TRANSIT SIGNAL PRIORITY IN THE BOSTON REGION: A GUIDEBOOK

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INTRODUCTION TO THIS GUIDEBOOK

Throughout the Boston region, planners are becoming interested and invested in transit signal priority (TSP) as a tool to improve transit service. Increasing traffic congestion is affecting transit vehicles that travel in mixed traffic, such as buses and surface-running Green Line trains. This increases transit travel time and results in unreliable transportation. Increased travel time also can lead to other transit service issues, such as crowding, and often requires more operating resources to provide the same level of service. In many congested places, it is not feasible to widen roadways or construct new ones in order to increase capacity. TSP can be used to improve transit service within the existing roadway infrastructure.

TSP has gained traction as planners and engineers begin to focus on the movement of people rather than the movement of vehicles. Giving a transit vehicle priority through a signalized intersection can result in the more efficient movement of people because transit vehicles often carry more passengers than private automobiles.

Many municipalities in the region are modernizing and standardizing their signal equipment, identifying suitable locations for TSP, and planning and implementing pilot projects and permanent installations. The Massachusetts Bay Transportation Authority (MBTA) is prioritizing service improvements and upgrading the equipment necessary to make a broader implementation of TSP a reality. Private organizations such as the Barr Foundation are encouraging investment in strategies, including TSP, to improve bus service.

Though many entities in the Boston region are involved in efforts to implement TSP, it can be a challenge to communicate and coordinate projects across the various agencies involved. Moreover, while resources, case studies, and best practices about TSP are available from across the country and around the world, there is little documentation of TSP planning and implementation experiences in the Boston region.

The Boston Region Metropolitan Planning Organization (MPO) has developed this guidebook for use in planning and evaluating TSP in the Boston region. The guidebook is intended to be a resource for staff of municipalities and transit agencies who are interested in TSP. The guidebook explains the process for implementing a TSP project, describes considerations for each step of the process, and provides examples from current projects in the Boston region.

This guidebook is not intended to provide a comprehensive assessment of the current state of the practice for TSP, but rather to consolidate national best practices and the experiences of local professionals, and to provide context to facilitate implementation of TSP in the Boston region. Chapter 8 of this guidebook provides a list of references for further information about TSP.

This guidebook is organized into the following chapters:

1. **Introduction to Transit Signal Priority** explains the benefits of TSP and introduces several technical components of TSP, including system architectures, priority criteria, and signal timing modification strategies.
2. **TSP in the Boston Region** summarizes existing and planned TSP projects in the Boston region, and describes the experiences of staff involved with those projects.
3. **Identifying and Prioritizing Locations for TSP** describes how organizations in the region have identified locations for TSP, and provides metrics that planners and officials can use to identify and prioritize potential intersections for TSP.
4. **Inventorying Data and Infrastructure** details the process of inventorying signal timing data, field equipment, and communication infrastructure to prepare for designing a TSP system.
5. **Designing and Implementing a TSP System** provides information on how to create a system architecture that takes advantage of existing communication equipment, details some of the strategies and techniques that can be employed to prioritize transit vehicle movement, and offers a high-level overview of costs for TSP projects in the United States and Canada.
6. **Evaluating the Performance of TSP** provides metrics that planners and officials can use to evaluate the performance of implemented TSP projects.
7. **Keys to Success** highlights strategies and themes to consider when working on TSP projects.
8. **Further Reading** lists resources with additional information.
9. **Acknowledgements** recognizes the individuals interviewed by MPO staff over the course of the project.

IDENTIFY LOCATIONS CH 3

- **Goals:** What are the goals and objectives of the TSP system?
- **Data:** What data are available to identify and prioritize locations for TSP?
- **Analysis:** Based on the data, which locations are most likely to benefit from TSP? Which intersections or corridors have the most transit vehicle delay and transit passenger delay? For which transit routes is reliability affected by traffic signal delay?

INVENTORY DATA AND INFRASTRUCTURE CH 4

- **Signal equipment:** What kinds of traffic signals and controllers are in the field? What condition are they in? Are they compatible with TSP?
- **Signal timing:** How is time currently allocated to each approach? Are signals coordinated? How might time be reallocated to transit?
- **Communication infrastructure:** Do the signals communicate with a central control facility? Do transit vehicles communicate with a central control facility? What is the condition of the infrastructure?

DESIGN AND IMPLEMENT THE SYSTEM CH 5

- **System architecture:** How will the transit vehicles, traffic signals, and other components of the system communicate?
- **Priority conditions:** Under what circumstances will transit vehicles be given priority? When will it not be given?
- **Signal timing modification strategies:** What techniques will be used to give priority to transit vehicles within the signal cycle?

MONITOR AND EVALUATE PERFORMANCE CH 6

- **System monitoring:** Is the system granting priority as intended?
- **Performance evaluation:** Is TSP reducing transit delay? Has transit reliability improved? Are there notable effects on non-prioritized traffic? Are other objectives of the system being met?
- **Adjustment and improvement:** Should modifications be made to improve the effectiveness of the system? Can transit schedules be adjusted or resources used more effectively based on the performance of the TSP system? Are there other ways to use TSP to improve transit service?

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INTRODUCTION TO TRANSIT SIGNAL PRIORITY

The purpose of TSP is to reduce delays to transit vehicles at traffic signals. Most commonly, this is done by using specialized equipment to either extend the length of time that a signal stays green when a transit vehicle is approaching or reduce the length of time that a signal stays red when a transit vehicle is waiting.

The most basic requirements of a TSP system are a means for transit vehicles to communicate that they are approaching a signal, and a means for the signal control system to react in response to such communications. Road segments on which TSP implementation is under consideration typically include more than one signalized intersection. It is essential that the treatment of each such intersection be part of a coordinated plan, so that reduced delays at one intersection are not outweighed by increased delays at others.

Benefits of TSP

Prioritizing transit vehicles through signalized intersections can provide numerous benefits for transit riders and agencies. The most fundamental benefit of TSP is reducing the delay that transit vehicles experience at signalized intersections. This can be particularly beneficial at individual congested intersections where transit service is subject to consistent or severe delays. TSP can also be implemented along an entire corridor, which can both decrease travel time and improve overall reliability.

Transit vehicles that complete their trips faster and more predictably may require less scheduled layover time between trips, which can lead to more efficient use of vehicles and operators. Reducing the amount of time spent idling at red lights can result in system-wide cost savings and environmental benefits, including reductions in fuel consumption and vehicle emissions.

In terms of overall traveler throughput, reducing travel times for a transit vehicle means reducing travel times for each passenger on board. Ultimately, faster and more reliable service may make transit a more attractive mode choice and can lead to an increase in ridership.

Many transit agencies around the country have successfully implemented TSP. Seattle-based King County Metro equipped 28 intersections along three corridors and 1,400 buses with TSP capabilities. The agency reported a 25 to 34 percent reduction in signal delay for eligible buses, a 35 to 40 percent reduction in travel time variability, and a 5.5 to 8 percent reduction in travel time along the corridors during the peak hour.

In Los Angeles, the Metropolitan Transportation Authority has implemented TSP along nine corridors, with another 19 planned. Along these corridors, 283 buses are equipped with transponders for TSP, and 654 signalized intersections are controlled and monitored from a traffic management center. The agency has seen a 19 to 25 percent reduction in travel times along the corridors, and ridership increases from four to 40 percent since implementing TSP and other bus service improvements, such as introducing headway-based service, increasing stop spacing, and implementing strategies to reduce dwell time.

In Vancouver, TransLink has equipped 59 intersections with TSP capabilities along a major corridor between downtown Vancouver and suburban Richmond, and an additional four intersections along a 1.5-mile long segment of dedicated bus lanes. The agency reports a 23 percent modal shift from auto to transit resulting from a 40 to 50 percent reduction in travel time variability along the corridors.

