Synchronization of the ‘time’ used in operation of the transit system and traffic management system
- Well-defined TSP operational business logic

TSP Strategy: Passive vs. Active vs. Adaptive

By definition, TSP requests that are granted and implemented create an “interruption” to the regularly defined traffic signal operation at an intersection, as well as to the coordination between traffic signals within a corridor. These interruptions to normal traffic operations can be managed and in some cases minimized through definition of the TSP business rules and associated traffic signal system operations. The following are the three categories of current TSP strategies for traffic signal system operations as TSP service requests are granted:

Passive TSP

Passive TSP is utilized in a “Centralized” TSP system that adjusts the corridor’s traffic signal timing plans in favor of transit vehicle movements (instead of general traffic). It is utilized when an agency desires to provide a more coordinated and progressive movement of transit vehicles within a corridor.

The Passive TSP approach is often more easily implemented, as it may require less costs associated with physical infrastructure improvements. The following are scenarios where the use of a passive TSP approach may be considered:

- An arterial corridor that has high transit demand and lower traffic volumes
- Corridors where transit vehicle operations are more predictable and defined (e.g., the transit dwell time is short and/or predictable)

Deployment of a passive TSP approach when not appropriate may have adverse impacts to both transit and non-transit traffic. The use of a passive TSP approach should be avoided if there are regular variations in overall transit demand, transit dwell times are consistently variable and unpredictable, and if the corridor regularly experiences broader fluctuations in non-transit related traffic demands.

Active TSP

Active TSP strategies are generally defined as being responsive to an individual transit vehicle’s TSP request and adjusting traffic signal timings to provide it with suitable green time to cross the intersection. Active TSP approaches are considered more efficient and flexible in operation when compared to Passive TSP approaches. It is based upon advanced communication technologies that detect the presence of the transit vehicle and estimates the transit vehicle’s arrival time at the intersection.

The following is a summary of the typical traffic signal control settings and features utilized in operating an active TSP solution.

Green Extension – When TSP priority is granted, if the approaching transit vehicle is estimated to arrive during the green phase, the traffic signal controller will extend the time of the green phase to allow the transit vehicle to smoothly cross the intersection. The green extension logic can ensure the priority movement of transit traffic and reduces the operational impact to traffic on the same corridor as the transit vehicle. The green extension is considered a fundamental active TSP logic and is supported by most of the major traffic signal controller vendors.

Early Green/Red Truncation – When TSP priority is granted, if the approaching transit vehicle is estimated to arrive during the red phase, the traffic signal controller will seek to truncate the current red phase and start the next green phase earlier when possible. The early green/red truncation is also considered a fundamental active TSP logic and is supported by most of the major traffic signal controller vendors.

Figure 1 shows the concept of how the green extension and early green/red truncation active TSP logics operate.

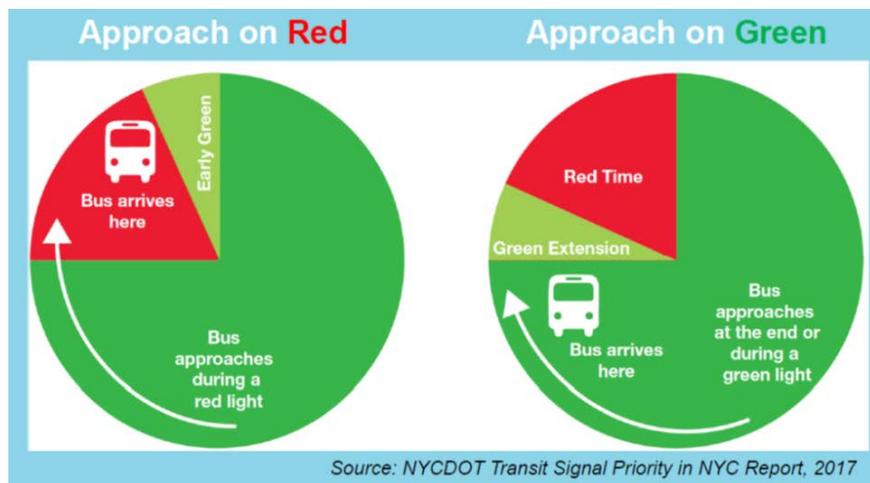


Figure 1: Concept of Green Extension and Early Green/Red Truncation

Phase Actuation / Insertion / Queue Jump Phase – In some cases, when TSP is combined with other transit treatment technologies such as Queue Jumps or Bus Lanes, additional transit-only traffic signal phases may need to be added into the traffic signal timing logic and actuated when TSP service requests are granted. These transit-only phases are only activated when certain business rules and operational conditions are satisfied, such as:

- A transit vehicle is detected at the intersection and a Queue Jump phase is called for

- Special leading left-turn-only phase is dedicated and operated when transit vehicles are present

More often, the use of this TSP logic is implemented when a Queue Jump solution is desired to expedite the movement of a transit vehicle through the intersection. Several TSP studies have indicated that the use of Queue Jump solutions based upon traditional TSP approaches (such as Green Extension and Early Green/Red Truncation) fails to work effectively during peak hours, when long vehicle queues can block the transit vehicle’s access to the green phase at an intersection. When excess queueing is present, the repeated call for normal TSP operations can create substantial adverse impacts to both transit and non-transit operations in the corridor. The design of a transit queue jump lane, along with transit-only traffic signal phasing and indications allows transit vehicles to safely by-pass existing traffic queues to maintain schedule reliability and provide improved transit service. Figure 2 shows an example of how the Queue Jump transit-only phase would operate. This TSP logic demands the traffic signal controller is capable of dealing with extra phases besides normal traffic signal phases.

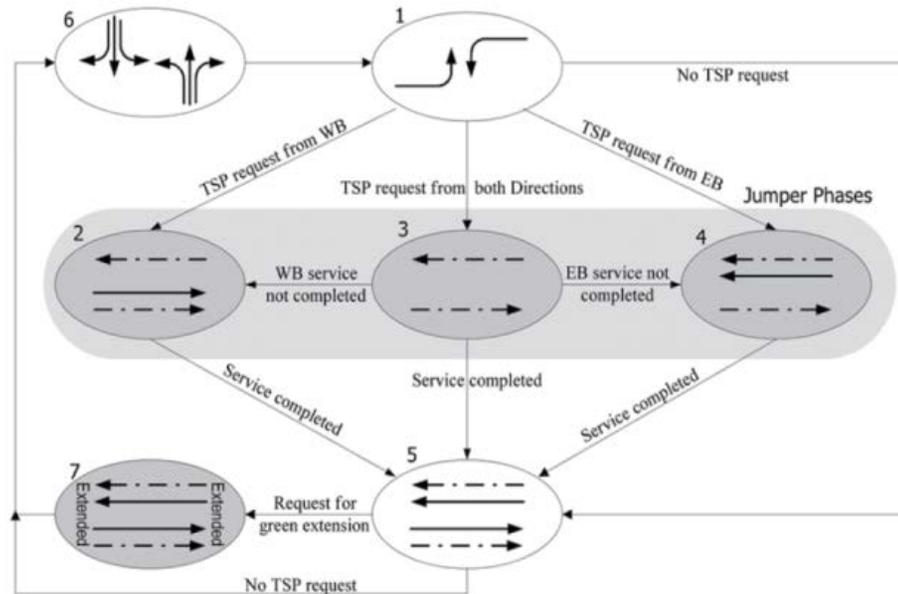


Figure 2: Example of Actuated TSP Phase for Queue Jump

Phase Suppression / Rotation – Phase Suppression / Rotation refers the concept of allowing the traffic signal controller to rotate certain phases (or, change the phase sequence) in favor of transit movements. This TSP logic demands that the traffic signal controller make, model and firmware version be capable of managing extra phases beyond the industry normal traffic signal phases.

