an Overview of Transit Signal Priority

Prepared by the Advanced Traffic Management Systems Committee and Advanced Public Transportation Systems Committee of the Intelligent Transportation Society of America (ITS America). The revised document was endorsed by the ITS Public Transportation Forum of ITS America and America Public Transportation Association (APTA) and the Transportation System Operations and Planning Forum of ITS America.

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★ Foreword

This overview of Transit Signal Priority (TSP) was originally co-developed by the Advanced Traffic Management System (ATMS) and Advanced Public Transportation System (APTS) committees of the Intelligent Transportation Society of America (ITS America). It represents the culmination of efforts made by multiple contributors working to produce a resource that provides relevant information on Transit Signal Priority in a highly accessible format. Due to the high interest in the document and the subject, the US DOT funded a project to gather more data from around the country and provide outreach through a series of workshops. The information gathered has been used to update and add more detail to this document. The updated document was reviewed and approved by the ITS Public Transportation Forum (co-sponsored by ITS America and the American Public Transportation Association) and the Transportation System Operations and Planning Forum (sponsored by ITS America). This resource is available electronically through the ITS America web site at *http://www.itsa.org/*.

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ExecutiveSummary

This paper provides an introductory guide to implementing Transit Signal Priority (TSP). It has been written by engineers and technicians who have actually implemented TSP and includes the lessons learned from field experience. Importantly, it is co-authored by both public transit operators and traffic engineers, and attempts to move toward a consensus of opinion among groups who have sometimes had very different perspectives on the significance and consequences of TSP. This document provides balanced information to both the transit and traffic engineering communities in order to enhance their knowledge about the possible benefits, alternative approaches, and issues concerning TSP.

Overview of Transit Signal Priority Fundamentals

TSP is an operational strategy that facilitates the movement of in-service transit vehicles, either buses or streetcars, through traffic-signal controlled intersections. It is important to note that although priority and preemption are often used synonymously, they are in fact different processes. While they may utilize similar equipment, signal priority **modifies** the normal signal operation process to better accommodate transit vehicles, while preemption **interrupts** the normal process for special events such as an approaching train or responding fire engine. Objectives of emergency vehicle preemption include reducing response time to emergencies, improving safety and stress levels of emergency vehicle personnel, and reducing accidents involving emergency vehicles at intersections. On the other hand, objectives of transit signal priority include improved schedule adherence, improved transit efficiency, contribution to enhanced transit information, and increased road network efficiency.

Transit Signal Priority can be implemented in a variety of ways. Priority treatments include passive priority, early green (red truncation), green extension, actuated transit phase, phase insertion, phase rotation, and adaptive/real-time control. Use of the active treatments should also consider impacts associated with methods of recovery to transition the signal controller back to coordination. In its more basic form, TSP is accomplished at the local intersection level, by detecting the transit vehicle and direct interaction with the local intersection signal controller. A more sophisticated approach operates at the street network level by utilizing bus location information to provide selective priority based on factors such as lateness. TSP system components consist of three major elements, the transit vehicle detection/ priority request system, the traffic signal control system, and a communications system to link the vehicle detection system with the traffic signal control system, possibly through a transit/traffic management center.

TSP Benefits and Costs

Expected benefits of TSP include improved schedule adherence and reduced travel time for buses, leading to increased transit quality of service. Potential negative impacts consist primarily of delays to side street traffic, but these delays have proven to be minimal. Experiences from prior deployments generally indicate bus travel time savings on the order of 15% with minor impacts on the cross street traffic. However, substantial variability exists in the nature of deployments and magnitude of impacts. Costs are dependant on the configuration of the system, with somewhat higher costs associated with signal upgrades, equipment/software for the intersection, vehicles, or the central management system. Many systems have been implemented without costly upgrades. Because costs can be substantially affected by the desired functionality, comparisons with other TSP systems with different capabilities should be considered with caution.

Planning for Deployment of TSP

When planning a TSP system, the roles and relationships between various stakeholders must be taken into consideration. Primarily, the emphasis is on the relationship between the traffic and transit agencies, but other stakeholders can have a significant influence on the planning of a TSP system. Regional management and coordination of TSP issues between these stakeholders may be accomplished with the use of two oversight committees, one addressing technical issues, and one addressing policy issues. Implementation planning should utilize systems engineering processes, due to the system complexity and the need to integrate TSP with other major ITS systems. With regard to planning for procurement, a variety of contract mechanisms may be utilized, depending on the situation. If solid relationships already exist between the involved agencies, there is also the potential for the system to be implemented by a single systems integrator rather than procuring components separately.

Planning, deployment and operations of TSP systems involve consideration of many different factors, as outlined in this paper. While previous deployments may have similarities, the particular environment and conditions under which a new TSP system is being considered should be given full consideration. In addition, as technologies evolve, the capabilities available in TSP systems and subsystems may increase significantly. These improvements can provide the potential to achieve objectives which require a higher level of system sophistication. In terms of objectives, all stakeholders need to be involved in the determination of a set of TSP system objectives and desired system functionality that reflects local policies and tradeoffs. Through the use of a systems engineering process, a TSP system that addresses these objectives and system functionality may be planned, developed, and supported through all of its life-cycle phases.

Based on knowledge and experiences established on both a technical as well as a policy level, the following recommendations are proposed for agencies considering a TSP project:

- Identify a champion.
- Utilize the Regional ITS Architecture (or National ITS Architecture if the regional architecture has not been developed).
- Identify the stakeholders internal and external to your organization.
- Establish a multi-department team of leaders with responsibility to carry out the project within your agency or jurisdiction.
- Establish a regional team to guide the project from a regional perspective.
- Establish the goals and objectives. Set measurable levels of performance for these goals.
- Identify funding opportunities.
- Make sure that system objectives and requirements are clearly articulated in requests for bids.
- Require pre-installation testing before acceptance of a system.

TSP Design/Implementation Issues

There are many factors influencing the implementation of a TSP system, including roadway geometry, traffic volumes, traffic signal hardware and software, traffic signal operation, person delay, pedestrians, adjacent intersection/corridor operations, traffic agency signal operation policies and practices, transit system characteristics, transit stop location and design, existing transit agency hardware and software, and transit agency operating policies and practices. Each of these factors needs to be considered in light of the particular deployment environment, and usually, the particular intersection involved. Multiple types of priority treatments may be more appropriate than trying to apply one solution everywhere. Also, assessing the TSP capabilities of the existing traffic and transit hardware/software is necessary, as these capabilities, or lack thereof, will affect the budget and schedule for TSP implementation. When selecting and designing a TSP system, the subsystems, consisting of transit vehicle detection, communications, traffic control, and TSP logic, must be considered together, as each subsystem is interrelated. For example, the TSP algorithms available depend on the firmware and controller type used.

TSP Operations and Maintenance Issues

Operations and maintenance of a TSP system are influenced by the technology chosen for implementation, priority system integration with the signal network, age and generation of signal hardware, vehicle intelligence, climate and geology, system ownership and transit operating rules. The technologies currently available can—in most instances—provide significant improvements in operating speed without a great degree of sophistication or expense. However, maximizing on-time performance requires a good deal more effort in time and money. That effort includes the need to collect operational performance data—as part of the normal operation of the system—to measure the benefits and impacts of TSP. In terms of life cycles, transmitter and receptor equipment can often outlast replacement cycles of vehicles and traffic signal controllers. As a rule of thumb, annual maintenance expenses for radio-based technologies are less than one percent of system purchase price, with a premium paid in additional maintenance expense for optical and infrared technologies. However, software upgrades, as a result of enhanced features or retrofitting a technology with new capabilities, can have a significant impact on operating and maintenance expenses. The level of sophistication present in a TSP also influences operating and maintenance. Relatively low cost operations can be implemented by allowing the traffic signal devices to "decide" on granting priority solely on the basis of the internal operating algorithms of the controller, not on the status of the transit vehicle. More sophisticated systems provide the signal system or the transit vehicles themselves with significant ITS capabilities. These differences should be considered in conjunction with the desired functionality of the system, as the simpler system design may not provide the ability to achieve desired objectives. Finally, the complexity of the jurisdictions having responsibility for the traffic signals and transit systems operating TSP can significantly affect the associated operating and maintenance costs.

Future Direction and Research Needs

There have been significant advances in transit signal priority including understanding of the issues—both technical and political—and the development of valuable experiences. As experience expands and the options and issues are better understood throughout the transit and traffic communities, it is anticipated that there will be increased deployment of this cost-effective technology. This will be especially true for the Bus Rapid Transit Systems being deployed across the continent. For example, 14 of the 17 planned BRT deployments, being facilitated by FTA, will include TSP as a significant element for increasing transit speed.

Future deployment will also be facilitated by the development and adoption of the NTCIP 1211 and TCIP TWG 10 standards.

Finally, workshops sponsored by the Joint Program Office and the Federal Transit Administration and organized by ITS America were held across the United States from February through July 2003. The first workshop focused on research needs while the following three workshops focused on outreach. The result of the first workshop was a list of identified research needs which were posted on the web along with a request for comments. The list was revised based on comments and submitted to FTA. Priority areas include:

- TSP Strategic Choices and Guidance
- Effective Utilization of TSP by Transit Agencies
- Improved Planning of TSP (especially for Bus Rapid Transit)
- Enhanced Analytic Tools (e.g., Simulation and Optimization)
- Technical Enhancements for Conditional Priority
- TSP Deployment Evaluation

The entire list of identified research needs, notes from each workshop, copies of all workshop presentations as well as TSP resources, a list of products and services, and a newsletter may be found on ITS America's TSP web page: *http://www.itsa.org/tsp.html*

> It is clear that **Transit Signal Priority** is a cost-effective approach for enhancing the attractiveness of transit and for increasing the capacity of the urban road infrastructure, and its use will continue to increase.

Introduction 1

1.1 Objective of Guide

This document presents an introductory guide to implementing Transit Signal Priority (TSP). While it does not have all the information one would need before embarking on a TSP project, it enables the reader to establish a good foundation of relevant knowledge and raises an awareness of most of the issues, pitfalls, and solutions surrounding TSP implementation and operation. In doing so it also provides a basis for an improved understanding and appreciation of the issues, considerations, and details associated with a particular situation, and allows for more effective communication between involved parties when potential TSP deployments are being considered and when planning, design, and implementation details are being discussed.

1.2 Audience

This paper draws upon the existing body of knowledge embodied in the experiences and perspectives of practitioners. It has been written by engineers and technicians who have actually implemented TSP and includes the lessons learned from field experience. Importantly, it is co-authored by both public transit operators and traffic engineers, and attempts to move toward a consensus of opinion among groups who have sometimes had very different perspectives on the significance and consequences of TSP. This document provides balanced information to both the transit and traffic engineering communities in order to enhance their knowledge about the possible benefits, alternative approaches, and issues concerning TSP. This broader knowledge will encourage better understanding among these communities and their decision makers.

1.3 Organization of Guide

The remainder of this guide begins by presenting an overview of TSP and gives a background on its fundamental characteristics. The following section offers suggested areas that should be considered in planning a potential TSP deployment. Further detail is presented on issues and alternative approaches directly related to TSP implementation, followed by a discussion of TSP operations and maintenance. The guide will conclude with some insights into the future direction of TSP and identified research needs. Appendices include a list of references, a list of TSP deployments, the list of TSP-related R&D needs identified at a workshop of experts in February 2003, and a glossary.

2 Overview of Transit Signal Priority Fundamentals

Overview

2.1 Background—What is TSP?

TSP is an operational strategy that facilitates the movement of in-service transit vehicles, either buses or streetcars, through traffic-signal controlled intersections. By reducing the time that transit vehicles spend delayed at intersection queues, TSP can reduce transit delay and travel time and improve transit service reliability, thereby increasing transit quality of service. It also has the potential for reducing overall delay at the intersection on a per-person basis. At the same time, TSP attempts to provide these benefits with a minimum of impact on other facility users, including cross-traffic and pedestrians.