In these case studies and more, nearly all agencies report little or no effect on non-priority traffic. For more information on the results seen in these and other case studies from across the United States and Canada, and for an in-depth reference on other aspects of TSP planning and implementation, see Smith's *Transit Signal Priority (TSP): A Planning and Implementation Handbook*.

Coordinated Traffic Signals

The traffic signals at an intersection are connected to and controlled by a traffic signal controller. The signal control cabinet houses equipment that is programmed with a series of signal timings and phases, and uses an internal logic to determine which phase—red, yellow, or green—to display to each intersection approach. These signal timings can be modified according to time of day, day of week, or type of vehicle. Commonly, the signalized intersections along a corridor can be grouped and coordinated to move vehicles more efficiently along it.

TSP works within an existing cycle length. That is, a cycle is typically not lengthened to accommodate a transit vehicle, but rather the phases are adjusted to allocate the time differently. In practice, extending the green phase to prioritize an approaching transit vehicle necessarily extends the red phase for non-prioritized opposing traffic. TSP must be carefully calibrated to avoid disrupting existing cycle timings and signal coordination.

Technical Considerations

This guidebook addresses three important technical components of a TSP system that planners will need to consider: system architecture, priority conditions, and signal timing modification strategies. These are introduced below and explained in greater detail in Chapter 5.

The **system architecture** of a TSP implementation includes the equipment used to facilitate communication between a transit vehicle and the traffic signal or control center. Because the TSP planning and implementation process rarely begins with a blank slate, it is often advantageous or necessary to integrate TSP with existing equipment and facilities and the means by which these components communicate with each other. Therefore, an inventory of the existing equipment and infrastructure is a key initial step when deciding the system architecture.

With transit signal priority, approaching transit vehicles do not have to be granted priority unconditionally. The **priority conditions**—the conditions under which priority can be granted—can be configured to reflect the objectives of a particular TSP implementation. If an objective is improved schedule adherence, priority requests can be considered only for transit vehicles that are running behind schedule. If an objective is improved headway adherence—maintaining scheduled headways along a route—priority requests can be considered only for vehicles lagging behind a specified headway target. These conditions can be modified and adapted over time to best serve an agency or municipality's goals.

Prioritizing Specific Vehicles

There is a spectrum of how generously to prioritize specific vehicles. One approach is known as passive TSP**. With passive TSP, traffic signals at an intersection or along a corridor are timed to favor transit service. While this can provide some benefit, it requires close monitoring of transit schedules, ridership, and movements—all of which are subject to significant variability—and subsequent adjustment of signal timing to remain effective over time.**

Active TSP**, on the other hand, modifies the signal timing in response to the presence of a transit vehicle if certain conditions are met. This guidebook focuses on active TSP, and in practice, TSP generally refers to active TSP.**

Transit signal priority can be further distinguished from signal preemption**. With preemption, a signal always accommodates a privileged vehicle, regardless of any other parameters. However, signal preemption is typically only used by emergency services and trains at railroad crossings.**

Once the decision has been made to prioritize a transit vehicle through an intersection, different strategies can be used to reallocate time within the signal cycle. There are three primary **signal timing modification strategies**: green-extension, red-truncation, and phase-insertion.

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TSP IN THE BOSTON REGION

The Boston region has a history with planning and implementing TSP.

As early as the late 1980s and early 1990s, the Green Line "B" and "E" light rail branches used sensors in the form of embedded loop detectors as part of a system to give trains priority at surface intersections. The system involved multiple stakeholders—the sensors were installed by the Massachusetts Department of Transportation (MassDOT) and maintained by the MBTA, and the signals were upgraded and maintained by the City of Boston. Over time, the system fell into disrepair and there was a lack of funding to return it to good working condition. The sensors have since been removed during various rehabilitation and construction projects over the years.

Agencies Involved with TSP in the Boston Region

The planning, implementation, operation, and evaluation of TSP requires communication and cooperation from multiple agencies and organizations. The following are the primary agencies currently involved with TSP in the Boston region.

Massachusetts Bay Transportation Authority (MBTA). **As the region's largest transit provider, the MBTA is in a unique position to guide the planning and implementation of TSP on a regional level. It has implemented TSP in several locations, including both permanent and pilot projects. The MBTA is pursuing TSP along corridors that have been identified as good candidates for dedicated bus lanes, and it is open to collaborating with municipalities on TSP projects in other locations.**

Municipalities. **Most traffic signals in the region are owned and maintained by municipalities. Each municipality's approach to TSP planning differs, but TSP generally is investigated in response to concern about congestion and delays to transit service at a particular intersection or along a particular corridor. Some municipalities have found the opportunity to collaborate and extend projects beyond municipal boundaries. The City of Boston is unique among the region's municipalities in that its traffic signals are largely controlled by a centralized traffic management facility. As such, Boston is prepared for a wider implementation of TSP, and will follow the guidance of the MBTA.**

Department of Conservation and Recreation (DCR). **DCR owns and maintains a network of parkways that traverse the region, and most of the traffic signals along these parkways. DCR has limited capacity to plan TSP, and typically serves in a supporting role to the relevant municipality. In an interview with MPO staff, DCR noted that some parkways have excess capacity, and there may be an opportunity to consider installing bus lanes in some locations.**

In 2008, the City of Boston worked with the MBTA to give priority to Silver Line buses at four signalized intersections along Washington Street. In 2012, the system was expanded to include an additional four intersections. TSP was also implemented at four intersections along MBTA bus route 57: at Washington and Brock Street/Lake Street; at Washington Street and Foster Street; at Cambridge Street and Gordon Street; and at Commonwealth Avenue and Babcock Street.

More recently, the MBTA has implemented pilot TSP projects on the Green Line, launching TSP at one intersection on each of the "B" and "E" branches in May 2017, and at one intersection on the "C" branch in June 2017. An additional pilot project in Cambridge, at the intersection of Massachusetts Avenue and Brookline Street, serves MBTA bus route 1. After four months in operation on the "B" and "E" branches, the MBTA reported an average green-light-time extension of 14 seconds, an average red-light-time reduction of eight seconds, and no demonstrable negative effects on non-prioritized traffic. On the "C" line, green-light time was extended by an average of 10 seconds, red-light time was reduced by an average of six seconds, and there was again minimal disruption to non-prioritized traffic.

In October of 2017, the MBTA proposed expanding the pilot program to include entire transit corridors: The Green Line's "B" branch along Commonwealth Avenue in Boston, the "C" branch along Beacon Street in Brookline, the "E" branch along Huntington Avenue in Boston, and along Massachusetts Avenue in Cambridge. Since mid-2018, the MBTA has been working on expanding the pilot program along the "B" and "E" branches. In November of 2018, TSP was activated at the first three of 10 additional intersections that have been planned for the Huntington Avenue corridor. Planning for the "C" branch will begin in early 2019.

The MBTA has also signaled that it will prioritize high-ridership, high-delay corridors for new projects, and will concentrate on corridors that have been identified as candidates for dedicated bus lanes in the future. This is guided largely by a 2016 CTPS study that identified corridors where dedicated bus lanes would result in significant passenger-time savings. Some of those locations currently have bus lanes in place.

A major milestone for bus service improvements came in December of 2017, when the Barr Foundation awarded three $100,000 grants to advance projects that implement elements of bus rapid transit (BRT) in Cambridge, Watertown, Arlington, and Everett. The Foundation hopes for eventual implementation of "gold standard" BRT in the Boston region as part of its mission to enhance regional mobility and reduce vehicle emissions. (See Chapter 3 for more on BRT and its relationship to TSP.)

With their Barr Foundation award, Cambridge and Watertown have partnered to invest in the Mount Auburn Street corridor used by MBTA bus routes 71 and 73. So far, dedicated bus lanes and queue jumps have been piloted, along with TSP on Mount Auburn Street at Homer and Aberdeen Avenues, and a queue-jump at the intersection of Coolidge Avenue near Fresh Pond

Parkway. The signals at Coolidge Avenue and Fresh Pond Parkway are owned and maintained by DCR, so there has been an emphasis on interagency cooperation and communication.