Adaptive Real-time TSP

Adaptive real-time TSP generally works within existing adaptive traffic signal control systems and is capable of building upon the most sophisticated TSP operation principles. These approaches typically handle TSP operations in a timely manner while simultaneously adapting the system operations to maintain optimal operations for non-transit traffic.

Overall, adaptive real-time TSP solutions are more sophisticated, allowing for additional operations criteria to be built into the TSP decision making logic, known as the “Conditional” TSP settings. These additional operations criteria may include consideration of person delays, transit vehicle delays, automobile delays, and/or combinations of these.

TSP Operational Rule - “Unconditional” vs. “Conditional”

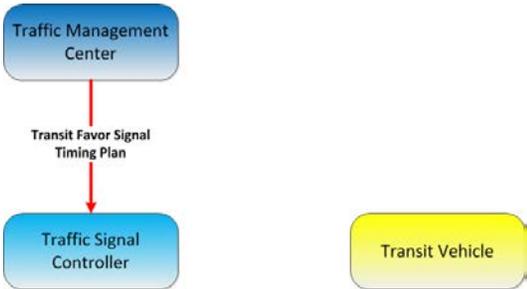
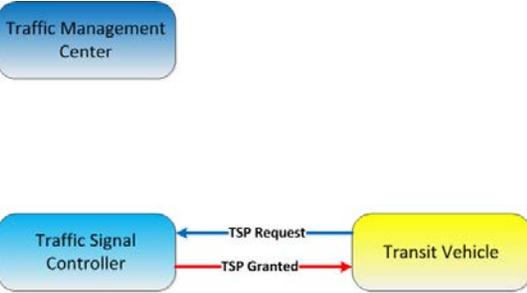
An “Unconditional” operational rule is where there are no defined rules that determine why a TSP request will be granted. In general, the Passive TSP approach is considered to operate under “Unconditional” operational rules, whereby all priority service requests including transit, emergency and other vehicles are treated equally. This approach disregards the reality that some TSP requests received and granted may not be necessary (such as when a transit vehicle receiving priority is already operating ahead of schedule or carrying a low number of riders). The granting of unnecessary TSP requests may lead to more intersection delays while not gaining any discernible transit operation benefits.

The “Conditional” TSP operational rule and system logic can be built such that it applies operational strategies that are reflective of specific transit and traffic operational needs. For instance, at a basic level the TSP functionality can be scheduled to turn on/off during specific times of a day or week. More complex “Conditional” TSP rules could be based upon additional, and real-time, information such as current transit vehicle information from AVL/CAD systems. A few common examples of “Conditional” TSP operational rules include:

- **Schedule control** – TSP requests granted based upon transit vehicle operating behind schedule by a pre-defined amount (i.e. running late by 5 minutes or more).
- **Headway control** – TSP requests granted if the gap between successive transit vehicles is greater than a pre-defined threshold (i.e. operating at 1.5 times of desired headway spacing), then the priority would be granted to the latter transit vehicle.

Table 1 summarizes some of the TSP operational rules and features described above, indicating the range of base “options” for how TSP could be configured for the Washtenaw Corridor. Note that only the Passive and Active TSP strategies are considered, since most of the adaptive TSP solutions are research based.

Table 1: Options of TSP System Architecture

| TSP System Architecture | TSP Request | TSP Decision Point | TSP Strategies | TSP Operation Rule | Notes |
|--|---------------|--------------------|----------------|--------------------|-------|
|  | N/A | Centralized | Passive | Unconditional | |
|  | Decentralized | Distributed | Active | Unconditional | |

| | | | | | |
|--|---------------|-------------|--------|-------------|--|
| | Decentralized | Distributed | Active | Conditional | Assuming transit vehicle can get schedule information from transit dispatching center real-timely via AVL system |
| | Decentralized | Centralized | Active | Conditional | Assuming transit dispatching center is able to collection real-time transit vehicles AVL information Assuming Center-to-Center Interfacing between transit dispatching center and traffic management center |
| | Centralized | Centralized | Active | Conditional | Assuming transit dispatching center is able to collection real-time transit vehicles AVL information Assuming Center-to-Center Interfacing between transit dispatching center and traffic management center |

b. Overview of TSP Lessons Learned and Performance Concerns

The following is a summary of the materials reviewed and lessons learned from the literature review that was conducted for this project, including a review of published articles, research and technical evaluations of TSP systems¹.

- Studies have found that TSP operations are most effective at signalized intersections operating in congested conditions (in traffic engineering terms, this means under level of service F conditions with a volume to capacity (v/c) ratio between 0.80 and 1.00).
 - TSP application are most effective under moderate-to-heavy traffic conditions (e.g., v/c <0.8).
 - TSP was found to not work as effectively when v/c approaches, or is equal to, 1.0.
 - TSP has moderate impacts on cross street performance when v/c ratios are above 0.8
 - TSP has a significant adverse impact with v/c ratios above 0.9 which causes high cross street delay and increases delay recovery cycles
- Transit vehicle arrival times have impacts on the performance of TSP. For instance, if a transit vehicle arrives early in the green phase it causes minimum disruption to the other traffic; while arrival of a transit vehicle later in the green phase can lead to significant system-wide disruptions
- Bus stop positions on the far-side of the intersection were recommended over near-side bus stops. Supporting this is the fact that a significant portion of a green extension operation can be wasted while a transit vehicle is alighting and boarding passengers at a nearside bus stop.

Literature reviews also provided insight on how TSP operations impact corridors that are operating intersections in a coordinated manner². Active TSP operations may lead to improved transit performance; however they may also lead to interruptions relative to coordinated corridor operations. To counter these adverse impacts, the traffic signal systems need to be capable of recovering back to coordinated operations as quick as possible after servicing a TSP request.

Other documented factors that impact the overall effectiveness of active TSP operations include³:

- Impacts and understanding of cross street congestion/operations
- Minimum green times for pedestrian movements during TSP operations

¹ Sources: 1-6 (see [References](#))

² Sources: 6 and 7

³ Sources: 1, 4, 5, and 8

- Heavily congested intersections with oversaturated conditions (e.g., v/c ratio is approaching to 1.0)
- Conflicts of multiple priority requests from both main street and side street (TSP, EVP, others)
- Variation of transit vehicle and operational needs relative to TSP

c. TSP and Connected Vehicle

Advancement and development of Connected Vehicle (CV) technologies can provide additional benefit to modern CV-based TSP solutions, as they more naturally support broader TSP functionalities and minimize the physical infrastructure necessary to deploy. A recent example of a CV-based TSP solution is the “Multi-Modal Intelligent Traffic Signal System” (MMITSS) that was conducted as part of the Connected Vehicle Pool Fund Study⁴ to demonstrate the capability of a CV-based TSP solution. Figure 3 shows the CV-based TSP solution concept.