2.2 TSP Fundamentals

2.2.1 Priority vs. Preemption

Before discussing the strategies used to implement TSP, it is important to revisit the definition of priority and how it differs from preemption. **Priority and preemption are often used synonymously**, when in fact they are different processes. Priority and preemption may utilize similar equipment (e.g., optical emitters/detectors, see Figure 1), and may appear similar in operation to an observer (e.g., signal indication for approaching vehicle transitions from red to green after a clearance interval for other approaches). However, signal priority **modifies** the normal signal operation process to better accommodate transit vehicles, while preemption **interrupts** the normal process for special events (e.g., train approaching a railroad grade crossing adjacent to a signal, emergency vehicle responding to an emergency call).

Preemption is traditionally used at railroad crossings and at signalized intersections for emergency vehicles where a very high degree of priority is warranted for safety and performance reasons. For example, objectives of emergency vehicle preemption[1] include reducing response time to emergencies, improving safety and stress levels of emergency vehicle personnel, and reducing accidents involving emergency vehicles at intersections. When a traffic signal is preempted there is no consideration for maintaining the existing signal timing plan such that coordination can be maintained between adjacent traffic signals. Preemption uses a special timing plan, requiring the traffic signal controller to transition out of and back into the coordinated operation of the normal signal timing plan. Transit Signal Priority attempts to provide some priority service opportunities within the coordinated operation of the traffic signal. This allows the objectives of priority to be considered without significantly impacting other traffic.

These objectives[1] include improved schedule adherence, reduced delay and improved transit efficiency, contribution to enhanced transit information, and increased road network efficiency. Improving schedule adherence can reduce waiting time and passenger anxiety by lessening the extent to which riders need to add additional time as a contingency (e.g., catching an earlier bus, leaving for bus stop early) in order to arrive on time at their destination. Reduced delay—but not elimination of delay – to transit vehicles can enhance transit efficiency as well as potentially improve schedule adherence. TSP may also facilitate the provision of enhanced rider information by enabling real-time detection information to be used for other purposes. Any resulting increases in ridership and the higher occupancies on transit vehicles can also contribute to the significance of reductions in transit vehicle delay. Since transit service is typically much more frequent than rail or emergency vehicle service, use of priority rather than preemption allows the system to maintain a higher level of performance. It should be noted that preemption could be applied to transit priority, but the benefits and impacts of this action must be carefully considered.

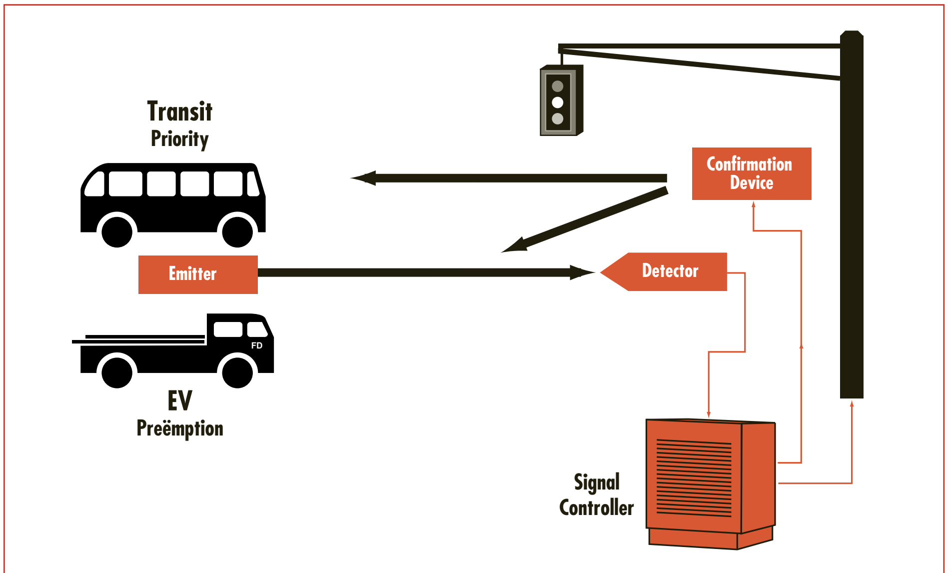

Figure 1: Priority and Preemption Example at Local Intersection Level[2]

2.2.2 Priority Treatments

There are several possible signal priority treatments possible to provide priority to the transit vehicles. These include:

- Passive Priority
- Active Priority
  - early green (red truncation)
  - green extension
  - actuated transit phase
  - phase insertion
  - phase rotation
- Adaptive/Real-Time Control

Passive Priority

Passive priority operates continuously regardless of whether transit is present or not, and does not require a transit detection/priority request generation system. In general, when transit operations are predictable (e.g., consistent dwell times), transit frequencies are high, and traffic volumes are low, passive priority strategies can be an efficient form of TSP. One such passive priority strategy is establishing signal progression for transit. The coordination plan would account for the average dwell time at transit stops. Since the signals are coordinated for the flow of transit vehicles and not other traffic, other traffic may experience unnecessary delays, stops, and frustration (i.e., phone calls to the signal operators). Therefore, the volume of traffic parallel to the TSP movements should also be considered with a transit signal progression approach. It is important to note that other "passive" improvements may also be of benefit to transit. Operational improvements to signal timing plans, such as retiming or coordinating signals on a corridor, may improve traffic flow and reduce transit travel time as well.

Active Priority

Active priority strategies provide priority treatment to a specific transit vehicle following detection, or a priority request by the vehicle/system. Various types of active priority strategies can be used.

An **early green** strategy shortens the green time of preceding phases to expedite the return to green (i.e., red truncation) for the movement where a TSP-equipped vehicle has been detected. This strategy only applies when the signal is red for the approaching TSP-equipped vehicle.

A **green extension** strategy extends the green time for the TSP movement when a TSP-equipped vehicle is approaching. This strategy only applies when the signal is green for the approaching TSP-equipped vehicle. Green extension is one of the most effective forms of TSP since a green extension does not require additional clearance intervals, yet allows a transit vehicle to be served and significantly reduces the delay to that vehicle relative to waiting for an early green or special transit phase. An early green and a green extension strategy may be applied together to maximize the time within the signal cycle in which transit would be eligible for priority. However, early green and green extension should not be given in the same signal cycle in order to maintain timing coordination.

Actuated transit phases are only displayed when a transit vehicle is detected at the intersection. An example would be an exclusive left turn lane for transit vehicles. The left turn phase is only displayed when a transit vehicle is detected in the lane. Another example would be the use of a queue jump phase that would allow a transit vehicle to enter the downstream link ahead of the normal traffic stream. A queue jump phase shows a signal (such as a white bar) that is intended for the transit vehicle only and allows the transit vehicle to move ahead of the rest of the traffic that is waiting for a green at the intersection. An application might be the location of a near-side bus bay; the queue jump phase allows the bus to re-enter the mainstream lane before the general traffic is given a green phase to move forward.

When a special priority phase is inserted within the normal signal sequence, it is referred to as **phase insertion**. The phase can only be inserted when a transit vehicle is detected and requests priority for this phase. An example would be the insertion of a leading left-turn-only phase for transit vehicles entering an off-street terminal on the opposite side of the street that would only be provided when requested by the presence of a transit vehicle.

The order of signal phases can also be "rotated" (i.e., **phase rotation**) to provide TSP. For example, a northbound left turn phase could normally be a lagging phase, meaning it follows the opposing through signal phase. A northbound left turning bus requesting priority that arrives before the start of the green phase for the through movement could request the left turn phase. With the phase rotation concept, the left turn phase could be served as a leading phase in order to expedite the passage of the transit vehicle.

Adaptive Priority/Real-Time Control

Adaptive/real-time TSP strategies provide priority while simultaneously trying to optimize given performance criteria. The criteria may include person delay, transit delay, vehicle delay, and/or a combination of these criteria. These strategies require the pre-existence of an adaptive control system which continuously monitors traffic conditions and adjusts control strategies; its application to TSP continuously optimizes the effective timing plan based on real-time, observed data, including transit vehicle location. They typically require early detection of a transit vehicle in order to provide more time to adjust the signals to provide priority while minimizing traffic impacts. Adaptive systems also often require the ability to update the transit vehicle's arrival time, which can vary due to the number of stops and traffic conditions. The updated arrival time can then be fed back into the process of adjusting the signal timings.

2.2.3 Signal Recovery/Transition

Although it is not a particular TSP strategy, it is important to mention the role of traffic signal recovery[3]. The TSP "process" does not always end when the transit vehicle passes through the signal. In instances where the transit vehicle must be detected before priority is granted, most signal controllers implement a recovery operation where the signal transitions back to normal signal operation (e.g., coordination), or compensates signal phases that were cut short or skipped during the priority event. Although the recovery method is critical, it is most important to be aware that it can have a dramatic impact on traffic operations following a priority event. Transition back into coordination can take several cycles and is one reason preemption has not been a popular choice as a TSP strategy. Implementation of signal recovery plays a vital role in mitigating impacts on cross streets and helping to maintain coordination along the corridor.

2.2.4 Unconditional and Conditional TSP

Unconditional Priority

There are generally two different approaches to providing TSP. The first is to provide priority to all transit vehicles approaching equipped intersections. This is called **unconditional priority**, and this approach can be used to maximize the travel time savings to transit vehicles. In its more basic form, TSP is accomplished by detecting the approaching transit vehicle upstream of the signalized intersection and sending a "check-in" priority request call to the traffic signal controller (as in Figure 1). As the transit vehicle moves through the intersection, it may be detected once again with a "check-out" message being sent to the controller to clear the request for priority from the controller system. Depending on when the transit vehicle is detected and generates a request for priority within these "check-in" and "check-out" detection zones relative to where the traffic signal controller is in its cycle, the transit vehicle may or may not trigger a transit signal priority event. Most TSP applications currently utilize this simple approach to vehicle identification, often using relatively less costly but more proven technology. In this case, the data transmitted is of a very simple nature (e.g., "I am a bus within the detection zone, and I request priority"). The request is transmitted to the traffic controller, assessed, and, if within user-specified criteria, is granted incremental extensions of the green phase servicing the transit route up to a maximum limit or a truncation of the corresponding cross street red phase. Such truncations would respect any minimum green times governed by pedestrian crossing constraints in effect to respect all minimum safety constraints.

Conditional Priority

An alternative approach, called **conditional priority**, uses more sophisticated systems, such as automated vehicle location (AVL) systems to determine if the transit vehicle is behind schedule, or meets other pre-defined conditions, before communicating to the traffic signal controller in order to request priority. This approach has been made feasible by recent technological developments.

If the transit property has implemented a more advanced AVL system (and a growing number have), the AVL system provides a means for knowing the degree of adherence of the transit vehicle to its pre-determined schedule. Using AVL, and a more comprehensive identification/data transmission system, the transit vehicle can communicate a more specific message to the traffic signal controller (e.g., "I am a bus that is behind schedule and request priority"). On the other hand, if the on-board (or central AVL) computer determines that the bus is ahead of its schedule as the bus approaches the intersection ("running hot"), or within certain pre-determined parameters (e.g., not more than 3 minutes behind), no request for TSP will be made to the traffic signal controller. Conditional priority means that a smaller percentage of transit vehicles are requesting priority, but may be viewed as preferable if the emphasis is more on improving service reliability than on decreasing absolute travel time. Conditional priority however requires a more advanced (and more costly) system, such as AVL, and tight integration of system logic and equipment among the vehicle systems, the transit management systems, and the traffic signal (and/or traffic management) systems.