Arlington has implemented TSP at three Massachusetts Avenue intersections: at Bates Road/Marion Road; at Franklin Street; and at Mill Street/Jason Street, all serving MBTA bus routes 77, 79, and 350. Arlington is also piloting TSP at the intersection of Massachusetts Avenue and Lake Street, along with a temporary dedicated bus lane from Lake Street to Alewife Brook Parkway. Early data from that pilot shows a five to six minute reduction in travel time—a 50 percent reduction—along the corridor for the average trip, and a more than 10 minute reduction in travel time for the average delayed trip (the trip with the 90th percentile travel time). Variability in travel time has seen a 40 percent reduction.

Everett has implemented TSP in conjunction with a recently installed dedicated bus lane along Broadway, to serve portions of MBTA bus routes 97, 104, 109, 110, and 112.

Most of these municipalities have identified future opportunities for TSP. Cambridge is working with the MBTA to expand TSP more broadly along the Massachusetts Avenue corridor. Watertown is interested in implementing TSP along the Arsenal Street corridor, which carries MBTA bus routes 70 and 70A through Brighton and Allston to Central Square in Cambridge; and along the rest of the Mount Auburn Street corridor, which carries MBTA bus route 71 to Watertown Square.

Everett is working on implementing TSP along Broadway south of Revere Beach Parkway in conjunction with the construction of a new casino and the associated roadwork. Everett is also seeking to implement TSP along Ferry Street and Elm Street as those corridors undergo full reconstruction beginning in 2020. These projects combined have the potential to provide TSP nearly citywide in the next three to four years.

The TSP projects that have been implemented to date have all involved the MBTA. However, the process used to implement TSP and the lessons learned from the TSP projects are applicable to other municipalities and transit agencies in the region.

For additional reading about potential future opportunities for transit service in the Boston region, see A Better City's 2013 report, *Surface Transportation Optimization and Bus Priority Measures: The City of Boston Context*, and a 2015 report by the Greater Boston Bus Rapid Transit Study Group, *Better Rapid Transit for Greater Boston: The Potential for Gold Standard Bus Rapid Transit Across the Metropolitan Area*.

Lessons Learned

MPO staff conducted interviews with staff from the following organizations about their experiences with TSP:

- Town of Arlington
- City of Boston
- City of Cambridge
- City of Everett
- City of Watertown
- MBTA
- DCR

The purpose of these interviews was to explore the decision-making processes of the various organizations and to identify challenges, successes, and potential issues with regard to TSP project planning and interagency cooperation.

Most agreed that it is important to collaborate with project stakeholders early in the process. The initial identification of a project's stakeholders may be challenging and might include unexpected organizations. For example, in the Boston region, DCR, a department known for managing and overseeing Massachusetts' state parks, also manages a network of parkways, and operates many of the traffic signals along them. Any project that crosses one of these parkways will necessitate some involvement from the organization.

Understanding Stakeholders

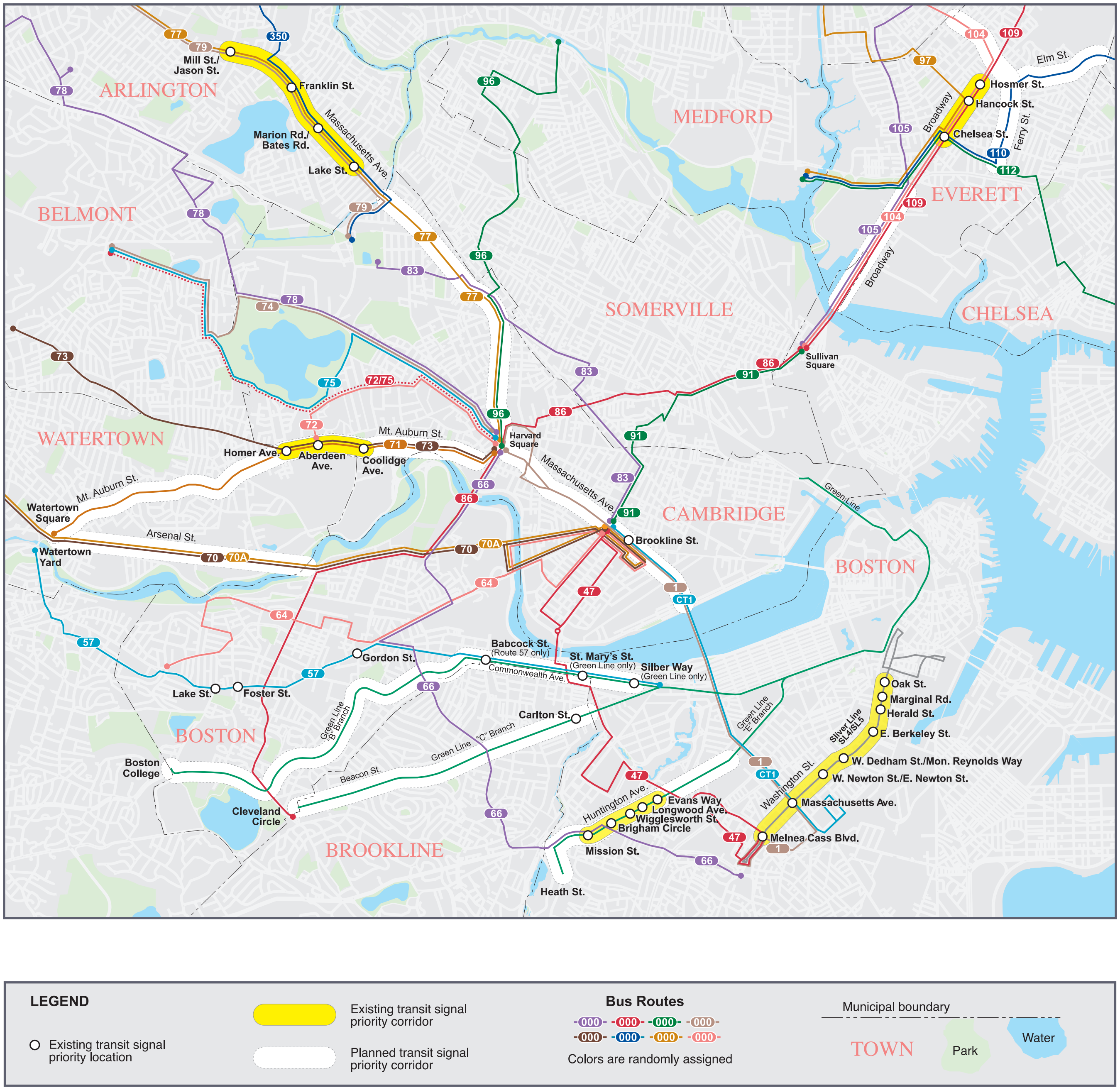
Being familiar with the stakeholders involved in a project may help clarify the context within which planners must work. These stakeholder groups might include:

- **Transit agency management and operations staff**
- **Municipal management, elected officials, and staff from the traffic, public works, planning, and public safety departments**
- **State, county, or regional transportation and planning authorities**
- **Representatives from funding sources**
- **Transit riders**
- **The public**

A comprehensive inventory of field equipment is essential to advancing a TSP project. Such an inventory is necessary when integrating TSP into existing equipment and facilities and the ways by which these systems communicate with each other.

The interviewed officials agreed that interagency coordination and communication is crucial for successful TSP planning. Developing strong working relationships fosters trust and can keep projects moving forward in the event of staff turnover. Being proactive in identifying partnerships can advance opportunities for projects, such as the partnership between Cambridge, Watertown, and DCR along Mount Auburn Street.

The municipalities agreed that there is a need for a strong champion to advance TSP in the region. Most felt that role naturally falls to the MBTA, as the region's largest transit provider, who can help prioritize and advance projects from a system-wide perspective.