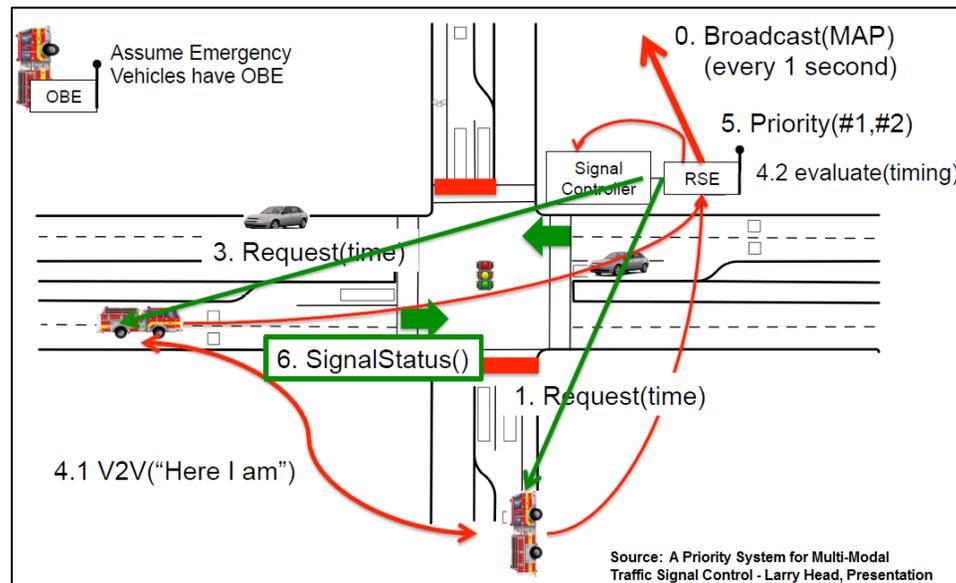


Figure 3: Traffic Signal Priority in the Connected Vehicle Environment

CV-based TSP solutions may provide the following benefits in comparison with traditional TSP solutions:

⁴ The Connected Vehicle Pool Fund Study is led by the Virginia Department of Transportation (VDOT) and University of Virginia in partnership with various DOTs (including MDOT). The MMITSS is developed by Dr. Larry Head’s team at University of Arizona and PATH of UC Berkley.

- **Better real time traffic information** – CV-based TSP solutions can collect and disseminate more accurate and real-time information about vehicles and vehicle trajectories in and around the intersection that enhance the traffic signal operations.
- **More accurate arrival time prediction** – CV-based TSP solutions can further enhance the accuracy of the transit vehicle arrival time prediction.
- **Advanced TSP logic would be possible** – CV-based TSP solutions and logic may be more flexible and can therefore more precisely grant TSP service where and when it is most necessary.

1.2 Existing Arterial ATMS Systems and TSP Capability

The Washtenaw Avenue/M-17 corridor is a Michigan Department of Transportation (MDOT) Corridor that is located in MDOT's University Region. The roadway is also located within two local agency jurisdictions: the City of Ann Arbor and the Washtenaw County Road Commission (WCRC).

Investigation into existing traffic signal technologies within the corridor is summarized as follows:

- Two traffic signal systems are currently operating in the corridor. They are maintained and operated by the two local agencies (City of Ann Arbor, and WCRC) for MDOT:
 - The City of Ann Arbor uses a central traffic signal system software (Siemens – TACTICS) to manage and monitor their traffic signal deployments. They also use an adaptive traffic signal control technology (Siemens – SCOOT) that optimizes traffic signal timings based upon real-time demand.
 - WCRC uses a central traffic signal system software (KITS) to manage and monitor their traffic signals. They operate their traffic signals with fixed time traffic signal timing plans that vary operations based upon prescribed Time-of-Day (TOD) changes.
- Both traffic signal systems use SIEMENS's EPAC traffic signal controllers, along with a variety of detection sensors at the corresponding intersections.
- The jurisdictional boundary of the two traffic signal systems is at the US-23 interchange.
- Both traffic signal systems are capable of supporting TSP functions and Center-to-Center (C2C) communication interfaces. However, neither system has been activated to utilize these TSP features.

Table 2 provides a comparison of the major features of the two traffic signal systems in the corridor.

Table 2: Comparison of Current Traffic Signal System in the Corridor

| | City of Ann Arbor | Washtenaw County Road Commission |
|--|---|------------------------------------|
| Total Signals located in the Corridor | 27 | 8 |
| Number of MDOT Traffic Signals | 17 | 8 |
| Number of Local Agency Traffic Signals | 10 | - |
| Traffic Signal Controller | SIEMENS EPAC (SCOOT Firmware) | SIEMENS EPAC |
| Communication System | Fiber | High-speed/High-bandwidth wireless |
| Detection System | Yes MicroLoop/Synsys/Gridsmart/Radar | Yes Loop/Synsys |
| Traffic Signal Operations Technology | SCOOT | Fixed-timing |
| Central Traffic Signal Management Software | TACTICS/SCOOT | KITS |
| TSP Capability | Yes (not activated) | Yes (not activated) |
| EVP Preemption Capability | Yes (not activated) | Yes (not activated) |
| Center-to-Center Capability | Yes (not activated) | Yes (not activated) |
| Connected Vehicle Capability | Yes | No |
| CV Road Side Unit (RSU) Deployment | 2 operational / 8 to be deployed | No |

a. SIEMENS Controller's Capability for TSP Functions

SIEMENS EPAC controllers are currently deployed throughout the Washtenaw Corridor, although different controllers use different internal firmware. The controller firmware differs in its capability to support TSP:

- The City of Ann Arbor intersections (SCOOT) uses the controller firmware that naturally supports existing SCOOT TSP functions (described below).
- WCRC intersections use a controller with firmware version above 3.50, which will support multiple TSP strategies (full or partial priority), as well as Queue Jump control logics setup.
- With the currently used SIEMENS EPAC controllers, the internal controller operation systems are all OS-X based. SIEMENS is in the process of retiring its OS-X based product line and is developing a Linux based controller. It is suggested that the eventual TSP implementation will consider this product migration trend and consider upgrading the controllers to new Linux based hardware.

b. SCOOT TSP Capability

The City of Ann Arbor SCOOT system is an adaptive traffic signal control technology and system that is capable of operating with TSP functionality. The current TSP features within SCOOT are summarized as follows:

- SCOOT can support passive TSP solutions, which can use the split and offset weighting parameters to give priority to links or routes.
- SCOOT can support active TSP by granting priority to individual transit vehicles. The following are some key details of how SCOOT supports active TSP:
 - **Transit Vehicle Detection** – SCOOT can support various transit vehicle detection solutions, such as bus detection loops, onboard transponders, or AVL systems. SCOOT algorithms desire detection of the approaching transit vehicle 10 to 15 seconds in advance of the stop-bar.
 - **Optimization** – Signal timings can be optimized to benefit transit vehicles, either by green phase extensions or causing succeeding phases to occur earlier (a recall). Green phase extension requests can be awarded centrally, or the traffic signal controller can be programmed to implement green phase extensions locally at the intersection (a local extension).
 - **Recovery** – Once a transit vehicle has passed through the traffic signal, a period of traffic signal timing recovery occurs that brings the timings back into alignment with the normal SCOOT optimization.
 - **Restrictions on Priority** – Priority can be restricted depending on the saturation of the intersection as measured and modelled by SCOOT. Priority could then be managed by specifying target degrees of saturation for phase extensions and recalls. Non-priority phases can be run to these target saturation values, in the case of a priority extension or recall respectively. Normally the target saturation limits are set so that the intersection is not allowed to become over saturated, although some degree of over-

saturation may be allowed to service an extension. This means that bus priority will be most effective at intersections that have some spare capacity.