2.2.5 System Components

Figure 2 illustrates the main elements of a TSP system and alternative communications scenario. There are three main systems involved:

- The Priority Request Generator (PRG) system that generates the request for priority. Alternative approaches exist for generating a request for priority: wayside detection of the transit vehicle by the local traffic signal control system (PRG-5); direct active communication from the transit vehicle (PRG-4); or communication via the transit and/or traffic management centers based on knowledge of transit vehicle location (PRG-1, 2 or 3).
- The communication system that links the components and systems.
- The Priority Request Server (PRS) contained within the traffic signal control system that receives and processes the request for priority at the intersection(s).

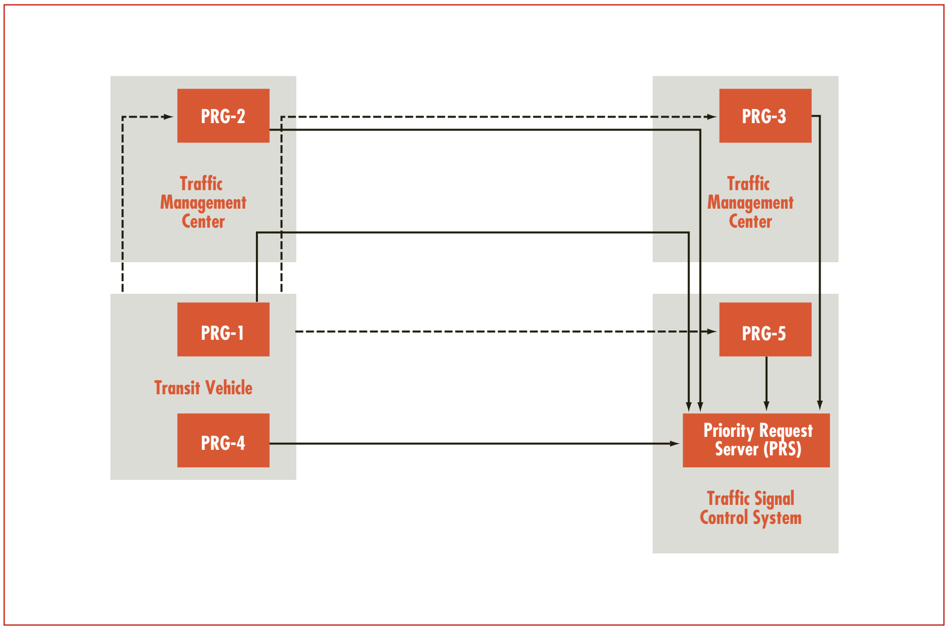

Figure 2: TSP Main Systems and Component

Note: The PRG can be located in either the transit vehicle, the transit management center, the traffic management center, or in the traffic signal control system equipped with wayside transit vehicle detection.

Transit Vehicle Detection/ Priority Request System

The Transit Vehicle Detection/Priority Request system is responsible for initiating requests for priority based on predefined criteria, which may be unconditional (e.g., priority automatically requested for all buses on certain routes) or conditional (e.g., priority requested for buses behind schedule by more than five minutes). Depending on the approach selected[4], the detection/priority request system may be based at the local intersection level or at the management center level. A transit vehicle may be detected at the local intersection level through a combination of an on-board transmitter and a receiver on the intersection approach. For detection at the network level, a transit vehicle may communicate with a transit or traffic management center, providing its location directly. When a priority request is generated, either at the intersection or network level, it may be forwarded directly to the local intersection controller or first pass through a central management center for approval and/ or processing.

Communications System

The communications system for TSP includes the provision of detection/ priority request information from transit vehicles to the local intersection or to transit and traffic management centers, and, if a management center is used, from center-to-center and center-to-intersection as applicable. In addition, the TSP system should include a mechanism for capturing data related to TSP utilization, for off-line analysis and refinement of strategies. This will require additional communications from the individual intersection controllers to the data archiving server(s) at the traffic and/or transit centers or contracted suppliers.

Traffic Signal Control System

The traffic signal control system is responsible for acting on the priority request and making any applicable changes to the signal indications via the local traffic signal controller. For a simpler system, the local traffic signal controller may be able to perform this function completely, while in other cases, a centralized traffic signal control system arbitrates the request prior to directing the local controller to take applicable action. Depending on predefined parameters, the traffic signal control system may or may not make actual changes to the signal indications. For example, if a local policy limits the number of priority activations to one per cycle, a second priority request received by the traffic signal control system would not result in further changes to the signal indications. The traffic signal control system is also responsible for ensuring that higher priority requests (e.g., emergency/railroad preemption) override other requests in order of priority.

Further discussion on TSP system components is included in Section 5.0, which covers TSP design implementation issues. However, it should be noted here that an important issue relating to the system components is that of standards, including the development of the National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) and associated Transit Communications Interface Profile (TCIP). By establishing standards for interactions between the system components, these efforts may help to make TSP implementation easier and/or less expensive. NTCIP Standard 1211, "Object Definitions for Signal Control and Prioritization", describes the interfaces with the signal control system. NTCIP 1211 defines four scenarios for transit signal priority operations based on the location of the transit Priority Request Generator (PRG) and the path used to get to the traffic signal system's Priority Request Server (PRS). The PRG can be located in the transit vehicle and communicate directly to the PRS in the controller as is common to date, or be located in either the vehicle, the transit management center, or the traffic management center, and communicate through the transit and traffic centers, as in more sophisticated centralized approaches. (All four scenarios are variously represented in Figure 2).
An effort is currently being undertaken by the American Public Transportation Association (APTA) to develop the corresponding TCIP standards from the transit perspective. The results of both efforts are expected to be available in the near future.

3 TSP Benefits & Costs

3.1 Benefits

Several benefits are anticipated from implementing a TSP system. These benefits typically include: reduced transit travel times, improved transit schedule reliability, reduced stops which leads to reduced wear and tear on equipment, less pavement maintenance and increased rider comfort, reduced emissions, and ultimately, an increased attractiveness of transit created by an increased competitiveness to the single-occupancy automobile. Some value-added benefits of the TSP system can also exist which are difficult to quantify (e.g., potentially using the TSP system for a fuel management system). Besides the benefits, TSP systems may also have negative impacts. One of the most commonly cited impacts is the potential increase in traffic delay on side streets.

Transit vehicles spend an average of 15% of their trip time waiting at traffic signals. By example, significantly reducing this wait by 40% on average would reduce a 60-minute round trip to 55 minutes, providing a more competitive service. A key point is that if this route requires a 5-minute headway, only 11 buses are required to support that interval, compared with 12 under the 60-minute trip length. Reduced vehicle and operator costs contribute toward a favorable return-on-investment. However, in order to achieve these savings, it is necessary that the reduced travel time be consistent. Since bus trips are scheduled in advance, the allocated running time may only be shortened if the same trip consistently takes less time[5].

In at least one study, the benefit/cost ratio associated with such reductions from deploying TSP was found to be approximately 2:1 over a 10-year operating period, giving a payback period of approximately three years. Note also that a reduction in the number of transit vehicles used means that a decrease in pollution emissions can be achieved as well.

Successful implementation of TSP has been practiced in Europe since 1968. The European philosophy to TSP is generally more aggressive and intended to provide a high reward for transit vehicles and passengers compared to other vehicles. Zurich and Amsterdam have a majority of intersections enabled for TSP. Installations in England and France have shown a six to 42% reduction in transit travel time, with only 0.3 to 2.5% increases in auto travel time.

In North America, Los Angeles, Toronto, Portland, Seattle, Tacoma, Chicago, and others, have TSP installations in place (see Appendix 1). Other communities such as Albany, Salt Lake City, Houston, Montreal, Broward County, and Santa Clara Valley have TSP projects in the development or deployment stages. In fact, TSP is becoming increasingly important with the growing interest in Bus Rapid Transit (BRT) systems; 14 of the 17 BRT consortium members are incorporating TSP in their designs.

The potential benefits from TSP for reducing transit signal delay, and improving travel times and reliability are encouraging TSP deployment across the continent. In Toronto for example, average transit signal delay reductions of up to 46% using TSP has justified expansion to over 350 signalized intersections (15% of total) along four bus and six streetcar routes, all in mixed traffic. Other TSP deployments include a two-mile stretch in Cicero, IL on Cermak Road that is the site of an Illinois Department of Transportation demonstration using wire loops at 10 signalized intersections. Suburban PACE buses, using transponders and absolute TSP, realized an eight-minute trip time versus 12 minutes before TSP (a 33% reduction). In Los Angeles, two projects demonstrated application of TSP in conjunction with the introduction of Metro Rapid, a Bus Rapid Transit system, at approximately 100 signals along each corridor (14-16 miles)[6]. Results indicated an average 8% decrease in overall bus running time, and a 33-39% reduction in bus delay at signalized intersections.

Studies associated with the deployments[7,8,9] have shown that there has been little or no impact on the travel times of other motorists along streets operating with TSP, when effectively designed. In fact, the deployment of TSP may positively benefit vehicles traveling in the same direction of the transit vehicle by introducing signal coordination, or momentarily widening the green band for that approach to the traffic signal. As such, some study results confirmed modest improvements for the balance of traffic flow along transit routes with TSP. Studies have shown there to be no general pattern of change to pedestrian delay as a result of the implementation of bus transit priority, with any increases or decreases being minimal.

Unfortunately, a limited amount of before and after data exists for TSP systems. Results from a limited number of case studies are summarized in Table 1. These results are based only on field data. A number of before and after studies have also been performed using simulation models[10,11]. It is important to note that the results in Table 1 will vary based on several factors including system design (i.e., transit detection system and signal control equipment), TSP strategy, type of data collection procedure, traffic volumes, and the combination of implementing TSP with other preferential treatments (e.g., queue jumps, exclusive transit lanes, etc.).

★ Lessons Learned

- In general[12], the case studies reveal that implementing TSP results in:
  - Reductions in transit travel times, transit delay, stops, and schedule unreliability; and
  - Minor impacts to cross-street traffic and buses.
- TSP strategies with higher customer and operational benefits for transit attempt to provide consistently faster and/or less variable travel times and improved on-time performance[5].
- Impacts are difficult to measure in the field when differences between before and after TSP data are small.
- It is difficult to control before and after field conditions when measuring the impacts of TSP. Variations (e.g., traffic volume changes, incidents, weather, holidays, and prompt arrival of data collection personnel) can substantially impact results. Although it is possible to turn off signal priority to gather data and turn it back on to compare, this process can be upsetting to the general public drivers who regularly traverse an intersection, and therefore is not ideal. Simulation can help predict the results and measure the impacts.

3.2 Costs

An even more limited amount of information exists regarding TSP costs. Typically, cost data is reported in terms of average dollars per intersection. It is important, however, to make sure the cost data is comparable. For example, some cost data may only include roadside equipment while other data include the cost to equip the buses. In addition, some systems are more expensive in terms of roadside equipment, while others use more expensive on-board equipment. Therefore, making a comparison of cost per intersection is very difficult because it then depends on the ratio of buses versus intersections. Furthermore, costs can vary substantially based on the desired functionality of the system. For example, if the desire to grant priority is co-managed between the signal engineer and the transit operator, this design (for institutional reasons) may cost more than one where the decision to grant priority is left to one agency.