ARLINGTON
MEDFORD
BELMONT
EVERETT
SOMERVILLE
CHELSEA
WATERTOWN
CAMBRIDGE
BOSTON
BOSTON
BROOKLINE
Mill St./
Jason St.
Franklin St.
Marion Rd./
Bates Rd.
Lake St.
Massachusetts Ave.
Hosmer St.
Hancock St.
Chelsea St.
Broadway
Ferry St.
Elm St.
Broadway
Sullivan
Square
Harvard
Square
Massachusetts Ave.
Mt. Auburn St.
Homer Ave.
Aberdeen
Ave.
Coolidge
Ave.
Watertown
Square
Mt. Auburn St.
Watertown
Yard
Arsenal St.
Brookline St.
Green Line
Babcock St.
(Route 57 only)
Gordon St.
Commonwealth Ave.
St. Mary's St.
(Green Line only)
Silber Way
(Green Line only)
Lake St.
Foster St.
Carlton St.
Green Line
"B" Branch
Green Line
"C" Branch
Beacon St.
Boston
College
Cleveland
Circle
Green Line
"E" Branch
Oak St.
Marginal Rd.
Herald St.
E. Berkeley St.
Silver Line
SL4/SL5
W. Dedham St./Mon. Reynolds Way
W. Newton St./E. Newton St.
Washington St.
Massachusetts Ave.
Melnea Cass Blvd.
Huntington Ave.
Evans Way
Longwood Ave.
Wigglesworth St.
Brigham Circle
Mission St.
Heath St.
77
79
350
78
96
105
97
104
109
110
112
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77
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74
96
73
75
72/75
83
86
91
86
72
71
73
91
66
83
86
91
70
70A
70A
70
64
1
CT1
47
64
57
57
66
47
1
CT1
66
47
66
1
LEGEND
Existing transit signal priority location
Existing transit signal priority corridor
Planned transit signal priority corridor
Bus Routes
000
Colors are randomly assigned
Municipal boundary
TOWN
Park
Water

3

IDENTIFYING AND PRIORITIZING LOCATIONS FOR TSP

One of the first steps in selecting potential locations for TSP should be to define what the decision makers hope to accomplish through TSP. The next step should be to analyze whether TSP would be an effective strategy in meeting these goals. MPO staff interviewed representatives from organizations in the Boston region to understand their experiences with planning and implementing TSP, including their motivations. Each organization has had a different experience in getting involved with TSP and selecting locations for implementation.

Funding. Securing funding is a critical element in advancing any TSP project, and sometimes the availability of funding can assist with the initial identification of projects. The December 2017 Barr Foundation grants provided a key motivation for Cambridge, Watertown, Arlington, and Everett to proceed with each of their projects. The MBTA secured $1 million through 2018 for TSP and $1.5 million through 2019 for dedicated bus lane projects, and is able to use this pool of funding when working with municipalities. Where grant funding is not available, capital planning has helped municipalities prepare for the costs of upgrading and standardizing equipment and incorporating TSP and other transit accommodations into corridor construction projects. Cambridge has allocated $250,000 through its participatory budgeting process to implement TSP on Massachusetts Avenue to benefit MBTA bus route 1.

Corridors with more transit service. In many municipalities, transit service runs primarily along a major corridor leading towards downtown Boston or a rapid transit station. Massachusetts Avenue in Arlington and Broadway in Everett are two examples. TSP can be optimized by focusing on these corridors, which typically have more routes running along them, with those routes typically running at higher frequencies. The MBTA is focusing on high-ridership, high-delay corridors for future TSP implementation.

Opportunities for partnerships. If a municipality is pursuing TSP at an intersection near a municipal boundary or along a corridor that crosses a municipal boundary, the other municipality may be interested in collaborating to extend TSP further along the corridor. Cambridge and Watertown saw an opportunity to improve service along the Mount Auburn Street corridor, which carries MBTA bus routes 71 and 73 through Watertown and Cambridge to Harvard Square. Recognizing a mutual benefit, the municipalities agreed to partner to implement TSP and other transit improvement strategies, such as queue jumps and dedicated bus lanes.

Sometimes partnerships develop where infrastructure crosses boundaries. One such example is between Everett and Boston. Despite the municipal boundary generally following the Mystic River, there is a small piece of Boston on the north side of the Alford Street bridge. As such, a traffic signal in this area is under the control of the City of Boston. Moreover, some of the signals along that corridor are connected to this Boston signal, and are thus under the control of the City of Boston, despite being fully in Everett. As TSP is further integrated into the corridor,

the two municipalities will need to work closely together.

The MBTA has focused on TSP projects where municipalities are eager to collaborate with them. One such example was a partnership with Arlington throughout the TSP planning, implementation, and piloting process along Massachusetts Avenue.

The MBTA requires the following when undertaking a TSP project:

- **Opportunity for municipal partnership**
- **Sufficient time within the signal cycle to reallocate to transit**
- **Modern traffic control device with space for the necessary additional hardware**
- **Far-side transit stop or no stop at the intersection**

Corridors with dedicated bus lanes. The MBTA has indicated that it will prioritize TSP projects based on corridors with dedicated bus lanes or corridors that might have dedicated bus lanes in the future. The MBTA's approach is to use TSP as part of a package of changes to improve bus service.

For MBTA service, it is easiest to implement a TSP project with the support of the MBTA. However, it is not impossible for municipalities to implement TSP on corridors that are lower priorities for the MBTA. For example, Everett was able to implement TSP independently using video detection of transit vehicles in the dedicated bus lane. Watertown has pursued its interest in TSP on the Arsenal Street corridor by upgrading its traffic signal equipment in anticipation of a future opportunity for TSP.

As TSP becomes more widely implemented, there are a number of ways to further prioritize locations for projects, depending on the needs of the particular intersections, corridors, transit routes, municipalities, and agencies involved. The following criteria may be used to help identify and prioritize potential locations for projects.