c. KITS TSP Capability

KITS is a central traffic signal system ATMS software that can support a variety of traffic signal operations. KITS has a TSP-supporting feature that:

- Is able to support a “Centralized” TSP system architecture
- Can interface with existing transit AVL/CAD systems
- Can relay TSP requests, map requests to a transit signal and movement, and forward requests to the appropriate traffic signal controller
- Can receive transit vehicle information from an AVL/CAD system; a CAD system at the transit agency can send transit vehicle, transit signal location, direction of travel, etc. to KITS, which can then be forwarded to the traffic signal after applying pre-defined business rules
- Offers an adaptive traffic signal module (called Kadence) that can overlay the TSP function in support of adaptive real-time TSP operations

Figure 4 shows a sample architecture of KITS’s “Centralized” TSP solution.

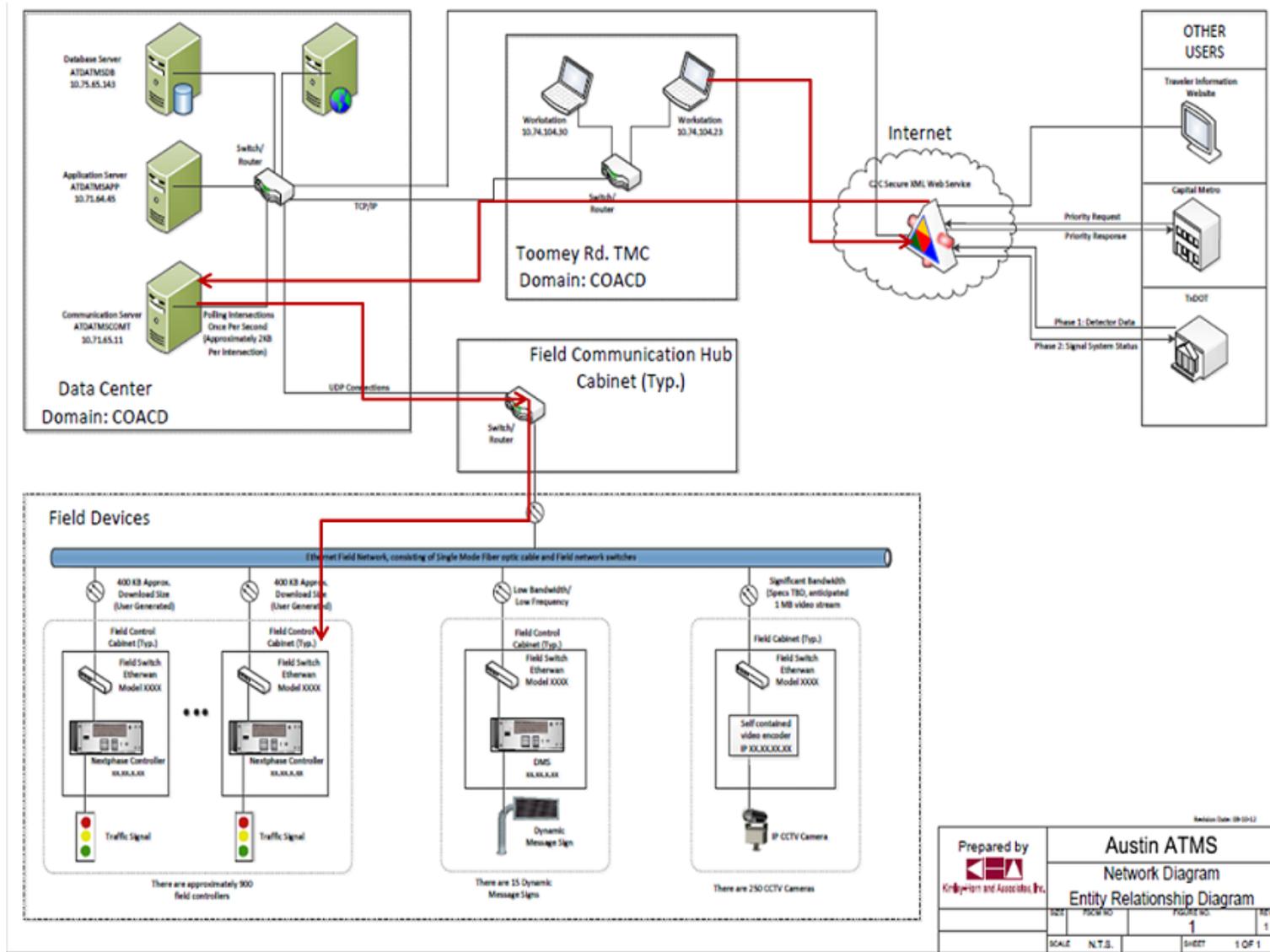


Figure 4: Sample of KITS's "Centralized" TSP Solution

2. Evaluation of TSP Deployment Options

2.1 TSP Deployment Recommendations

a. Recommendation of TSP Intersections along the Washtenaw/M-17 Corridor

The recommendation is to implement TSP in the area between the Geddes Avenue @ Washtenaw Avenue intersection (west side of the corridor) and Cross Street @ Washtenaw Avenue intersection (east side of the corridor). This is the main east-west corridor in the area, currently carrying significant traffic levels as well as producing high transit ridership. There are 25 MDOT signals in total, maintained by City of Ann Arbor (17) and Washtenaw County Road Commission (8). Technically, each of these intersections is capable of building TSP functions into the existing traffic signal timing plans. However, only main corridor intersections were considered with 12 belonging to City of Ann Arbor and 7 belonging to WCRC (19 in total).

b. Recommendation of Queue Jump Intersections along the Washtenaw/M-17 Corridor

Four Queue Jump locations have been proposed for consideration along the Washtenaw/M-17 Corridor: at Sheridan/Manchester, Huron, Carpenter/Hogback and Hewitt. These queue jumps would align with locations where congestion is currently seen to impact schedule adherence for AAATA's Route 4 service. Each Queue Jump intersection would incorporate special TSP-actuated signal phases along with the Queue Jump design. The following Table 3 highlights the proposed Queue Jump intersections in red.