Factors that can affect cost include:

- Design and desired functionality of TSP system (e.g., conditional priority is more complex than unconditional priority because of the requirement to integrate with systems that assess real-time schedule adherence or other conditions)
- Type of roadside and on-board equipment, and any planned upgrades thereof
- Developing new equipment vs. use of off-the-shelf equipment
- Upgrading signal controller firmware to provide TSP
- Operations and maintenance of equipment
- Training personnel in how to program/use TSP equipment
- Trenching required to access power and to place in-road detection equipment
- Ease of installing on-board equipment
- Pilot study(ies) and before/after studies
- Time needed to establish interagency relationships and form agreements

Based on a very limited amount of reported data, costs have ranged between $8,000 and $35,000 per intersection. This cost range varies greatly due to the differences in system designs (and thus functionality) and items included in the costs. It is possible that costs for other existing systems as well as planned systems will fall outside of this range.

Location	Transit Type	No. of Intersections	TSP Strategy	Benefit/Impact
Portland, OR[13] Tualatin Valley Hwy.	Bus	13	early green, green extension	• Bus travel time savings of 1.7 to 14.2% per trip • 2 to 13 seconds reduction in per intersection delay • Up to 3.4% reduction in travel time variability
Europe[14,15]	Bus	Five case study sites	Various	• 10 seconds/intersection average reduction in transit signal delay • 40 to 80% potential reduction in transit signal delay • 6 to 42% reduction in transit travel times in England and France • 0.3 to 2.5% increase in auto travel times • 1 to 2 year payback period for installation of transit priority systems
Seattle, WA[16,17] Rainier Avenue	Bus	20	early green, green extension	• 24% average reduction in stops for TSP eligible buses • 5-8% reduction in travel times • 25-34% reduction in average intersection bus delay for TSP eligible buses • 40% reduction in critically late trips (trips not completed before next trip scheduled start) • Life cycle benefits are $15,000 service benefit per intersection and $40,000 passenger benefit per intersection (over 10 years life)
Sapporo City, Japan[18] Route 36	Bus	unknown	unknown	• 6.1% reduction in bus travel time • 9.9% increase in ridership • 7.1% reduction in bus stops at signals which resulted in a 20.8% reduction in stopped time
Toronto, Ontario[19,20]	Street car, Bus	350	early green, green extension	• Up to 46% reduction in transit signal delay • 10 street cars removed from service • 4 buses removed from service in 2 initial corridors • Payback less than 5 years • Cross street traffic not significantly affected
Chicago, IL[21] Cermak Rd.	Bus	15	early green, green extension	• 7 to 20% reduction in transit travel time depending on time of day, travel direction • Transit schedule reliability improved • Reduced number of buses needed to operate the service • Passenger satisfaction level increased since TSP was implemented • 1.5 second/vehicle average decrease in vehicular delay (range: +1.1 to –7.8) • 8.2 second/vehicle average increase in cross-street delay (range: +0.4 to +37.9)
San Francisco, CA[22]	LRT and Trolleys	16	early green green extension	• 6 to 25% reduction in transit signal delay
Minneapolis, MN[23] Louisiana Ave.	Bus	3	early green, green extension, actuated transit phase	• 0 to 38% reduction in bus travel times depending on TSP strategy • 23% (4.4 seconds/vehicle) increase in traffic delay • Skipping signal phases caused some driver frustration
Los Angeles, CA Wilshire & Ventura Blvds.[6,24]	Bus	211	early green, green extension, actuated transit phase	• Introduced as part of Metro Rapid BRT • 8% reduction in average running time • 33-39% decrease in bus delay at signalized intersections • Minimal impacts to cross street traffic: average of 1 second per vehicle per cycle increase in delay • TSP did not change the traffic Level of Service
Pierce County, WA Pacific Ave and 19th St. corridors[25]	Bus	42	signal coordination, early green, green extension, low priority preempt	• Initial deployment in two corridors involving both signal coordination and TSP • Signal coordination reduced total signal delay 18-70% for general purpose traffic, and 5-30% for transit • TSP reduced transit signal delay an additional 20-40% beyond signal coordination • TSP had little impact on traffic progression

Table 1: TSP Benefits and Impacts—Case Studies

Planning for Deployment of Transit Signal Priority 4

Planning

4.1 Retrospective

Until recently, widespread installation of the TSP strategy in North America had not occurred for various reasons, including:

- Lack of broad awareness of the technical feasibility and cost-benefit
- Lack of proven, accurate, reliable, and cost-effective detection products
- Limited installations of vehicle location systems by transit properties
- Absence of standards
- Traffic signal controllers did not have the capability to support TSP
- Traffic signal controller software did not have the ability to support TSP
- Costs associated with deploying and maintaining traffic signal controllers, transit vehicle, and TSP was cost prohibitive
- Institutional, planning and partnering issues between the transit properties and the local transportation departments (who often operate the traffic control signals)

Although TSP is a widely accepted and utilized technology in Europe, its use in North America has been slower to develop. Due to the limitations with technology, there were few early efforts to implement TSP in parallel with the early development of Automatic Vehicle Location (AVL) Systems. The technology was still maturing, primarily with respect to feasible transit vehicle detection methods.

During the 1980's and early 1990's a number of transit properties implementing Light Rail Transit (LRT) lines worked with their local traffic departments to provide priority control for their the LRT vehicles. Often this form of TSP was in conjunction with grade crossing gates and controls. This allowed both improved safety and enhanced priority for the LRT vehicles. However, there were also advances being made in the deployment and evaluation of TSP for use with buses used as streetcars as well as buses in mixed traffic at signalized intersections

TSP for buses has been slower to develop for a variety of reasons, as previously mentioned. However, the situation has evolved considerably in recent years, and there is growing momentum to implement TSP for both buses and streetcars. This is clearly illustrated in a survey conducted by the Canadian Urban Transit Association (CUTA) in December 1999 of all transit properties in North America operating over 100 vehicles[7]. Of these, 75% responded as follows:

- To date, 36% of transit properties reported having TSP in use in at least one intersection, and 26.7% reported benefiting from transit-only signals or phases. However, only a handful of transit properties benefit from TSP at a large number of intersections. In fact, the majority of intersections currently equipped for this purpose can be found in just three transit service districts.
- However, the situation is changing rapidly: 44% report TSP projects underway, and 54.7% have TSP projects in the planning stage.
- Furthermore, the number of intersections to be equipped with transit signal priority has the potential to more than double by the year 2003.
- At this point, 70% of transit properties, with over 100 surface vehicles, are either implementing or planning TSP projects

Several factors may explain this growing interest:

- The technology is clearly maturing as experience grows.
- Awareness of Intelligent Transportation Systems (ITS) and applications of advanced technologies with transit systems is growing in both the traffic engineering and transit communities, which is increasing knowledge about TSP.
- TSP can provide a highly cost-effective approach for communities wishing to improve transit operations.

Furthermore, TSP is a technology that is not only applicable to large transit properties and large traffic signal control systems, but is also scaleable to suit smaller operations as well.

4.2 Planning the Transit Signal Priority System

To aid others in planning TSP, practitioners have identified the basic steps to success. Based on knowledge and experiences established on both a technical as well as a policy level, the following recommendations are proposed for agencies considering a TSP project:

- Identify a champion.
- Utilize the Regional ITS Architecture (or National ITS Architecture if the regional architecture has not been developed) to frame the planning process for TSP and to help identify stakeholders.
- Identify the stakeholders internal and external to your organization.
- Establish a multi-department team of leaders with responsibility to carry out the project within your agency or jurisdiction.
- Establish a regional team to guide the project from a regional perspective.
- Establish the goals and objectives. Set measurable levels of performance in these goals.
- Identify funding opportunities.
- Make sure that system objectives and requirements are clearly articulated in requests for bids.
- Include considerations of pre-installation testing criteria and process as part of TSP planning process.

This section explains in some detail the issues surrounding the following areas related to transit implementation planning:

- Stakeholders: Roles & Responsibilities
- Interagency Relationships
- Regional ITS Architecture
- Regional Management and Coordination of TSP Issues
- Implementation Planning
- Procurement

4.2.1 Stakeholders: Roles & Responsibilities

Roles and responsibilities, though common from place to place, are not always identified and agreed upon early in the planning phase of this very comprehensive project implementation process.

Stakeholders and their roles and responsibilities throughout the planning, design, and implementation of a transit signal priority (TSP) system are usually similar from one metropolitan area to the next. The core stakeholders nearly always include transit agencies and public agencies that are responsible for traffic signal operations since the TSP system will affect their operations on a daily basis. Although these two agencies are at the core, the importance of including other agencies and decision-making entities cannot be overstated. These agencies include emergency services, metropolitan planning, federal agencies, public officials, and the general public. General descriptions of typical stakeholders and their roles and responsibilities are provided below. It is important to note, however, that these are only general descriptions and that there are "no set rules" regarding who should be involved and what their roles and responsibilities should be.

Transit Agencies

Transit agencies typically champion the development of a TSP system although recently the traffic signal agencies are taking more of a leadership role. Within the transit agency, there are usually at least three separate groups involved in developing a TSP system: (1) planning, (2) operations, and (3) scheduling. Their roles and responsibilities typically include:

- leading the project through the planning, design, and implementation phases
- developing and fostering relationships with the other stakeholders
- communicating issues, concerns, and interests of the transit agency
- determining when TSP is to be requested and how frequently it can be requested
- acquiring funding
- equipping buses with TSP equipment (i.e., identifying buses eligible for TSP)
- identifying potential routes for TSP
- revising schedules based on TSP's impact on travel times
- overseeing pilot studies/before and after studies
- reviewing TSP operations and implementing management and control strategies to improve service

Traffic Engineering/Signal Systems Operators

Traffic engineers have critical roles throughout all phases of the life-cycle of a TSP system. Their issues, concerns, and perspectives need to be heard, understood, and addressed early in the process. Within the signal operating agencies, the signal engineers and maintenance staff are the ones typically involved throughout the TSP development process. Examples of responsibilities or concerns are listed below and can vary from one location to another:

- communicating issues, concerns, and interests of the signal operators
- determining when TSP is granted, how frequently it is granted, and how much time is given to provide TSP
- interconnecting the roadside TSP equipment (that detects a TSP-eligible vehicle) with the signal controller
- ensuring the TSP functionality of the signal controller
- integrating TSP architecture into existing traffic management system architecture
- maintaining roadside TSP equipment

Emergency Service Providers

Emergency service providers (e.g., emergency medical services, fire/rescue, etc.) in numerous metropolitan areas use emergency vehicle preemption systems to expedite their response to incidents. These systems are not identical to TSP systems, but are similar in a number of ways. Opportunities may exist to integrate these systems into one system thus reducing capital, operations, and maintenance costs. The required functionality of each system and timing of system deployment, however, may preclude the installation of a single system.

It is also important to mention the political weight that most emergency service providers carry. Safety is a top priority of elected officials. Therefore, if it possible for the transit agency to share the championing of a joint TSP and emergency vehicle preemption system with the emergency service providers, there is a greater chance of receiving support and funding for the system.

Metropolitan Planning Organization

Metropolitan planning organizations have a considerable amount of control over the funding of transportation projects within their region. To receive their support, transit organizations should involve the MPO to provide an understanding of the goals and potential benefits of the project.

Federal Agencies

Federal agencies (e.g., Federal Transit Administration-FTA and Federal Highway Administration-FHWA) bring experience with similar projects from around the country and thus have a good idea about what works and what does not. Both FTA and FHWA staff are extremely knowledgeable of potential funding sources and can make technical assistance and training available. In addition, the federal agencies play a role in ensuring that applicable standards and architecture issues are addressed in TSP projects.

Public Officials

Public officials (e.g., city council, mayor, etc.) are stakeholders in a TSP project since they control a portion of the funding. These officials are custodians of public funds. As such, they need to be informed about the benefits derived from the expenditure of public funds. They also need to be able to justify the expenditures to their constituents. Their expectations also need to be managed and not oversold on the benefits of TSP.