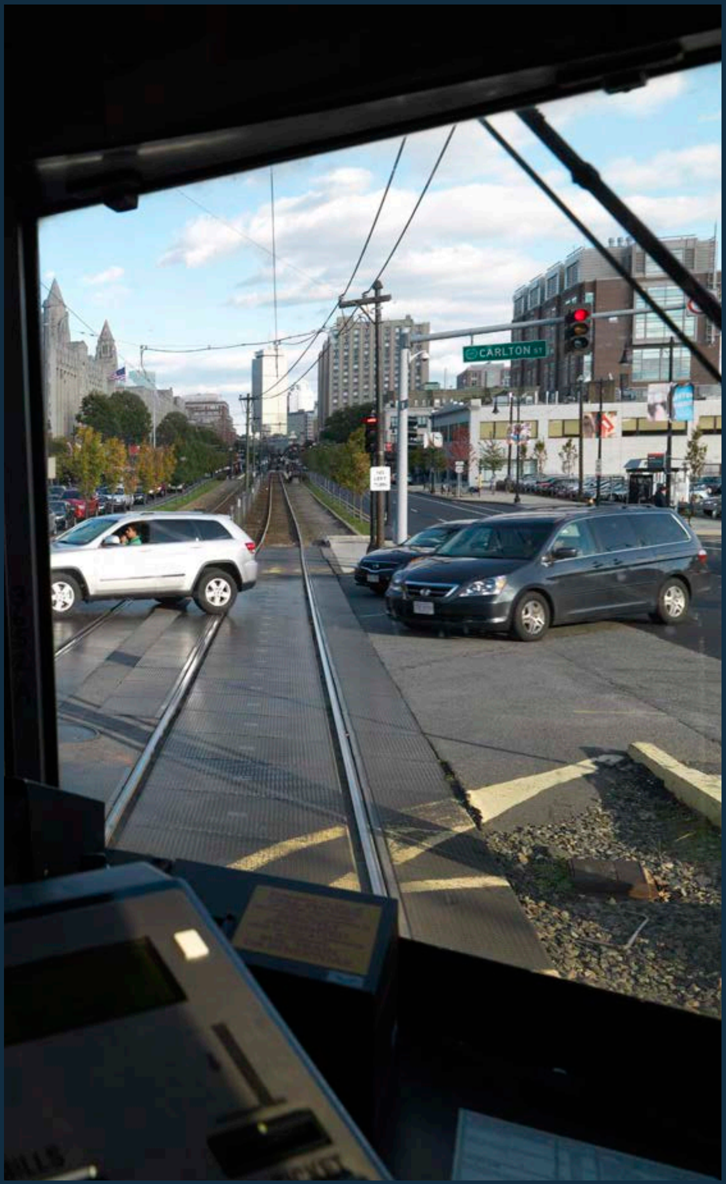
Delay and Variability Metrics

- **Transit vehicle signal delay.** Long signal delay to transit vehicles, which increases travel time and can reduce reliability along a route, can be directly addressed using TSP.
- **Transit passenger signal delay.** If two locations subject vehicles to the same delay, planners may elect to prioritize the intersection that serves the route with higher ridership.
- **Transit reliability.** By reducing transit vehicle signal delay, TSP can improve schedule adherence on routes with poor reliability.

Physical Conditions

- **Existing signal and communication equipment.** Projects that take advantage of compatible equipment and infrastructure can be delivered faster and at lower cost than those where new equipment is required. However, if new equipment is needed, there may be an opportunity to collaborate across jurisdictions to upgrade or standardize equipment.
- **Perpendicular transit service.** Needing to service requests from competing approaches can limit the effectiveness of TSP. Corridors with low volumes of perpendicular transit service are better candidates for TSP, unless the perpendicular services are not prioritized.
- **Location of existing bus stops.** TSP works best with far-side transit stops, those stops found directly after an intersection. Near-side transit stops, those found before an intersection, will likely need to be relocated, which often requires financial, technical, and political resources.

Far-Side Transit Stops vs. Near-Side Transit Stops



In most applications, TSP works better with far-side transit stops; that is, in locations where the transit stop is immediately after, rather than before, an intersection. At an intersection with TSP, when a transit vehicle eligible for priority passes the detection point of the signal, the signal controller must make a calculation: If the signal is green, the control system calculates whether it can be held green long enough for the vehicle to clear the intersection. If the signal is red, the system calculates the amount of time that the red phase can be reduced to allow the vehicle to proceed. Such calculations cannot be made reliably if there is a transit stop between the detection point and the signal, because the length of dwell time is too variable. Consequently, the locations of transit stops relative to signalized intersections are an important consideration in TSP feasibility studies.

Relocating a transit stop from the near side to the far side of an intersection can eliminate conflicts with vehicle detection points but other factors may outweigh the benefits. For example, if the largest source of ridership at a stop were on the near side of the intersection, the majority of passengers would be inconvenienced by having to cross the intersecting street to the far side, especially if there is a long wait for a crossing signal. The existing near-side location may have a shelter or benches, for which there is insufficient room on the far side. If routes serving a near-side stop diverge at the intersection, more than one far-side stop would be needed as a replacement, and transferring between the routes would be less convenient at separate stops.

Other Considerations

- **Expected effects on cross-street traffic.** Regardless of the extent to which official policy may favor giving priority to transit vehicles over other traffic, a TSP system that would result in a net increase in person-hours of travel time in all types of vehicles combined is unlikely to win public support.
- **Costs.** Planners should consider overall project costs when prioritizing TSP projects. These costs may include new signal and controller equipment, reconfiguration of travel lanes, and relocation of transit stops.
- **Public and political support.** TSP projects are more likely to advance with strong public and political support.

Speeding Up Transit Service

TSP is just one tool that might help speed up transit service. A growing number of cities around the world are turning to *bus rapid transit* (BRT), which can provide a level of service and comfort comparable to modern rail rapid transit systems. While elements of BRT—including TSP—can be implemented over time, the "gold standard" BRT system includes the following elements:

- A dedicated right-of-way**, so buses can travel unrestricted by mixed traffic**
- Busway alignment, **typically in the median of wide avenues and boulevards, so stations can be located away from curbside parking, bicycle and pedestrian traffic, and other conflicts**
- Off-board fare collection, **to speed up the boarding process and to allow for all-door boarding without the need for additional on-board fare validation**
- Intersection treatments, **to reduce conflicts with other vehicles and to speed up and prioritize transit service—TSP is one such treatment**
- Platform-level boarding, **to speed up boarding and increase accessibility and ease of use for riders with wheeled devices**

Implementing "gold standard" BRT is no small project, but many other measures, such as the following, can still provide significant benefits to transit service:

- **Increased bus stop spacing**
- **In-lane bus stops**
- **Queue jumps**
- **Parking removal or restrictions**
- **Turning restrictions for general traffic**
- **Improved signal timings and coordination**
- **Yield-to-Bus legislation**

For additional reading on prioritizing transit service through built improvements, see National Association of City Transportation Officials' (NACTO) *Transit Street Design Guide*.

4

INVENTORYING DATA AND INFRASTRUCTURE

Once planners have identified the locations suitable for TSP, it is necessary to conduct a thorough inventory of existing field equipment and signal timing data. The inventory should include the model of every traffic signal and signal controller. The software programs used by TSP to process communications will need to be compatible with the signal controller. There are a number of common types in use in the United States and Canada. For each intersection, the inventory should include the current signal timings—that is, how the different red and green phases are allocated to each approach of the intersection. Whether groups of adjacent signals are coordinated—at a series of complicated intersections or along a corridor—should be noted.

Typical TSP goals include reducing travel times for transit vehicles and improving reliability of transit service. To predict the extent to which TSP could help to meet these goals, it is necessary to try to measure the share of overall delay that occurs at traffic signals. This will often require an extensive data-collection effort that would not otherwise be undertaken. Measuring the actual benefits of a TSP project will require collecting comparable data after implementation.

Data collected before TSP implementation may indicate that low-cost signal improvements could produce many of the benefits sought from TSP. Such improvements might include increasing the amount of green time allocated in each cycle to the street serving a transit route and reducing the amount of green time allocated to intersecting streets, or adjusting the offsets between the starts and ends of green intervals at successive signals.

On a road segment with several signalized intersections and low overall travel speed, traffic analysis may determine that conditions at one or two of the intersections are the source of most of the delays. Efforts can then be concentrated on improving traffic flow at these intersections, which may not necessarily include use of TSP. Changes in designation of lanes for straight and turning moves or changes in the signal timings allocated to these moves may reduce the need for TSP.

It is also necessary to note the existence of any central traffic control facilities. These traffic management centers receive data from signals and controllers as to their status and condition, and staff can monitor this information, receive notification of faulty equipment, respond to changes in traffic conditions, and make adjustments if necessary.

The condition of the infrastructure is an important consideration. For example, most traffic signals in the City of Boston are connected to a traffic management center, but the condition of the copper wiring and the distances involved mean that communication is not instantaneous, and can take anywhere from five to 10 seconds. As discussed in Chapter 5, that time needs to be accounted for when determining a new signal-timing plan that accommodates prioritized transit vehicles.

It is also necessary to understand the communication equipment and capabilities of the transit agency. Many transit agencies now use a transit management center, where the location of each transit vehicle can be monitored in real time.

The MBTA's automatic vehicle location (AVL) system monitors the location of buses in *near* real time. In practice, the system receives an update on a vehicle's location every 30 to 60 seconds. However, when an ongoing upgrade is complete, the system will provide location updates every five seconds, providing a much higher degree of accuracy as to the location of vehicles.