Table 3: Summary of Intersection Status in the Corridor

| Signalized Intersection | Detection | Controller | TSP | QJ | RSU Ready | Territory |
|---|---------------|--------------|-----|-----|-----------|-----------|
| I94BL,US23BR (WASHTENAW) @ OBSERVATORY,FOREST | 0 | EPAC (SCOOT) | Yes | | | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ S UNIVERSITY | Loop | EPAC (SCOOT) | Yes | | Deploying | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ HILL | Loop | EPAC (SCOOT) | Yes | | Deploying | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ DEVONSHIRE,AUSTIN | Loop | EPAC (SCOOT) | Yes | | | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ BROCKMAN | Loop | EPAC (SCOOT) | Yes | | Deploying | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ STADIUM | Loop | EPAC (SCOOT) | Yes | | Deploying | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ MANCHESTER,SHERIDAN | Wireless Loop | EPAC (SCOOT) | Yes | Yes | | ANN ARBOR |
| I94BL,US23BR @ PLATT,GLENWOOD | Wireless Loop | EPAC (SCOOT) | Yes | | Deploying | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ HURON PKWY | Loop | EPAC (SCOOT) | Yes | Yes | Yes | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ PITTSFIELD | Loop | EPAC (SCOOT) | Yes | | | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ YOST BLVD / ARBORLAND | Loop | EPAC (SCOOT) | Yes | | Yes | ANN ARBOR |
| I94BL,US23BR (WASHTENAW) @ SB US-23 | Loop | EPAC (SCOOT) | Yes | | | ANN ARBOR |
| M17 (WASHTENAW) @ CARPENTER & HOGBACK / NB US-23 | Wireless Loop | EPAC | Yes | Yes | | WCRC |
| M-17 (WASHTENAW) @ DALTON - GLENCOE HILLS DR | Loop | EPAC | Yes | | | WCRC |
| M17 (WASHTENAW) @ GOLFSIDE | Video | EPAC | Yes | | | WCRC |
| M17 (WASHTENAW) @ HEWITT | Video | EPAC | Yes | Yes | | WCRC |
| M17 (WASHTENAW) @ MANSFIELD | 0 | EPAC | Yes | | | WCRC |
| M17 (WASHTENAW) @ OAKWOOD | Loop | EPAC | Yes | | | WCRC |
| M17 (HURON) @ M17 (CROSS) | 0 | EPIC | Yes | | | WCRC |

2.2 Proposed TSP Solutions

Based on the technical analysis of how TSP control strategies and solutions may best fit and benefit given the current dynamics of the Washtenaw Corridor, the following summarizes the resulting key TSP system characteristics that could be applied:

- TSP Request Point – Decentralized or Centralized
- TSP Decision Point – Centralized
- TSP Strategies – Active
 - Green Extension and Early Green/Red Truncation
 - Phase Actuation to support intersections equipped with Queue Jump features
- TSP Operation Rule – Conditional
 - Including Schedule Control features

Based upon the above characteristics, two unique TSP system architectures are proposed for consideration.

a. TSP System Option 1: GPS/AVL and/or CV based

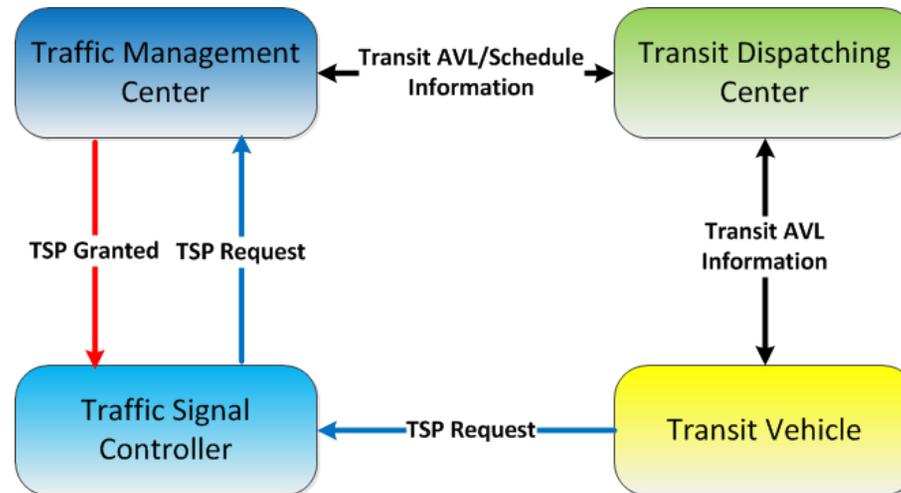


Figure 5: TSP System Architecture – GPS/AVL-based and/or CV-based

The proposed architecture in Option 1 can be met through deployment of either a GPS/AVL based solution and/or a CV-based TSP solution. Relative to this architecture the following infrastructure and agency systems need to be in place and functional:

- Wireless communications needs to exist between transit vehicles and the traffic signal systems at the individual traffic signal and intersection level.
- Transit vehicles will initialize the TSP service request, based upon their on-board AVL information and the schedule information and status as received from the transit dispatch center.
- Transit dispatch center needs to be capable of collecting and transmitting transit vehicle AVL data and schedule status information in a real-time manner.
- A Center-to-Center interface needs to be in place between the transit dispatch center and the traffic management center.
- The TSP decision making logic would need to be located in the traffic management center, with the option of creating additional “Conditional” transit operation rules that guide the TSP service request granting process.
- The Traffic management center needs to be capable of triggering the TSP functions of the corresponding traffic signal controllers through a Center-to-Field communications link.

The above requirements for System Option 1 correlates to the following more common industry terms for existing TSP solutions:

- Traditional TSP System Based upon transit GPS/AVL System
- Connected Vehicle Based TSP System

b. TSP System Option 2: Center-to-Center based

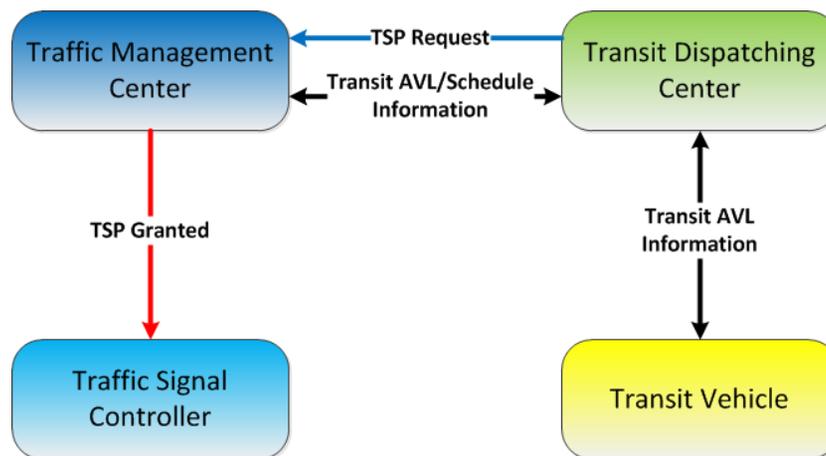


Figure 6: TSP System Architecture – Center-to-Center based

The proposed architecture in Option 2 can be met through deployment of a Center-to-Center based TSP solution. Relative to this architecture, the following infrastructure and agency systems need to be in place and functional:

- Transit dispatch center needs to be capable of collecting and transmitting transit vehicles AVL and schedule status data information in a real-time manner.
- Center-to-Center interface needs to be in place between the transit dispatch center and the traffic management center
- Transit dispatch center will initialize the TSP service requests.
- TSP decision making logic would need to be located in the traffic management center, with the option of creating additional “Conditional” transit operation rules that guide the TSP service request granting process.
- Traffic management center needs to be capable of triggering TSP functions of the corresponding traffic controllers through a Center-to-Field communication link.
- This Option does not require wireless communications between the transit vehicles and traffic signal controllers at the local intersection level.