Public

The public is also a stakeholder. They are the ones that directly benefit from the system. They also want to know how their tax dollars are being spent. The public can be involved through a variety of mechanisms. For example, information about the TSP project could be disseminated through flyers on the transit vehicle or a web site. In communities where the public is more active, open houses or community meetings may be more appropriate methods of informing the public about goals and benefits of the project.

4.2.2 Interagency Relationships

Interagency relationships must be developed and nurtured in order to accomplish successful and mutually beneficial results. The most critical relationship is that between the transit agency (or agencies) and the signal engineer(s). The most critical factor in developing this relationship is gaining respect for each other's goals, objectives, capabilities, and limitations.

One consideration in developing good working relationships is whether initial contact should be made at an upper management level or at a lower staff level. From the standpoint of maximizing buy-in and minimizing bureaucracy, the best place to start is at the staff level. However, the lack of enthusiasm of staff that are typically pressured with the details of day-to-day operations should not become a barrier to the process. The project champion needs to present the project as an opportunity to address a broad spectrum of needs to accomplish the TSP objectives.

In some areas of the country, albeit probably few, the relationships may already exist; and the level of comfort among individuals involved may be high enough to jump right into the planning process. In other areas, perhaps the individuals know of each other, but have had no reason to collaborate on projects of this nature. Still in others, the relationship is non-existent. Perhaps in these situations, an educational strategy is the first step in developing those relationships. Both transit and traffic signal professionals must sit down and understand each other's "language."

As the transit agency is usually the lead in implementing TSP, it might be worthwhile putting together a package of information for discussion early on in the planning process. The document you are reading can serve as an introduction to TSP. This package could also include the latest in techniques, products and benefit statistics from successful implementations of transit priority. Likewise, the signal operators have expertise that is required and this expertise needs to be leveraged as well. A similar educational package should be presented to the transit agency. The educational process continues as each party becomes familiar with the other's operations, goals and objectives. The goals, benefits, costs, and other critical issues need to be understood by all team members.

★ Lessons Learned

- Open communication and understanding of goals and objectives are absolute key elements in the success of the transit priority system.
- Early identification of a champion is essential.
- Development of a cooperative partnership agreement between the different stakeholders early in the planning process allows the project team to focus on the issues.
- There are no set rules on which stakeholder should and should not be involved. Embracing more stakeholders reduces the risk of unexpected opposition in later stages of the project. Working with a wide variety of stakeholders is time-consuming and sometimes difficult in the beginning. But the result of gathering a wide range of input in the beginning is a much more successful and widely accepted project in the long run. The investment is worthwhile.
- In some metropolitan areas where multiple transit agencies exist, the transit agencies have partnered to develop a regional TSP system based on a common system architecture.
- An education effort between transit and traffic personnel is a good first step in helping each group to understand the "language" and key issues of the other group.

4.2.3 Regional Management and Coordination of TSP Issues

Because of the complexity and potential need for changes in agency policy, TSP project implementation could benefit from a two-tier management structure.

Once stakeholders are identified, a mechanism is needed for them to meet regularly, make decisions, and manage and resolve issues with TSP. A two-tier committee structure consisting of a technical committee and policy committee has been used. The agencies represented on each committee are the same. The roles of the individual representatives, however, are quite different.

The **technical** committee typically includes staff that is responsible for designing, implementing, operating, and maintaining the TSP system. They are the ones that delve into the details. Their responsibilities can include:

- developing and refining operational strategies and procedures
- providing the opportunity for all stakeholders to provide input
- preparing written agreements like (1) a TSP operations manual/specification that defines, for example, whether the TSP strategy can skip signal phases and the maximum reduction in cross-street green time; and (2) operations and maintenance agreements
- identifying corridors to implement TSP
- developing the evaluation criteria[26] for a pilot study
- selecting a specific TSP technology
- reviewing operations and making changes to address problems and to improve performance

The **policy** committee sets policy and resolves issues that are cross-cutting or that cannot be addressed by the technical committee. This committee typically includes upper level management (e.g., city manager or city engineer, general manager of the transit agency, etc.) within a public agency or even elected officials. The policy committee will develop operating agreements, and will often formalize or adopt procedures and recommendations made by the technical committee. The policy committee is often responsible for providing funding, or identifying funding opportunities and policies.

4.2.4 Regional ITS Architecture

If a Regional ITS Architecture has been written it can serve as an excellent tool in several respects. If a project is using federal funds, compliance with the Regional or National ITS Architecture is required. The architecture helps tremendously in the identification of stakeholders. Sometimes transportation professionals overlook the importance of communicating with regional stakeholders such as emergency 911 and fire fighters. The regional architecture should identify those stakeholders who have an interest in communicating with the traffic and transit agencies on issues such as TSP. Operational agreements in the Regional ITS Architecture can help ensure the continued successful operation of the TSP system after it is implemented. Additionally, the architecture can be used as a guide for integration with other ITS projects.

Information on the Regional ITS Architecture may be found by contacting the local metropolitan planning agency or the regional FTA or FHWA office. In the absence of a regional architecture, the National ITS Architecture can serve as a helpful guide. There is more information on the architecture in the section on implementation planning.

4.2.5 Implementation Planning

TSP projects are prime candidates for systems engineering processes because of the core purpose—the need to integrate major ITS systems. Without the proper planning, implementation can be exceptionally difficult.

A TSP project is complex and an integral part of regional Intelligent Transportation Systems integration. As such, it should follow a systems engineering process to plan, develop, and support all of the life-cycle phases of the system. It should not be developed in isolation but rather be integrated with existing and planned systems of involved agencies. Developing a TSP system follows a series of steps that are similar to the implementation of other transportation technologies. For the most part, these steps involve planning, data collection, analysis (e.g., simulation or other), design, simulation (optional), implementation, operations and maintenance, ongoing collection of operational data, evaluation and refinement. An example of these steps is provided in Figure 3. Each step involves several decisions and a variety of stakeholders. The timeframe for this process can vary greatly depending on a variety of conditions like existing interagency relationships, funding, and technology procurement or development. Managing expectations of upper management and political officials is very important in the early planning stages. The planning process can be lengthy and officials are always anxious to carry out projects that can affect the "bottom line." Here, too, managing schedule expectations is important.

On the technical end, the systems engineering approach generally involves developing a concept of operations, user needs and requirements, conducting requirements analyses, identifying and defining interfaces, developing functional specifications, and defining the process by which the TSP system will be procured, installed, and tested before being deployed in actual operations. Many other processes the n take place in the development and integration phases of the system being implemented. The Federal Highway Administration has developed a course called Introduction to Systems Engineering (Course Number: 137024) offered by the National Highway Institute. See *http://www.pcb.its.dot.gov/* or contact your local FHWA or FTA office for more information. In addition, the International Council on Systems Engineering (INCOSE) is an excellent resource for information on this subject. See *http://www.incose.org/* for further information.

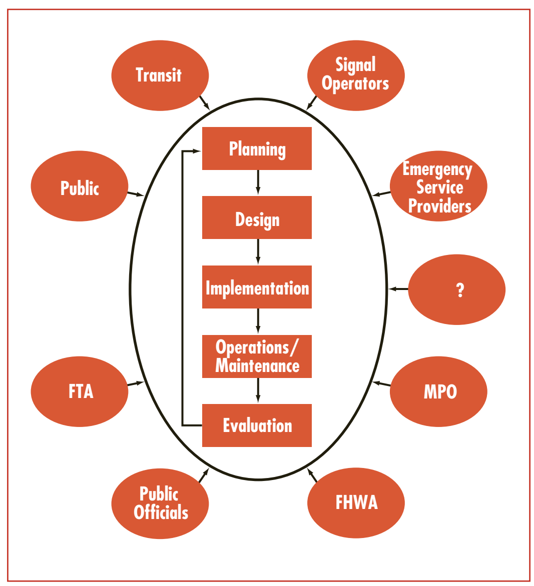

Figure 3: Steps and Stakeholders in TSP Deployment

Successful integration of a transit signal priority system requires tackling both technical and institutional issues. USDOT sponsored the development of the National ITS Architecture in response to such issues associated with ITS projects. The National ITS Architecture, as defined in the Transportation Equity Act for the 21st Century, is the common framework for ITS interoperability that defines:

(A) the functions associated with intelligent transportation system user services;

(B) the physical entities or subsystems within which the functions reside;

(C) the data interfaces and information flows between physical subsystems; and

(D) the communications requirements associated with the information flows.

The architecture, whose foundation is set in systems engineering principles, provides a common structure, technical and institutional, for the design of intelligent transportation systems, and it should be used as guidance in the development of transit priority systems. More information on the National ITS Architecture can be found on the ITS web site at *http://www.its.dot.gov/*.

The Transportation Equity Act for the 21st Century (TEA-21), enacted in 1998, requires that ITS projects receiving funding from the Federal Highway Trust Fund (including the Mass Transit Account) conform to the National ITS Architecture. A Rule and Policy were published by FHWA and FTA, respectively, in January 2001 which stipulate that the National ITS Architecture be used to develop a local "regional architecture" and that a systems engineering process be used implement ITS projects. The Rule and Policy, identical in content, describe the elements needed in the development of a regional architecture and the elements required in a systems engineering development process. Both components of the Rule and Policy aim to foster integration of Intelligent Transportation Systems, engage a wide range of stakeholders, and enable electronic information sharing. Traffic signal priority is a strategy that needs to be part of regional, integrated systems and should be included in regional architectures. For more information on architecture conformity, visit the USDOT ITS web site at *http://www.its.dot.gov/*.

It is possible that your region has already developed a Regional ITS Architecture which would be used rather than the National ITS Architecture. To find out if the regional architecture has been developed you should contact your local metropolitan planning organization or your local FTA or FHWA office.

★ Lessons Learned

- Time required to proceed through the TSP development process varies.
- The National ITS Architecture is an excellent tool to assist in the development of regional and project architectures.
- Because the planning process can be lengthy, try to avoid selecting the technology too early since the technology is changing rapidly.
- Be as thorough as time permits in research and preliminary analyses, and be realistic in determining potential outcome

4.2.6 Procurement

There are a multitude of contract mechanisms applicable for procuring intelligent transportation systems. No one method fits all cases, so use mechanisms that are appropriate and cost-effective for the need.

There are five elements, potentially, to be purchased or modified for the transit priority system:

- intersection equipment
- bus equipment
- communication system between the vehicle and intersection equipment
- central traffic signal management system
- transit management system

The first three elements are essential. The last two elements are optional and usually depend on characteristics of the existing systems. If the signal system is controlled or monitored from a central location, it is likely that the operator of the system will want to implement control and/or management functions at this level. If the transit agency has implemented automatic vehicle location, this element could also be integrated into the project.

In several cases of implementations that were studied, the transit authority was the procuring agency for the field equipment, including intersection and bus elements. The exception occurs when priority system equipment for emergency services is already in place at the intersection; but even so, modifications may still be necessary to implement this second priority function. The transit agency is also responsible for any transit management system modifications or integration necessary. The signal operator usually procures the services necessary to develop or modify the central traffic signal management system.

A common goal among system implementers is to hire one party to develop and integrate the system needed. If the relationships are strong enough and if it makes sense to do so, one agency could take the lead as the contracting agency. An interagency agreement or memorandum of understanding would be executed to facilitate this arrangement.

There are several types of contracts appropriate for transit priority project procurements[27]. These include fixed-price; time and materials; and cost-plus contracts. One or more contract types used in combination refer to a contracting approach[13]. Approaches applicable to TSP projects include engineer/contractor or design-bid-build; systems manager; design/build; design to cost and schedule; and build to budget. The pros and cons to each of these approaches are discussed at length in Volume 2 of The Road to Successful ITS Software Acquisition[28], Report No. FHWA-JPO-98-036. This 214-page paper can be downloaded from the USDOT Electronic Document Library *(http://www.its.dot.gov/welcome.htm)* using a browse search.