Several municipalities have adopted policies and practices to maintain equipment inventories and to standardize equipment when possible. The MBTA has retained the IBI Group as a consultant for the inventory process. The IBI Group has collected signal timing and equipment data from each of the municipalities that are advancing TSP projects, performs field verification when necessary, and helps to identify and prioritize appropriate locations for TSP.

5

DESIGNING AND IMPLEMENTING A TSP SYSTEM

Once planners have identified a location suitable for TSP and collected the necessary data, there are many ways to design the system.

Historically, a major impediment to implementing TSP has been communication abilities—especially communication between transit vehicles, intersections, and central traffic control facilities. A significant consideration in TSP implementation is the extent to which traffic and traffic signals can be monitored and controlled remotely from a central location. If signals are controlled entirely by the settings in control boxes located at each intersection, TSP implementation is feasible only if the hardware and software in the control boxes can be modified to accept information from transit vehicle detectors to extend green intervals or shorten red intervals in accordance with specified decision rules. Although physically possible, budgetary considerations may preclude some signal control upgrades.

If traffic signals along a corridor can be controlled from a central location, TSP implementation may require little or no modification to the signal controllers at individual intersections. However, it is necessary that the decision rules for intervention, whether manual or automated, be capable of integrating the additional rules specific to TSP.

System architecture refers to the configuration of equipment that is used for communication between a transit vehicle, signal controller, and, if they exist, traffic and transit management centers. A system architecture can be decentralized, with communication occurring between a transit vehicle and intersection directly; centralized, with communication being routed through traffic and transit management facilities; or a hybrid of the two. The figure on the following page shows how the various components of a TSP system can be configured to communicate.

Determining a system architecture is an important consideration. Rarely does the TSP planning and implementation process begin with a blank slate. It is often advantageous—or necessary—to design a system that incorporates existing equipment as much as possible.

In the Boston region, different municipalities have different equipment and communications facilities, so several different architectures will be required.

With a **vehicle-to-intersection** architecture—a decentralized system—a priority request generator located on the transit vehicle sends a priority request to a receiver mounted to a traffic signal mast arm. This receiver is wired to the signal controller, which takes the request and determines whether to grant or deny the request according to certain conditions. A similar alternative uses loop detectors embedded in the pavement to detect approaching transit vehicles.

TSP systems in Cambridge, Watertown, and Arlington currently use a vehicle-to-intersection architecture.

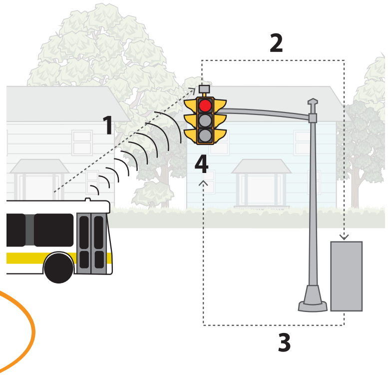
Another decentralized system is the **intersection-to-vehicle** architecture, which uses video cameras to detect and notify the signal controller of an approaching transit vehicle.

Everett uses the intersection-to-vehicle method for the TSP system on Broadway, where they currently have a dedicated bus lane. Because they lack centralized communication equipment, DCR plans to use video detection to notify its signal controllers of approaching transit vehicles.

TSP SYSTEM ARCHITECTURES

Vehicle-to-intersection

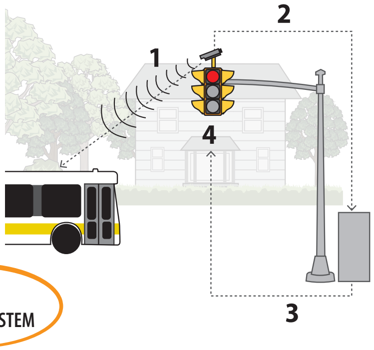
1. Bus transmits request to receiver
2. Receiver notifies controller
3. Controller evaluates request and returns result to signal
4. Signal gives priority, if approved



ARLINGTON, CAMBRIDGE, AND WATERTOWN USE THIS SYSTEM

Intersection-to-vehicle

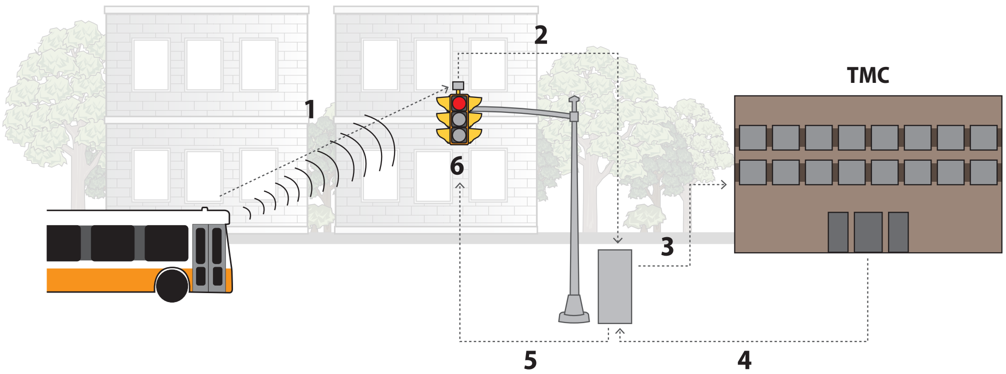
1. A video camera monitors the intersection
2. Camera notifies controller
3. Controller evaluates request and returns result to signal
4. Signal gives priority, if approved



EVERETT USES THIS SYSTEM

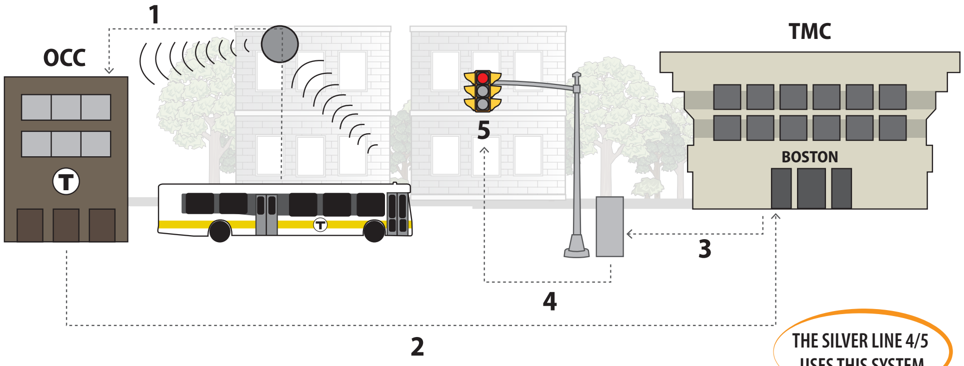
Vehicle-to-center

1. Bus transmits request to receiver
2. Receiver notifies controller
3. Controller notifies traffic management center (TMC)
4. TMC evaluates request and returns result to controller
5. Controller notifies signal
6. Signal gives priority, if approved



Center-to-center

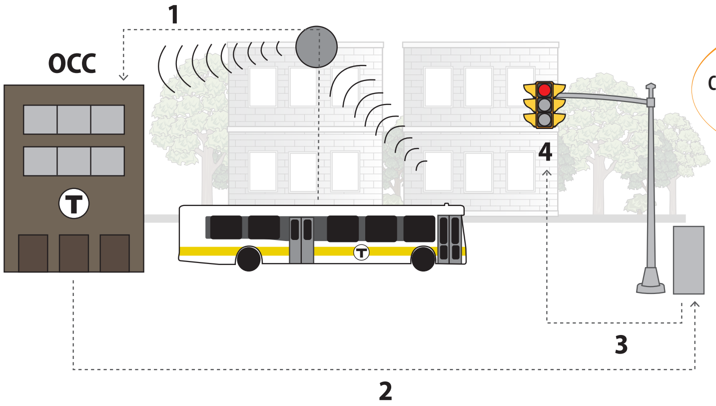
1. Bus transmits location to transit operations control center (OCC)
2. OCC transmits request to TMC
3. TMC evaluates request and returns result to controller
4. Controller notifies signal
5. Signal gives priority, if approved



THE SILVER LINE 4/5 USES THIS SYSTEM

Center-to-intersection

1. Bus transmits location to transit OCC
2. OCC transmits request to controller
3. Controller evaluates request and returns result to signal
4. Signal gives priority, if approved



MUNICIPALITIES WITHOUT CENTRALIZED TRAFFIC CONTROL CAN USE THIS SYSTEM FOR MBTA SERVICE

As more equipment is introduced, systems can become more centralized. In a **vehicle-to-center** architecture, requests received by a signal controller are forwarded to a traffic management center, which evaluates the request and returns the result. From a centralized traffic management center, traffic engineers can monitor real-time traffic conditions, receive notification of field equipment malfunctions, and adjust criteria for modifying signal timings.