Table 4 provides a summary of the two candidate TSP system solutions.

Table 4: TSP System Options for the Washtenaw Avenue Corridor

| | Option 1 | | Option 2 |
|--|---|--|---|
| | GPS/AVL-based | Connected Vehicle-based | Center-to-Center (C2C)-based |
| General Description | Traditional TSP technology (normally offered by transit GPS/AVL system vendors) | TSP technology built upon the connected vehicle technologies | C2C interfaces are needed only between and transit AVL system and the two traffic signal systems. |
| TSP System Architecture | Decentralized TSP request Centralized TSP decision making Active TSP Conditional TSP | | Centralized TSP request Centralized TSP decision making Active TSP Conditional TSP |
| Transit Vehicle On-board System | IVN Device (on-board) (Existing AVL/CAD system) | OBU (On-board Unit) – connected to transit vehicle CAN and interfacing with AVL system | IVN Device (on-board) (Existing AVL/CAD system) |
| Transit Vehicle Detection | Traditional loop, IR, or advanced GPS/AVL system (existing) | Advanced GPS/AVL system | N/A |
| Communication between Transit Vehicle and Intersection | Wi-Fi, cellular (3G/4G/LTE), or proprietary radio system | DSRC or future 5G (between OBU and RSU) | N/A |
| Extra Roadside System for TSP Function | Proprietary TSP interface device with traffic controller | RSU (Roadside Unit) – Interfacing with traffic controller | N/A |
| Center-to-Field Communication | Assuming existing traffic management system available | | |
| Center-to-Center Communication | C2C between transit dispatching center and traffic management center | | |

2.3 Estimation of Deployment Costs

The TSP deployment cost could vary based on different system architecture of the TSP solution. In general, the potential system elements that will drive costs include:

- Transit on-board system upgrades
- Communications system upgrades
- Traffic signal infrastructure upgrades
- System software upgrades

Table 5 summarizes the potential cost factors and range of cost estimates associated with the candidate TSP solutions (detailed cost estimates available as appendix).

Table 5: Cost Assumptions of TSP Options for Washtenaw

| | Option 1 | | Option 2 |
|---|--|--|---|
| | GPS/AVL-based | Connected Vehicle-based | Center-to-Center (C2C)-based |
| Description | Traditional TSP technology (normally offered by transit GPS/AVL system vendors) | TSP technology built upon the connected vehicle technologies | C2C interfaces are needed only between and transit AVL system and the two traffic signal systems. |
| Transit on-board system upgrades | Vendor-based TSP on-board device | On-board Unit (OBU) Installation (OBU needs to connect to transit vehicle CAN and interface with AVL) | N/A |
| Communications system upgrades | Set up vendor-based transit vehicle to roadside communication Setup up C2C communication between transit dispatching center and traffic management center | Setup DSRC communication between vehicle and roadside (Note: DSRC communication is available for the City of Ann Arbor portion of the corridor) Setup up C2C communication between transit dispatching center and traffic management center | Setup up C2C communication between transit dispatching center and traffic management center |
| Traffic signal infrastructure | Vendor-based TSP interface device with | RSU (Roadside Unit) installation (WCRC | Upgrade traffic sign/signal facility for |

| | | | |
|--|--|--|--|
| <p>upgrades</p> | <p>traffic controller</p> <p>Upgrade traffic sign/signal facility for TSP intersection</p> <p>Upgrade traffic signal controller or its firmware</p> <p>Update traffic signal timing plan for TSP/Queue Jump phases</p> | <p>portion of the corridor)</p> <p>Upgrade traffic sign/signal facility for TSP intersection</p> <p>Upgrade traffic signal controller or its firmware</p> <p>Update traffic signal timing plan for TSP/Queue Jump phases</p> | <p>TSP intersections</p> <p>Upgrade traffic signal controller or its firmware</p> <p>Update traffic signal timing plan for TSP/Queue Jump phases</p> |
| <p>System software upgrades</p> | <p>Center-to-center interfacing software between transit dispatching center and traffic management center</p> <p>Centralized TSP decision making software module tied with traffic management software</p> | <p>OBU based TSP request generation software module</p> <p>Center-to-center interfacing software between transit dispatching center and traffic management center</p> <p>Centralized TSP decision making software module tied with traffic management software</p> | <p>Center-to-center interfacing software between transit dispatching center and traffic management center</p> <p>Centralized TSP request generation software module</p> <p>Centralized TSP decision making software module tied with traffic management software</p> |
| <p>Total Estimated Cost</p> | <p>On-board: \$66,000</p> <p>Infrastructure: \$629,000 – \$701,000</p> | <p>On-board: \$22,000 – \$39,000</p> <p>Infrastructure: \$608,000 – \$730,000</p> | <p>On-board: \$0</p> <p>Infrastructure: \$484,000 – \$556,000</p> |

2.4 Challenges to Deployment and Operation

Although TSP can have significant benefits for transit performance, there are a number of potential challenges of TSP implementation that will need to be studied further and managed during design, deployment and operation. Some general challenges for consideration include:

- Impacts on traffic for other users in the corridor, including the need to balance the impacts on cross street traffic to reduce potential for adding delays.
- The ability to estimate the transit vehicle's arrival time, which will in turn impact on TSP's efficiency at intersections.
- Determining conditions (rules) where TSP will provide benefits to ensure a high percentage of effective TSP operations.
- Methods for handling conflicting TSP requests at intersections.
- Methods to accomplish traffic signal recovery after TSP operation.

In particular, the potential challenges for the Washtenaw/M-17 corridor TSP implementation are as follows.

a. Traffic Signal System Coordination

There are two traffic signal systems running on the corridor, maintained and operated by two local agencies (City of Ann Arbor, and WCRC) on behalf of MDOT:

- The City of Ann Arbor is using the TACTICS central software to maintain and monitor traffic signals, and using SCOOT adaptive traffic signal control software to optimize the traffic signal operations in real-time.
- WCRC is using the KITS system central software to maintain and monitor traffic signals, while the signals are running with fixed signal timing plans breaking down with Time-of-Day (TOD) changes.

The jurisdictional boundary of the two traffic signal systems is at the US-23 interchange, which is the most congested area along the corridor. A key challenge overall for Washtenaw will be to set up coordination between the two systems, which would be expected to help with relieving congestion and TSP operation in that area.

b. Freeway Traffic around the US-23 Interchange

Freeway traffic on US-23 also impacts the traffic conditions on the corridor, which would suggest that the development of ICM (Integrated Corridor Management) functions might also help with TSP performance.

c. Heavily Congested Intersections

Some intersections on the corridor suffer heavy cross street traffic and heavy congestion during peak hours. Long queues around the intersections might reduce the effectiveness of TSP or even Queue Jump operations. The following Figures are two examples of such intersections.