★ Lessons Learned

- If the project requires software development, some contracting mechanisms work better than others do. Fixed-price contracts are not recommended for this type of acquisition. Fixed-price contracts are, on the other hand, very appropriate for traditional purchases and installation of hardware in the field (typical construction contracts).

5 TSP Design/Implementation Issues

The implementation of a TSP system requires careful consideration of numerous design issues. Coordination of the installation of equipment on transit vehicles, transit operations and management procedures, communications technologies, traffic signal control equipment, and traffic signal management systems is complex. Ideally, a test corridor will be identified and the components of the system installed and tested before large-scale roll out. This will provide an opportunity to identify technical challenges, equipment issues, policy and procedure gaps, as well as to allow all of the stakeholders to gain some experience and understanding of the integrated systems.

5.1 TSP Implementation Parameters

There are many factors that affect the implementation of a TSP system. The following sections identify some of these factors, as they relate to 1) the roadway geometry and traffic signal system, and 2) the transit system.

5.1.1 Implementation Factors Related to Roadway Geometry and the Traffic Signal System

The factors related to the **traffic signal system** include:

- Roadway geometry
- Traffic volumes
- Traffic signal hardware and software
- Traffic signal operation
- Person delay
- Pedestrians
- Adjacent intersection/corridor operations
- Traffic agency signal operation policies and practices

Roadway geometry is one of the most important factors for the operation of any transportation system since it directly dictates transportation system capacity and types of possible operations. Roadway geometry is impacted by the type and level of surrounding land development. Surrounding development, among other factors, impacts the location and number of intersections, generates traffic in the area and dictates transit stop locations. Roadway geometry is usually the limiting factor in TSP implementation. For example, when two major arterials cross at an at-grade intersection, the geometry dictates that the through movements may not be served simultaneously by a signal; thus, a TSP implementation will face constraints in the ability to adjust signal timings without adversely impacting the operation of the other arterial.

Although **traffic volumes** vary constantly in any area, peak hours seem to be the most important time intervals to evaluate TSP. During peak hours, all networks and arterials are operating under constrained conditions with the greatest volume of regular traffic as well as transit vehicles. If a transit agency wants to achieve a cost reduction, which is generally achieved by eliminating one or more vehicles from operation and still maintaining the same schedule, it typically has to be accomplished during peak hours when the highest number of transit vehicles are in operation. The impacts of TSP on regular traffic are primarily dependent upon the volume of traffic traveling in the same direction as the transit route as well as the volume on approaches conflicting with the transit route.

Traffic signal hardware and software (also referred to as firmware) determine how TSP will operate. For any TSP project, one of the initial steps should be to evaluate the existing controllers and firmware to answer the following questions:

1. Can the controllers implement TSP?
2. Can the controllers implement the TSP functionality required by the operating agencies?

If the desired TSP functionality is not possible, new signal controller hardware and firmware will need to be purchased. There are generally three types of signal controllers available today: (1) NEMA, (2) Type 170, and (3) Advanced Transportation Controllers (ATC) (such as Type 2070). In general, the most common form of TSP implemented by the first two types of controllers is an early green/green extension for TSP-equipped vehicles. ATC controllers are relatively new and provide the greater computing power that may be necessary for more advanced types of TSP (e.g., adaptive/real-time systems that predict transit's arrival time and adjust the signal time to facilitate the passage of the transit vehicle while attempting to minimize traffic impacts).

A variety of firmware is available for each type of controller. The primary consideration is how the firmware implements TSP. With an initial TSP project, a policy is usually developed by the signal operators and transit agency that defines general functional requirements for TSP. The controller firmware has to be capable of adhering to this policy. Some examples of the functional requirements may include:

- specifying the type of TSP treatment provided (e.g., early green/green extension)
- designating permitted phase sequencing and skipping
- restricting the allowable percentage of reduction in green time for any movements
- maintaining all vehicle and pedestrian clearances
- maintaining traffic signal coordination

Traffic signal operation is dictated by the traffic agency policy and by the traffic signal system capabilities. One philosophy behind TSP control strategies is to operate traffic signals to minimize total person delay, an evolutionary step from current signal control strategies which serve to primarily minimize total vehicle delay.

Reducing **person delay** and improving transit schedule reliability are among the main goals of TSP. In order to achieve these goals, TSP performance is generally measured by comparing transit travel times, vehicle delay and person delay. The reduction in transit vehicle travel time is generally accompanied with a reduction in person delay, since transit vehicles usually have a significantly higher occupancy than automobiles. A delicate balance needs to be maintained between transit vehicle delay and other traffic delay in order to deliver a TSP system that is viewed as a success by all stakeholders. Person delay is one of the best measures to assess this balance. However, effective measurements of person delay can be challenging. Dynamic route choice by auto users may result in changes in delay due to diversion to alternate routes. In addition, the underlying demand for transit service should reflect potential for increased ridership, and in turn additional service, as a result of service quality improvements associated with TSP. Person delay measurements for a given bus should also consider that passengers waiting at a downstream stop are also subject to delay in waiting for its arrival. Although corridor/network wide data is important, intersection approach data has to be evaluated as well.

Pedestrians have a great influence on TSP operations at signalized intersections. In most instances, the time required for a pedestrian to safely cross the street at a signalized intersection limits the time available to provide TSP, and can decrease the responsiveness of certain priority treatments (e.g., early green), due to the necessity of waiting for the pedestrian phase to terminate before the priority phase can be activated. Importantly, the pedestrians are often transit customers—hence they require service at the same time as the transit vehicles. Delay for pedestrians should also be considered, as priority can potentially lengthen the maximum waiting time for pedestrians waiting to cross the priority corridor. The impacts of shortening pedestrian walk times should be evaluated on an intersection-by-intersection basis to investigate these impacts and institute appropriate mitigation measures (e.g., establish a maximum red time for pedestrians).

Adjacent intersection/corridor operations (e.g., cross-street progression) need to be considered when implementing TSP. The decision about which adjacent intersection/corridor to consider has to be made based on field conditions and characteristics of the traffic system operation. Impacts on traffic signal coordination should be examined with any TSP implementation plan.

Traffic agency signal operation policies and practices have to be evaluated in advance of implementing TSP. These procedures have been proven to be one of the most influential factors in determining the type and method of TSP that is ultimately implemented.

5.1.2 Implementation Factors Related to the Transit System

Similarly, the factors related to the **transit system** include:

- Transit system characteristics
- Transit stop location and design
- Existing transit agency hardware and software
- Transit agency operating policies and practices

The **type of transit system** will have an impact on the TSP implementation. For example, it is easier to implement a TSP system for rail-based than for roadway-based transit. Rail systems are generally located on a semi-exclusive right-of-way and therefore, the prediction of vehicle arrivals is much more precise because they are not impeded by other traffic. Less variability in the travel time from the point where the transit vehicle is first detected until it passes through the intersection improves TSP effectiveness. This is similarly true for bus systems with exclusive or HOV lanes.

Transit stops may need to be relocated to maximize the effectiveness of TSP. Far-side stops are generally more compatible with TSP. Near-side stops present some additional challenges that are generally related to where the transit vehicle should be detected. If the transit vehicle is detected upstream from a near-side stop, the dwell time at the stop needs to be considered in the TSP timings. In addition, if a queue of vehicles blocks the transit vehicle from getting to the near-side stop additional delay can occur and a more complex signal timing or phasing may be required to provide effective priority. It is important to consider the trade-offs between passenger benefits of near side stops and benefits of signal priority.

Existing transit agency hardware and software have a strong impact on the final elements to be implemented for the TSP system. This includes for example any AVL or passenger counting system that the transit agency may have that may be possibly used for detection and/or schedule adherence monitoring in association with conditional priority. Very careful evaluation of the existing systems has to be conducted to determine if they can be used, and if so, how they can be used for the TSP system. In general, two existing systems need to be evaluated: vehicle detection (used for automatic vehicle location) and communication. If existing systems cannot satisfy requirements of the TSP system, they need to be upgraded or replaced.

Similar to the traffic agency, **transit agency** operating policies and practices have to be evaluated in advance of any TSP implementation. In some jurisdictions, there are policies in place to give preference to transit, in order to encourage travelers to shift modes from auto to transit. These policies may give rise to TSP objectives which emphasize maximum reductions in transit delay subject to tolerable delays to auto traffic. Operating practices may also designate selected transit corridors or services to receive a higher level of service. These corridors may potentially receive a higher level of TSP while other roads might provide little or no priority to transit.

It is important to keep in mind that the expected impacts of signal priority vary by deployment[9]. Factors that effect potential benefits that are difficult to overcome include existing traffic levels of service, transit headways, and existing bus stop locations. Other factors, such as existing traffic signal controller functionality, are easier to deal with, but more expensive nonetheless.

★ Lessons Learned

- Roadway geometry, traffic volumes, traffic signal operations, pedestrians, adjacent intersections and corridors, type of transit system (light rail vs. bus), and transit stop locations influence the design and operations of a TSP system. These issues must be addressed on an intersection-by-intersection basis.
- Multiple types of priority treatments for differing environments may be more appropriate than trying to apply one solution everywhere. Not every intersection may have conditions appropriate for priority, so it may be desirable to deploy priority selectively at particular intersections.
- Assessing the TSP capabilities of the existing traffic and transit hardware/software is necessary. These capabilities, or lack thereof, will affect the budget and schedule for TSP implementation.
- TSP attempts to reduce effective person delay and improve schedule reliability.
- Far-side stops are generally more compatible with TSP. Near-side stops present additional challenges for designing and operating a TSP system. A balance between the benefits of each must be considered on a stop-by-stop basis.
- The operating policies of traffic and transit agencies are a significant factor in determining the design and operation of a TSP system.

5.2 TSP Main Sub-Systems

The main sub-systems of a TSP system were shown in Figure 2. This section discusses the implementation and design issues associated with the various TSP sub-systems.

5.2.1 Transit Vehicle Detection/Priority Request System

There are a number of detection technologies that can detect transit vehicles at a designated location on a route. Concerns relating to small tolerance accuracy, stability of the detection zone, reliability, as well as implementation, maturity and interchangeability of the technology, and maintenance costs, have resulted in the applicability of only a few transit priority detection technologies at this time. Transit routes that operate on an exclusive right-of-way can use any detection system, such as conventional induction loop detectors, optical emitters, radar detectors, video detectors, global positioning satellite (GPS)/AVL, and Radio Frequency (RF) tags among others since the detector does not need to discriminate between transit and other vehicles. For transit systems that share right-of-way with other vehicular traffic it is much more difficult to separate the transit vehicle from other vehicles and fewer detection technologies can perform this task, such as RF tags, optical emitters, infrared detectors, and GPS/AVL systems.

In general, each detection system has advantages and disadvantages. There is not a detection system that could be recommended for all applications. The selection of the detector system should be based on the answers to numerous questions including the following:

- What is the ultimate goal of the project?
- What kind of information is important for the operations and management of a TSP system?
- What are the existing systems (detection, communications, traffic controller equipment)?
- What are the field conditions (geometry, existing structures, weather)?
- What are the budget constraints?

Transit vehicle detection systems, for the most part, fall into four categories: driver activated, point detectors, area detectors, and zone detectors.

A **driver activated** detection system is not a desirable method for transit vehicle detection. Experience with the UTCS/BPS project[29] in Washington, DC showed that the drivers tended to turn the transmitters on and leave them on even when priority was not needed. This approach introduces a human factor that can lead to inconsistent results. In addition, manually activating the system increases the driver workload during the most critical parts of their operation, approaching and leaving the transit stop, which raises safety concerns.