If transit agencies also have a centralized control facility—a *transit* management center—to monitor real-time locations of transit vehicles, TSP can be fully centralized in a **center-to-center** architecture. As a transit vehicle approaches an intersection, the transit management center notifies the traffic management center, which evaluates the request and forwards the result to the signal controller.

The City of Boston has most of its traffic signals hardwired to a traffic management center at Boston City Hall.

The MBTA has a transit management center, which has been configured to communicate with Boston's traffic management center. TSP within Boston city limits can be implemented in a fully centralized, center-to-center system, as has been demonstrated by the Silver Line along the Washington Street corridor. Cambridge is exploring communications options to allow central control of signals, which could lead to a future center-to-center approach in Cambridge as well.

A **center-to-intersection** architecture is a hybrid of centralized and decentralized systems. In this system, the transit management center bypasses the traffic management center and communicates with the intersections directly. This may be an option for municipalities that lack a traffic management center.

Once planners have selected the appropriate architecture, a TSP system is configurable in a number of ways. Depending on the goals of the municipalities and agencies involved, planners will need to determine the **priority conditions**—the conditions under which priority requests are considered. The text on the following page describes some of the ways in which a transit vehicle can be prioritized.

A center-to-intersection architecture was the initial TSP implementation method along Washington Street used by the Silver Line—it has since been upgraded to a center-to-center system.

Granting or Denying a Priority Request

Signal controllers govern which phase—red, yellow, or green—a traffic signal displays to a given approach at a given time. The controllers are programmed with logic that prevents, for example, green lights being shown to two or more conflicting movements. They can be programmed with one or more automatic timing cycles that can change according to the time of day; for example, the timings used during rush hour would be different from the timings used late at night. They can also be programmed to coordinate groups of signals.

TSP software adds additional criteria that the controller uses to determine which phase to show in response to a priority request. The TSP logic may include criteria related to the following:

- When in the signal timing cycle the request is received. **If the request is received while the signal has sufficient green time remaining for the transit vehicle to travel through the intersection, a priority request may be ignored. On the other hand, if the signal will soon turn red, the green time can be extended.**
- How recently a request has been granted. **To avoid excessive disruption to the programmed traffic cycles, TSP systems typically include additional rules, for example, that only one out of every three buses that meet the criteria for signal priority will have priority granted, or that the signals must have completed at least two uninterrupted cycles between cycles when priority is granted.**
- Whether the vehicle is on time. **Some TSP systems grant priority only to vehicles that are running late, as defined by the transit agency, relative to a scheduled departure time or given headway.**

These parameters, among others, can be configured on a situational basis according to the needs of the municipalities and agencies involved.

Within a set cycle length, there are a number of ways to reallocate green time to prioritized vehicles, or **signal timing modification strategies**. A common strategy is **green extension**. With green extension, if a transit vehicle is on pace to arrive just before the light turns red, the green light is extended to allow enough time for it to pass through the intersection. In contrast, a **red truncation** strategy cuts a red light short if a transit vehicle is waiting for the light to change or is approaching a red light. Another strategy is **phase insertion**, which adds an additional phase to a signal cycle to facilitate a particular movement through an intersection. This is commonly used, for example, when a transit vehicle needs to make a left turn against heavy opposing traffic.

The amount of time to reallocate is a decision influenced by a number of factors, such as the following:

- Variability in traffic volume and speed on the approach
- Typical traffic volume on the non-prioritized approach
- Existing coordination with nearby signals, and the acceptable amount of time for traffic signals to resynchronize with each other
- Dwell time, in the case of near-side bus stops, which can be highly variable

The amount of time that a municipality can reallocate within a signal cycle plays an important role in the effectiveness of TSP. Cambridge reallocates up to 35 seconds for transit priority phases—Boston, only 10 seconds.

Configuring the priority criteria and signal phase reallocation strategies can be a highly technical endeavor. Some of the municipalities interviewed by MPO staff noted a lack of staff resources to plan and design the technical details of a TSP implementation. For that, specialized consultants are available for hire.

Financial Considerations

Overall project cost is a major driver in the feasibility of implementing TSP projects. TSP costs can be broadly categorized as intersection dependent, vehicle dependent, right-of-way improvements, and ongoing maintenance. At intersections, communication equipment is required to receive priority requests. Depending on the technology used, this can range from $5,000 to $20,000 or more per intersection. On board vehicles, a beacon is needed to generate and send priority requests. This can range from approximately $50 to as much as $2,500 per vehicle.

MBTA buses already have the necessary equipment for center-to-center TSP installed on them: the location of every bus is monitored in real time by the MBTA's AVL equipment. With the MBTA's transit management center configured to communicate with the City of Boston's traffic management center, there is no need for additional equipment for TSP within Boston city limits.

Right-of-way improvement costs include construction and striping of new lane configurations, relocation of bus stops, and other right-of-way treatments necessary for the project to move forward. These, along with ongoing maintenance costs, are highly project dependent.

Arlington needed to relocate a bus stop from near-side to far-side for its TSP pilot at Massachusetts Avenue and Lake Street. Staff noted that this was a challenge due to a need to balance the competing uses of the curb lane and sidewalk space at that location.

Experience in Other Regions

The costs associated with implementing and maintaining a TSP system vary widely based on a number of factors. The following table shows a summary of some of the experiences in other cities.

Location	Transit Agency	System Description	Cost
Seattle, WA	King County Metro	1,400 buses 28 intersections 3 corridors	$2.7 million, plus $28,000 annually
Los Angeles, CA	Metropolitan Transportation Authority	283 buses 654 intersections 9 corridors	$10 million
Vancouver, BC	TransLink	28 buses 63 intersections 2 corridors	$860,000, plus $20,000 annually

The MBTA's pilot program is estimated to cost $1.125 million, or $12,640 per signal.

Everett estimated TSP-compatible traffic signals to cost about $10,000 per intersection where existing signal equipment was fully modern, or $30,000 to $50,000 per intersection where controllers and other equipment required upgrading. The City of Everett had previously used Complete Streets funding to upgrade signal equipment at all TSP locations.

The MBTA has outlined preliminary roles and responsibilities for partnerships with municipalities. Once implemented, operations and maintenance of signal equipment will typically be the responsibility of the municipalities, while on-board equipment and ongoing support and evaluation will be the responsibility of the MBTA.

6

EVALUATING THE PERFORMANCE OF TSP

Measuring the impacts of TSP helps planners, traffic engineers, and other officials monitor, manage, and improve the system. The metrics that a particular municipality or agency will choose to track will depend upon the stated goals and objectives of the TSP system. *Transit Signal Priority (TSP): A Planning and Implementation Handbook* provides several case studies that document the performance metrics used by transit agencies across the United States and Canada.

The following metrics can be used to evaluate the performance of transit signal priority.

Most pilot projects in the Boston region have not been operational long enough to generate significant data. Once they have, the metrics listed on this page can be used to help evaluate their performance.