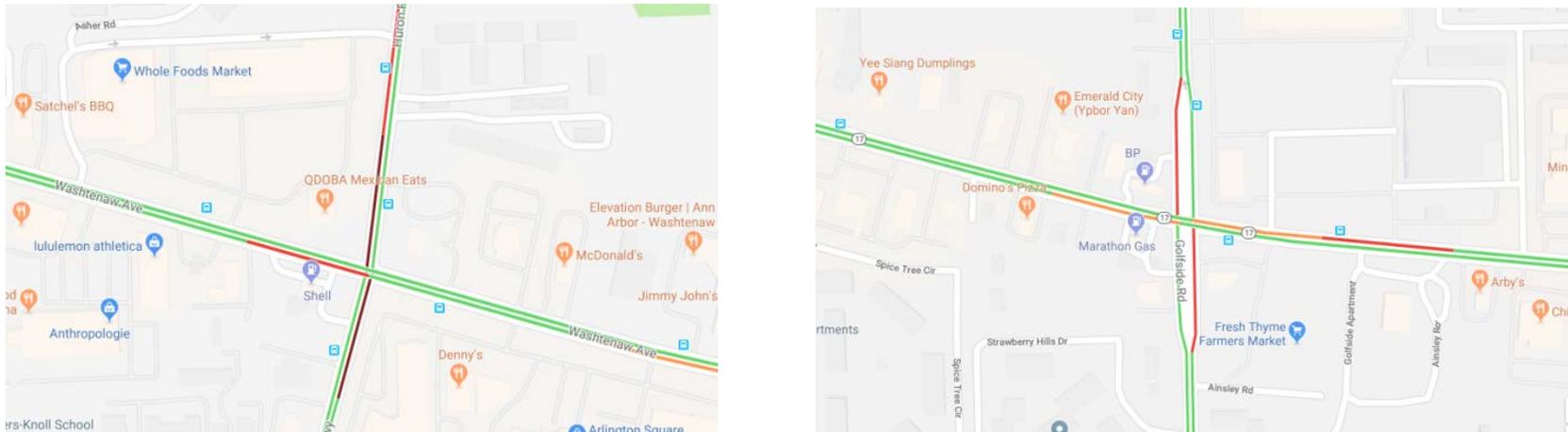


Figure 7: Example of Oversaturated Intersections (Left: Huron Pkwy @ Washtenaw; Right: Golfside @ Washtenaw)

Figure 8 shows the sample of 24-hour volume migration of the Huron Pkwy @ Washtenaw intersection with data exported from the existing SCOOT system (average of Tuesday, Wednesday, and Thursday data). The data indicates the significant demand challenge that occurs during peak periods, particularly in the afternoons when traffic levels on EB Washtenaw and SB Huron are at peak levels.

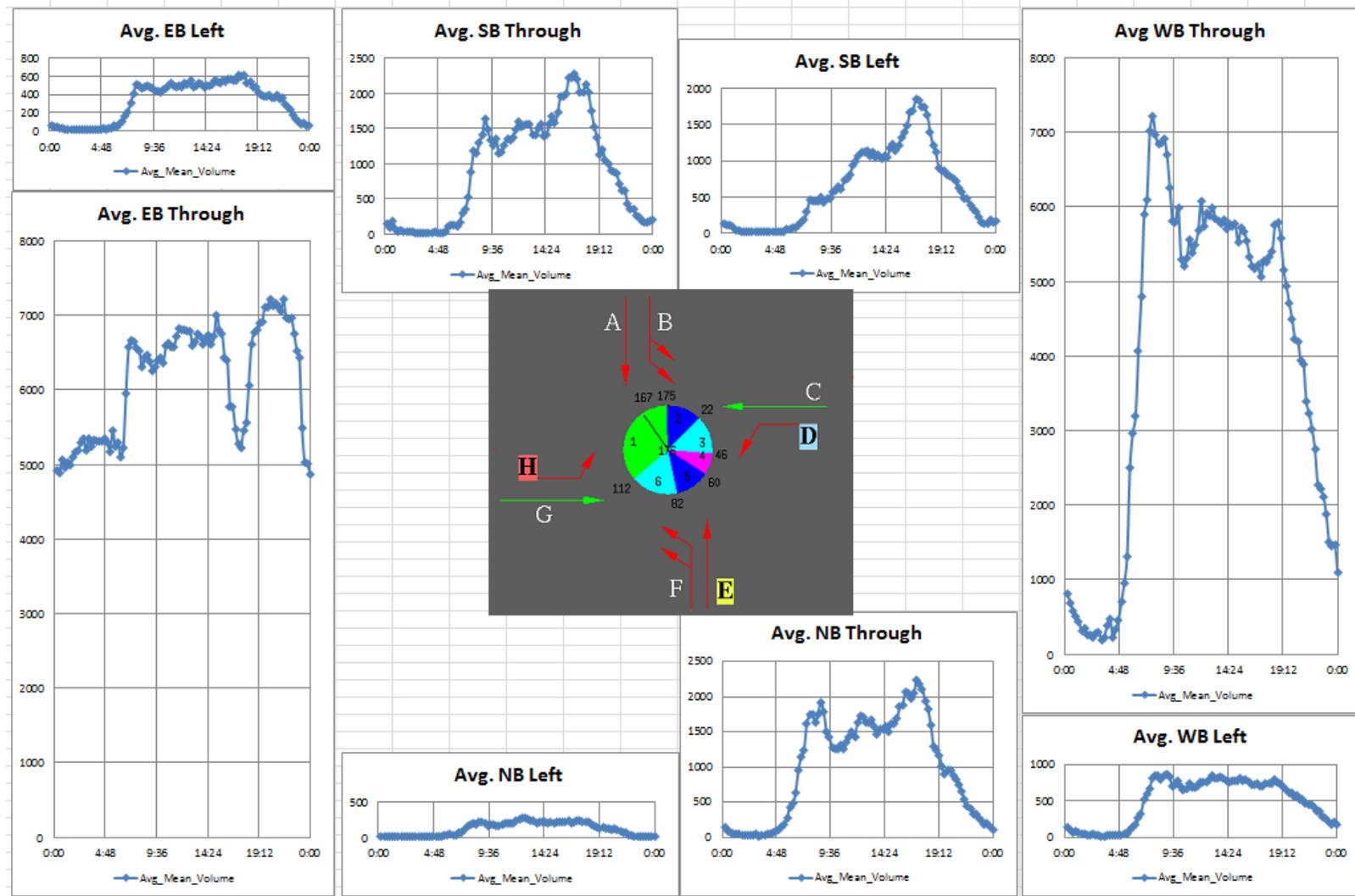


Figure 8: Volume Migration of Huron Pkwy @Washtenaw Intersection (Average Tuesday, Wednesday and Thursday Data)

3. Recommendations

3.1 TSP Implementation Recommendation

After comparing the three candidate TSP solutions, the recommended TSP deployment roadmap is a two-stage TSP migration path toward the Connected-Vehicle based TSP as the final TSP solution:

The recommended roadmap is based on the following considerations:

- The Center-to-Center interface between transit system and traffic management system is necessary for all of the candidate TSP solutions.
- The Connected Vehicle technology is a part of promoting future transportation solutions, which naturally supports and enhances TSP functionality.
- The MDOT Connected Vehicle strategic plan promotes a “CV Enabled Signals Policy”, which potentially enforces any new upgrades to MDOT traffic signal intersections to be Connected Vehicle enabled.
- Half of the Washtenaw Corridor (through Ann Arbor) is already covered by Connected Vehicle facilities.

a. Stage 1: Center-to-Center based TSP

The detailed deployment plans for this stage would include:

- Upgrade traffic signal infrastructure for the whole corridor
 - Upgrade traffic sign/signal facility for TSP intersections
 - Upgrade traffic signal controller or its firmware in supporting TSP or Queue Jump phase
 - Update traffic signal timing plan for TSP/Queue Jump phases
- Build Center-to-Center interfacing between the transit dispatching system and the traffic management system. Since there are two traffic management systems within the corridor, two C2C interface software modules need to be built. Such an interface will forward real-time transit vehicles’ AVL locations, status and schedule information to the traffic management center.
 - Develop C2C interface between transit dispatching system and SCOOT (for City of Ann Arbor)
 - Develop C2C interface between transit dispatching system and KITS (for WCRC)
- Build “Centralized” TSP function modules (for both SCOOT and KITS), which include:
 - Centralized TSP request generation software module

- Centralized TSP decision making software module tied with traffic management software
- Integration testing, system launching and evaluation

b. Stage 2: Connected Vehicle based TSP Solution

The second stage involves two distinct steps, as indicated below.