Point detectors are one of the most common forms of detection used for TSP. They can be somewhat limited since they do not provide information about the transit vehicle between detection points. For example, traffic conditions can cause transit vehicles to speed up, slow down or even stop between detection points. This may lead to less predictability in transit's arrival at the intersection and consequently less efficient TSP operations. Therefore, point detectors are best suited for locations where the conditions between detectors are consistent. In this case, information from previous buses may potentially be utilized in generating estimates of travel time between detectors. If point detectors are utilized, multiple point detectors should be considered. As with all detection equipment, the number and location of detectors should be tailored for the particular field conditions.

An **area detector**, contrary to point detectors, monitors a vehicle's movement through an area. Area detectors improve the ability to predict the arrival of the transit vehicle at an intersection. Therefore, the TSP system should operate more efficiently. The ability to more readily determine the transit vehicle's location also provides the opportunity to use a more robust TSP strategy that can take advantage of this information. Area detectors, such as GPS/AVL, are emerging as the most favorable detection systems for TSP. However, since the vehicle location is monitored continuously, area detectors need to be coupled with a method to evaluate the location, in conjunction with other applicable information (e.g., route/schedule information), to generate priority requests under the desired conditions.

Zone detectors sense the presence of a vehicle on the approach to an intersection. Typically, these system only know that a vehicle is somewhere on the approach, within 500 feet, for example, and is requesting priority. These systems do not necessarily know where in the detection zone the vehicle is located or what movement or phase is required for service, just that it is present. Recent advances have provided additional information about the location in the zone that could be used in a fashion similar to area detection. Currently optical or IR detectors are available that provide zone detection.

Exit detection is another element that influences the TSP logic. Many TSP systems include a method to detect when the transit vehicle exits the signalized intersection. For example, when zone detection is used, the presence call is true when the vehicle is still in the detection zone and can be assumed to have exited the zone when the call is false. Exit detection provides more efficient traffic operations. As an example, a TSP-equipped bus is detected five seconds before the signal would normally turn red. The green extension strategy is set to extend the green signal by a maximum of 17 seconds. The bus, however, is detected at the exit detector 10 seconds after it requested priority (i.e., the bus took 10 seconds to travel from the check-in detector to the exit detector). Once detected at the exit detector, the green signal can be terminated. In this example, the green signal was extended only 5 seconds. If exit detection were not provided, the signal would have extended the green signal for an additional 12 seconds to the maximum green extension time of 17 seconds. This operation is less efficient since the opposing movements are unnecessarily delayed.

5.2.2 Communications System

Communication is a very important element of the TSP system. It provides a connection among TSP elements. The reliability of the TSP system is completely dependent on the communications system. Therefore, the importance of the communications system should not be overlooked, especially knowing that the communication is an expensive element that can easily become the most expensive TSP element. Sound communication selection can make the difference between a successful and unsuccessful project.

Typically, radio systems are used to communicate between the transit management system and the transit vehicle. Depending on the number of vehicles in the fleet, the management system can check the status of the vehicles every one to five minutes. More frequent communications can be supported for a small number of vehicles, but typically this is not used except in emergency situations.

Recently, new wireless technologies have been successfully applied. These systems allow the vehicle to report location and other vital information to the transit management system.

Another communications issue of concern is the communication of a request for priority to a traffic signal controller. Technologies such as DSRC, Optical, and IR have been used to communicate directly from the transit vehicle to the intersection controller. This is a key consideration since the communication range can affect how far in advance a request for priority is received. As outlined in the other scenarios defined in NTCIP 1211, other more centralized options include communicating the request for priority from the vehicle to the transit management system, to the traffic management system, then to the traffic signal controller, or even locating the priority request generator in either the transit or traffic management centers.

TSP Strategy	Typical Implementations			
	Transit Detection Required	Controller Types	Traffic Control System	Type of Implementation
Passive Priority	No	NEMA, Type 170, Type 2070	Fixed Time	Corridor, Network
Early Green	Yes	NEMA, Type 170, Type 2070	Actuated	Intersection
Green Extension	Yes	NEMA, Type 170, Type 2070	Actuated	Intersection
Actuated Transit Phase	Yes	NEMA, Type 170, Type 2070	Actuated	Intersection
Phase Insertion	Yes	NEMA, Type 170, Type 2070	Actuated	Intersection
Phase Rotation	Yes	Type 2070	Actuated	Intersection
Adaptive	Yes	Type 2070	Adaptive	Intersection, Corridor, Network

Table 2: Typical TSP Strategies and Implementation Requirements

5.2.3 Traffic Control System

Although the design and implementation of TSP operation is often an integral part of a large traffic signal control (or traffic management) system, it is not traffic control signal system dependent. In fact, having a central traffic control signal system is not a prerequisite for TSP. The methodology of the TSP system to engage the main street green extensions or cross street green truncations can be initially designed to reside in the algorithms of the intersection controller as an alternative to a central traffic signal control system, provided that the local intersection controller has the minimum programming capability. While this approach has disadvantages for mid-sized to larger transit operations, it may provide a reasonable starting point for small transit properties.

Traffic signal control at the intersection level falls into one of three categories: (1) fixed time, (2) actuated (free and coordinated), and (3) adaptive/real-time.

Fixed-time signals operate with a constant cycle length, phase sequence, and an exact amount of green time for each movement during every cycle regardless of whether traffic demand exists or not.

Actuated signal control has the ability to collect information about the current demand at the intersection. The controller can then reallocate green time on a phase-by-phase basis in response to the demand. Actuated signal control can operate as free or coordinated signals.

New strategies also exist to implement **adaptive/real-time** traffic signal control. Although the details of how each implements adaptive control varies, in general, a real-time, traffic adaptive signal control system assesses the current status of the network and with forecasting capabilities allows the signal timings to be adjusted to more efficiently accommodate traffic demand. Although offering many advantages, adaptive/real-time traffic signal control requires more detection, communications, and processing capability than actuated signal control, and is still relatively limited in North America.

★ Lessons Learned

- When selecting and designing a TSP system, the subsystems (transit vehicle detection, communications, traffic control, and TSP logic) cannot be considered independently. Each subsystem is interrelated.

5.3 Types of TSP Implementations

Inherent to each strategy is whether it can be implemented at the intersection level, along a corridor, and/or throughout a network. Table 2 summarizes some of the more typical applications of the TSP strategies and associated implementation requirements for transit detection, traffic signal controllers, and traffic signal systems.

It should be noted that the each of the different controller types provide different algorithms for TSP. NEMA controllers are widely used; there are several well-known manufacturers, and each NEMA manufacturer offers a unique TSP capability in the firmware of their controller. Type 170 controllers are also widely used, and there are also several hardware manufacturers, and there are a number of firmware products available from a variety of developers. Type 2070 controllers, also known as the Advanced Transportation Controllers (ATC), are compatible with both NEMA and 170 cabinets, and there are several manufacturers of both hardware and developers of firmware that provide TSP functions.

★ Lessons Learned

- The types of TSP algorithms available depend on the controller type used.
- Specific TSP algorithms depend on the particular firmware used within the controller.

TSP Operations and Maintenance Issues 6

Operations & Maintenance

With advances in solid state technology, detection, and communications, ITS applications of transit signal priority have become financially viable options within reach of most North American public transportation operators. As vendors consolidate, computer memory and processing speed becomes less expensive, and the public clamors for more effective public transit, the productivity gains from transit signal priority are almost certain to increase its application by an order of magnitude or greater. The question, then, is: to what degree are these gains offset by increases in operating and maintenance costs?

6.1 Overview

Unfortunately, the question has a level of complexity that defies a simple answer. There are a number of major factors that affect the range of costs experienced by implementing organizations. Among these are the technology chosen for implementation, priority system integration with the signal network, age and generation of signal hardware, vehicle intelligence, climate and geology, system ownership and transit operating rules. Aside from safety, the two most important elements of bus transit operation from the customer's standpoint are minimizing trip duration and maximizing on-time performance. The technologies currently available can—in most instances—provide significant improvements in operating speed without a great degree of sophistication or expense. However, maximizing on-time performance requires a good deal more effort in time and money. This importance also signifies the need to collect operational performance data—as part of the normal operation of the system, to measure the benefits and impacts of TSP.

Because operating components for bus priority are both bus and traffic signal based, it is important to recognize that system design on either side of the priority call can be a major determinant of initial and ongoing expenses. Fortunately, current technology permits major productivity gains at marginal—although not inconsequential—cost to the respective highway and transit agencies.

6.2 Hardware and Software

The majority of applications for transit signal priority rely on transmission of a priority call or request from a light rail vehicle or bus to a traffic signal programmed to grant the priority request, conditionally or unconditionally. The vehicle identifies itself to the traffic signal controller, which then considers the request. The priority call from the vehicle is made by a dedicated transmitter in the vehicle to the controller. Depending on the installation, the more common applications either have the receiver mounted in or near the controller cabinet or buried in the pavement and connected to the controller via buried cable. In either instance, reliable performance can be attained with ranges up to 500 meters.

Not surprisingly, failure of the on-vehicle hardware has been a relatively minor component of the operations and maintenance equation. With proper initial installation, current generations of transmitters and receivers are exceedingly reliable, to a great degree because of their simplicity. International experience, particularly in northern Europe, has demonstrated a very low failure rate of transmitters and receivers of all types.

Signal controllers of recent design have been incorporating standard cycles of high and low signal priority. High priority—or preemption—is generally restricted to emergency vehicle use and, in cases where rail crossings are interconnected, to grade crossing protection. If grade crossing protection is not needed, low priority is available to transit vehicles. Newer traffic control devices have a low failure rate, with power outage occurrences and incidents of traffic damaged equipment outweighing hardware or software failures.

Transmitter and receptor equipment can be expected to outlast replacement cycles of vehicles and traffic signal controllers. Abrasion of connectors and wires in vehicles can be identified in normal inspection cycles and, aside from vandalism, construction or weather-related pavement displacement, receptors are of similar reliability. Focused transmission and detection introduces additional concerns, as aimed devices are subject to misalignment or other interruptions in transmissions. While presumably infrequent, detection and correction of misalignment increases the maintenance expense associated with TSP. As a rule of thumb, annual maintenance expenses for radio-based technologies are less than one percent of system purchase price, with a premium paid in additional maintenance expense for optical and infrared technologies.

Software upgrades can have a significant impact on operating and maintenance expenses. These upgrades may come from enhanced features or may be a result of retrofitting a technology with new capabilities. Several analyses conducted on the costs and benefits of retrofitting older generation traffic signal equipment to handle signal priority have ended in favor of upgrading to interconnected TSP as a preferred option.

6.3 System Design

Additional operating and maintenance costs arise from the type of control systems applied by the highway and transit agency. Relatively low cost operations can be implemented by allowing the traffic signal devices to "decide" on granting priority solely on the basis of the internal operating algorithms of the controller, not on the status of the transit vehicle. The transit vehicle always requests priority, but the traffic signal controller only grants priority if the signal has not recently granted priority to a requesting vehicle. The principal responsibility for maintaining adequate operations in these circumstances falls to the traffic engineers and transit planners within the scope of their usual responsibilities.

More sophisticated systems provide the signal system or the transit vehicles themselves with significant ITS capabilities. These enhancements can include AVL, on-time performance, dynamic routing, load status, connection protection, vehicle system conditions, passenger safety and other features. Each feature, while not essential to TSP, adds additional operating and maintenance expense.

6.4 Jurisdiction

Not surprisingly, the complexity of the jurisdictions having responsibility for the traffic signals and transit systems operating TSP have a great deal to do with associated operating and maintenance costs. Once again, the Regional ITS Architecture can be helpful. Operational agreements in the architecture may lay out ahead of time some of the operational and jurisdictional issues.