- **Transit vehicle signal delay.** A successful TSP system will reduce transit vehicle signal delay, which can be measured by the average delay per transit vehicle, average queue length, or number of cycles required to clear the intersection.
- **Transit passenger signal delay.** A successful TSP system will reduce total transit passenger signal delay, measured as the transit vehicle signal delay multiplied by the number of passengers on board.
- **Overall travel time along the route.** A successful TSP system can help reduce overall travel time along a route. (Other non-TSP strategies can help further; for example, dedicated bus lanes and strategies that reduce dwell time.)
- **Transit reliability.** A successful TSP system can help improve transit reliability for either scheduled or headway service. Improved schedule or headway adherence reduces transit vehicle bunching, which can reduce crowding. Passenger wait times are also reduced with more reliable service.
- **Cross-street traffic signal delay.** A successful TSP system will not unduly disrupt existing traffic patterns. Most transit agencies report little to no impact on non-prioritized traffic.
- **Fuel consumption.** A successful TSP system will reduce the amount of time vehicles spend idling at red lights, which will reduce fuel consumption.
- **Ridership.** A successful TSP system can reduce delay, travel time, and schedule variability, increasing the attractiveness of transit usage. In some cases, the increased attractiveness of transit can lead to increased ridership.

The following items should be monitored to assist in judging the success of transit signal priority, and in modifying policy if necessary.

- **Frequency, type, and result of TSP system calls.** The TSP system software should log information about each request for priority, including the time of the request, the type of request (extended green, truncated red, etcetera), and whether the request was granted or denied. A priority request may be denied at a given condition because of TSP policy. If TSP requests are causing excessive intersection delays, the number of allowable requests may need to be reduced. Conversely, if priority requests are not causing significant delays, then additional priority requests may be allowed.

- **Public response.** Public support is important and helpful in measuring the success of TSP, and in ensuring its continued implementation can serve its communities as effectively as possible.

After evaluating the performance of TSP, planners should make changes to improve the system design, if needed. Planners should also identify opportunities to make other adjustments based on TSP performance. For example, improved reliability and reduced travel time may result in less recovery time being needed in the schedule. Planners should consider whether schedule adjustments or operating resource allocation can be modified as a result of TSP performance.

Before-and-after comparisons of scheduled round-trip times with the projected time savings will indicate whether the savings would be sufficient to allow either a reduction in the number of vehicles or to increase service frequency with the same number of vehicles. The predicted service improvements can be used as input to demand models to predict the impact on ridership, and average fares can be applied to ridership changes to estimate revenue impacts. Marginal cost formulas can be applied to changes in service to calculate changes in operating costs. Ultimately, any realized benefits from a TSP system can be used to continue to improve service.

7

KEYS TO SUCCESS

Success in planning and implementing TSP is highly variable, depending heavily on physical, political, and financial opportunities and constraints. However, the following keys to success can be applied to most projects.

Well-Defined Objectives

Clearly identify the goals and objectives of a TSP system, and use those goals to select locations for implementation and evaluate system performance once operational. Use measurable objectives in order to track progress. Measuring the effects of TSP on people throughput, in addition to vehicle throughput, can also help quantify the benefits.

Stakeholder Involvement

Identify the stakeholders that will be affected by a TSP project, and get them involved early in the process. Successful TSP projects will require support from transit agency management and operations staff, municipal staff and elected officials, local residents, and transit riders. Understand what each group prioritizes, and work to incorporate their points of view into a cohesive final product.

Good Partnerships and Communication

Develop strong professional relationships and agency partnerships throughout the planning, implementation, and evaluation phases of TSP projects. Maintain regular communications between agencies, consultants, and other stakeholders.

Formalized Interagency Agreements

Formalize interagency agreements early on in the process. Financial obligations, operations and maintenance responsibilities, and dispute resolution protocols should be agreed upon and clearly stated to ensure that the region's collective investment in TSP continues to be supported. Establish policies to conduct periodic monitoring and maintenance of field equipment and communication infrastructure.

A Motivated Champion

Identify an organization or individual—or perhaps an individual from each organization involved—that is motivated to implement and maintain successful TSP. TSP projects can be hindered by staff turnover and fragmented municipal and agency leadership. A champion serves to unify the various organizations and build consensus to keep projects moving forward.

A Clear Narrative

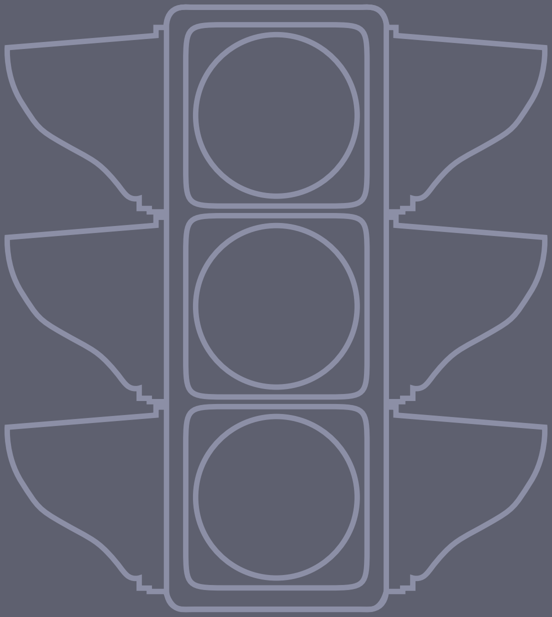
Evaluate all TSP projects, including pilot projects, to measure and quantify the benefits of TSP. If transit planners and traffic engineers see that the pilot projects benefit the entire transportation network, the next project can be easier and faster to implement. Use passenger-focused metrics and publish results in widely accessible formats to garner support from the public and elected officials.

Equipment Inventory and Standardization

Create and maintain a comprehensive inventory of existing equipment, and monitor opportunities to standardize that equipment. Installation, operation, and maintenance of TSP systems are all easier on standardized traffic signal and controller equipment. In the presence of multiple jurisdictions, region-wide efforts to standardize TSP-capable controller equipment can be valuable. Share access to this inventory with both traffic and transit management control centers.

A Funding Plan

Explore funding opportunities that may be available through municipal and interagency partnerships, grant programs, and other funding sources. Take advantage of existing equipment by designing a system that maximizes the use of existing resources. Identify which party will be financially responsible for different portions of the project, and the timelines for payment. Be aware of constraints and deadlines that may be attached to certain funding sources.



8

FURTHER READING

A Better City. *Surface Transportation Optimization and Bus Priority Measures: The City of Boston Context*. March 2013.

Florida Department of Transportation. *Transit Signal Priority Implementation Guidance*. July 2014.

Greater Boston Bus Rapid Transit Study Group. *Better Rapid Transit for Greater Boston: The Potential for Gold Standard Bus Rapid Transit Across the Metropolitan Area*. Spring 2015.

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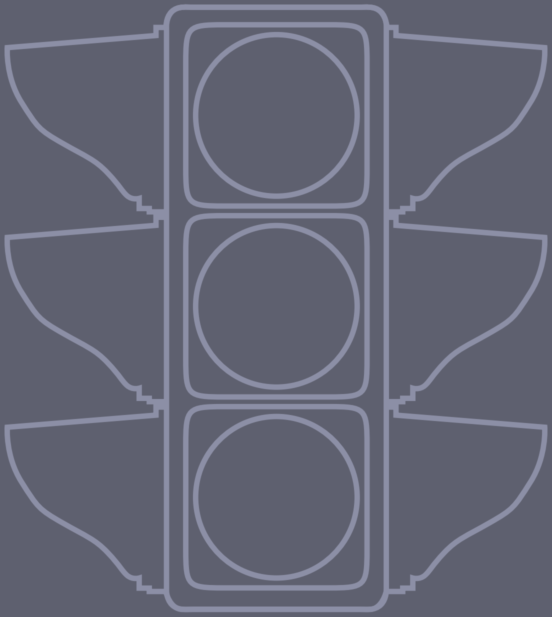

9

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