Stage 2A. Since the west portion of the Washtenaw/M-17 corridor (within the City of Ann Arbor boundary) has already been covered by DSRC deployment, this portion of the corridor has the potential to trial the Connected Vehicle based TSP solution. Detailed deployment plan includes:

- Upgrades to transit vehicle on-board system
 - Installation of OBU (Onboard Unit)
 - Integrating OBU with transit vehicle CAN and AVL system
 - Integrating on-board TSP request generation software module
- Integration testing, system launching and evaluation

Stage 2B. Following the success of a CV-based TSP solution on the west side of the corridor, the solution could be implemented throughout the entire corridor with the addition of Connected Vehicle infrastructure support within the WCRC boundary of the corridor.

- Build DSRC network for the east portion of the corridor
 - Installation of DSRC RSU (Roadside Unit) at the TSP intersections

Figure 9 presents an overview of the sequencing of a TSP deployment plan for the corridor.

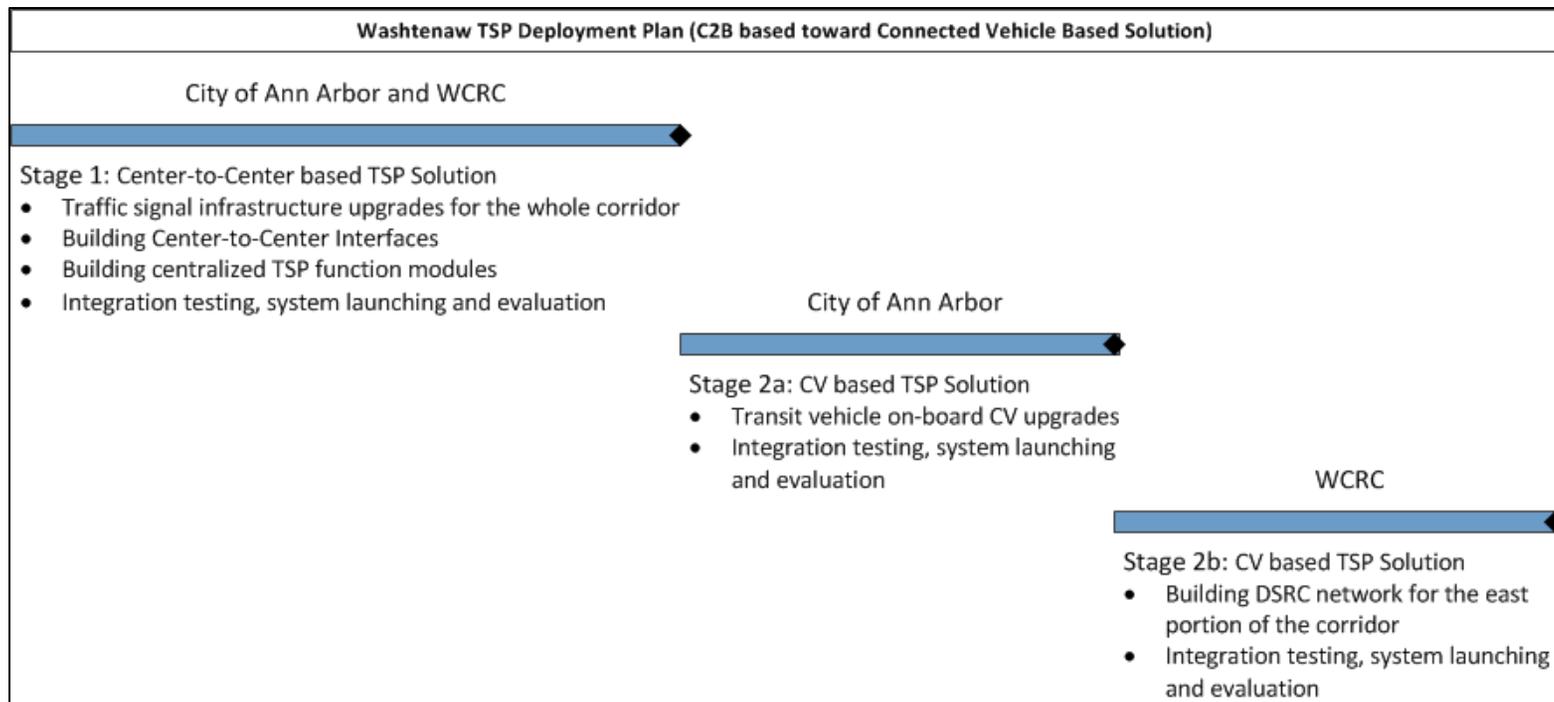


Figure 9: Washtenaw/M-17 Corridor TSP Deployment Plan

3.2 Cost of Recommended (Staged) Approach

Table 6 summarizes the stage-by-stage costs by category for the recommended TSP approach.

Table 6: Staged Cost Estimate

| Cost Type | Stage 1 (C2C TSP) | Stage 2 (CV-Based TSP) | Total Costs (Both Stages) |
|-------------------------------|------------------------------|------------------------------|------------------------------|
| On-Board Systems | - | \$22,000 | \$22,000 |
| Communication Systems | \$8,000 - \$80,000 | \$94,000 - \$153,000 | \$102,000 - \$233,000 |
| Traffic Signal Infrastructure | \$76,000 | \$38,000 | \$114,000 |
| Software Systems | \$400,000 | - | \$400,000 |
| Total | \$484,000 - \$556,000 | \$154,000 - \$213,000 | \$638,000 - \$769,000 |

4. Suggested Next Steps

This document provides an initial recommended strategy for implementation of TSP capabilities in the Washtenaw Corridor, which could have significant benefits for transit service effectiveness. Development and design of a TSP system will require additional investigation to better understand the “business rules” for the system and determine the scale of potential impacts related to the challenges (as well as potential mitigation measures).

Subsequent phases of investigation could occur during the impact assessment phase of the overall Washtenaw BRT project, and specific further steps of investigation may include:

- A detailed traffic study on the peak hour congestion status, in particular the traffic demand migration (v/c ratio) along the corridor for time of the day. This type of study would enable more specific estimates of the effectiveness and benefits of the TSP solution.
- A traffic simulation study of the corridor would allow for a more complete understanding of the potential impacts of certain operational strategies on corridor and cross-street traffic congestion, as well as help measure the effectiveness of different mitigation strategies.

5. References

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