Future Direction 7

Planning, deployment and operation of TSP systems involves consideration of many different factors, as outlined in this paper. While previous deployments may have similarities, the particular environment and conditions under which a new TSP system is being considered should be given full consideration. In addition, as technologies evolve, the capabilities available in TSP systems and subsystems may increase significantly. These improvements can provide the potential to achieve objectives which require a higher level of system sophistication. In terms of objectives, all stakeholders need to be involved in the determination of a set of TSP system objectives and desired system functionality that reflects local policies and tradeoffs. Through the use of a systems engineering process, a TSP system that addresses these objectives and system functionality may be planned, developed, and supported through all of its life-cycle phases.

There have been significant advances in transit signal priority including understanding of the issues, both technical and political, and the development of valuable experiences. As experience expands, and the options and issues are better understood throughout the transit and traffic communities, it is anticipated that there will be increased deployment of this cost-effective technology. This will be especially true for the Bus Rapid Transit Systems being deployed across the continent. For example, 14 of the 17 planned BRT deployments being facilitated by FTA, will include TSP as a significant element for increasing transit speed.

Future deployment will also be facilitated by the development and adoption of the NTCIP 1211 and TCIP TWG 10 standards.

Finally, workshops sponsored by the Joint Program Office and the Federal Transit Administration, and organized by ITS America, have identified a number of research needs that would further enhance and facilitate the deployment of TSP. These are listed in Appendix 2, and priority areas include:

- TSP Strategic Choices and Guidance
- Effective Utilization of TSP by Transit Agencies
- Improved Planning of TSP (especially for Bus Rapid Transit)
- Enhanced Analytic Tools (e.g., Simulation and Optimization)
- Technical Enhancements for Conditional Priority
- TSP Deployment Evaluation

It is clear that Transit Signal Priority is a cost-effective approach for enhancing the attractiveness of transit and for increasing the capacity of the urban road infrastructure, and its use will continue to increase.

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Appendix 1

Examples of Operational TSP Deployments

The following list identifies examples of transit systems that have worked with local or state traffic/highway departments to deploy transit signal priority that are operational. TSP deployments vary considerably from location to location, ranging from equipping a few intersections and a limited number of buses, to equipping entire corridors (such as for BRT) to system-wide deployments.

- Alameda-Contra-Costa Transit District (AC Transit), Oakland, CA
- Ben Franklin Transit, Richland, WA
- Calgary Transit, Calgary, Canada
- City of Glendale, CA
- Greater Vancouver Transportation Authority (TransLink), Vancouver, Canada
- Jefferson Transit Authority, Port Townsend, WA
- King County Metro Transit, Seattle, WA
- Kitsap Transit, Bremerton, WA
- Los Angeles County Metropolitan Transportation Agency, Los Angeles, CA
- Metropolitan Atlanta Rapid Transit Authority, Atlanta, GA
- Napa County Transportation Planning Agency/Vine Transit, Napa, CA
- Pace Suburban Bus Service, Arlington Heights, IL
- Pierce Transit, Tacoma, WA
- Sacramento Regional Transit District, Sacramento, CA
- San Francisco Municipal Transportation Agency (MUNI), San Francisco, CA
- Skagit Transit, Burlington, WA
- Toronto Transit Commission, Toronto, Canada
- Tri-County Metropolitan Transportation District of Oregon (TriMet), Portland, OR
- Union City Transit, Union City, CA

Appendix 2

TSP Research & Development Needs

The following list includes topics where research and development would help to encourage and enhance the deployment of TSP. This list of TSP-related R&D needs was developed during a workshop of practitioners, researchers, and suppliers held February 26, 2003 in Washington D.C. The list was subsequently vetted with experts during various workshops and meetings in 2003.

TSP STRATEGIC CHOICES

- **Planning and Implementing Transit Signal Priority: A Guide to Best Practice**
  To develop a comprehensive guidebook for local transit and traffic agency staff in order to assist them in the planning, development, and deployment of a TSP program or project
- **The Development of an Analytic Framework for Selecting Corridors and Intersections for TSP Treatment: Identification of Warrants and Sources of Data for Assessment**
  To develop an analytic framework and methodologies to assist transportation professionals in selecting corridors and/or intersections for TSP treatment, through a strategic approach to TSP that is based on corporate objectives. The framework should include approaches for collecting data from different potential sources (e.g., traffic checkers, APC, AVL, AFC), an analysis of the data through the application of warrants developed by the project, and a priority setting methodology
- **An Assessment of Signal Timing Strategies for TSP: Alternative Approaches, Design Parameters and Trade-Offs**
  To develop a comprehensive handbook on the technical aspects of traffic signal timing for TSP, including a guide to alternative approaches to setting signal timings based on traffic conditions, traffic system architecture, traffic control design parameters, and the trade-offs associated with different strategies.
- **TSP for Decision-Makers: A Multi-Media Guide to TSP Goals, Experience, Benefits, Costs, Requirements, and Key Choices**
  To develop a concise multi-media tool that is specifically designed for presentation to senior decision makers (e.g., policy board members, local politicians, etc.), in order to help them understand TSP-related goals, experience, potential benefits, costs, requirements, and key choices.
- **Decentralized versus Centralized Control for TSP: Objectives, Technical Development and Maintenance Requirements, and Benefit and Cost Implications**
  To develop a more comprehensive understanding of the various dimensions associated with the choice between decentralized and centralized control for the purposes of implementing TSP.
- **TSP and Automatic Vehicle Location (AVL): Factors Affecting the Transit Agency's Technology Development Strategy, Technical and Management Implications, and Cost-Effectiveness Considerations**
  To provide guidance to transit agency staff on the potential integration of TSP and AVL systems, and the various technical, management, and cost-related implications to be assessed as part of the TSP planning process.
- **Integrating Signal Priority for Transit and EMS in Regional ITS Architecture and Plans: Potential Role, and Model Descriptions**
  To develop an understanding of the potential role to be played by providing signal priority to transit and EMS vehicles in regional ITS architecture and plans, and to develop model language that can be used by regional ITS planners in regional ITS plans.
- **Incorporating TSP in Regional/Corridor Planning Models and Studies: Analytic Approaches and Methodological Tools to Assess Potential Contribution to Regional Mobility and Air Quality Objectives**
  To develop high level analytic approaches for incorporating TSP into regional and corridor planning tools (e.g., major investment studies, air quality plans, etc.), and to develop the technical methodologies for analyzing the potential contribution of TSP to stated mobility and air quality objectives, as established in federal programs (e.g., new starts, CMAQ, etc.).
- **TSP System Procurement and Acceptance: Development of Model Documents and Standard Procedures**
  To develop model documents and standard procedures for procurement and acceptance testing of TSP systems, incorporating best current practice, in order to assist local traffic and transit agency staff in their procurement and deployment efforts.
- **Implementing TSP in a Multi-Jurisdictional Environment: Case Study Experience, Institutional Issues, Best Planning, Procurement and Deployment Practices, and Development of Model Memorandum of Understanding**
  To explore experiences and the complex issues arising from the implementation of TSP in multi-jurisdictional settings, and to provide guidance concerning effective inter-organizational cooperation in the planning, procurement and deployment of TSP.
- **Integrating Physical and Signal Priority Measures for Transit: Inventory, Best Practices, and Issues**
  To explore the inter-relationships between physical transit priority measures (e.g., queue jumps, bus/HOV lanes, bus bulbs, etc.) and transit signal priority strategies, and to provide guidance to maximize potential synergies.

MEASUREMENT OF BENEFITS AND IMPACTS OF SIGNAL PRIORITY

- **Development of Standard TSP Measures of Effectiveness and TSP Deployment Evaluation Guidelines**
  To develop standard methodologies for reporting on and evaluating TSP experience; these methodologies should standardize the description of the TSP deployment, and the reporting and evaluation of impacts and outcomes based on standard measures.
- **Development of a TSP Deployment Database**
  To develop a systematic and coordinated inventory and database of TSP deployments in ways that would assist and encourage local agencies to deploy TSP. This would be achieved through the development of a coordinated web-accessible database
- **A Review of Major European TSP-Related Demonstration Programs, Identified Benefits, and Implications of Lessons Learned for American Deployment of TSP**
  To review the findings from several major European demonstration programs (e.g., PRISCILLA, ROMANSE, INCOME, ROSETTA, TABASCO, etc.) where TSP played a prominent role, and to identify the benefits and implications of lessons learned with respect to the deployment of TSP in the U.S.

- **Design and Development of a Signal Priority Corridor Field Test Environment, and Design of a Demonstration Program to Test Promising TSP Strategies**
  To design and develop a test corridor that would provide a controlled realistic environment for testing and measuring the impacts of current and advanced approaches to signal settings, under a variety of conditions, for both intersection and corridor control.
- **Program to Measure the Benefits and Impacts of Optimized Signal Settings, Without Priority, Unconditional TSP, and Conditional TSP, under Various Conditions**
  To explore the potential benefits and impacts on transit and traffic, under various traffic conditions and control system parameters, of three different traffic control approaches: optimized traffic settings without transit priority, unconditional transit priority, and conditional transit priority.
- **The Benefits of TSP for Transit: A Comprehensive Review of the Experience with TSP and its Contribution to Reduced Transit Travel Times, Improved Service Reliability, and System Performance Under Various Conditions**
  To provide a comprehensive review, based on experience and research, of the potential benefits of TSP to transit, not only in terms of reduced transit travel times, but also in terms of TSP's contribution to improved service reliability and reduced bunching, and overall system performance.

LOCAL TSP PROJECT ASSESSMENT AND DESIGN

- **Simulation and Optimization for TSP Design: Integrating TSP and Simulation Software, and Guidelines for Effective Approaches to Optimization Using Simulation Tools**
  To assess the various requirements for integrating TSP and simulation software for optimization purposes, and to develop guidelines for practitioners for effectively using traffic simulation software in the design of TSP.
- **Cost-Effectiveness of Local Data Collection for TSP Simulation Calibration: Identification of Alternative Approaches, Test, and Evaluation**
  To develop practical cost-effective data collection methods for calibrating TSP simulation tools.

TSP AND TRAFFIC CONTROL SYSTEM

- **The Development of TSP ITS Standards for Priority Request Messages**
  To develop an ITS standard for TSP with respect to the definition of the priority request message, that is compatible with Dedicated Short Range Communications (DSRC), NTCIP and TCIP standards.
- **A Review of Current and Emerging Detection and Communication Technologies for TSP: Capabilities and Implications for TSP System Design**
  To review current (optical, loops, RF, etc.) and emerging (e.g., GPS, video recognition, etc.) detection and communication technologies, and assess the capabilities and implications of these different technologies for TSP system design (activation distance, check-out capabilities, etc.).
- **Implications of Signal System Design and Traffic Parameters on TSP Request Activation Strategies**
  To explore the implications of the signal system design and traffic parameters on different request activation strategies and their effectiveness (e.g., prediction accuracy, priority requests success rates, etc.).
- **Accommodating Near-Side Bus Stops in TSP Project Design: Best Practice and Emerging Approaches**
  To identify best current practice and to explore emerging approaches for addressing the complex issue of accommodating near-side bus stops in TSP designs.
- **Technical Options for Conditional Priority: a Review of Approaches, and Technologies, and Evaluation Under Various Situations**
  To identify the range of technical options for conditional priority (involving schedule adherence monitoring and communication of requests for priority that fulfill conditions), to evaluate the effectiveness and implications of the various options, and to provide guidance for selection of best option under various local scenarios.
- **Hybrid Application of Unconditional and Conditional Control for TSP: Rationale, and Technical Feasibility**
  To develop a hybrid application involving both unconditional and conditional control, under different conditions, to evaluate its potential effectiveness, and to assess its technical feasibility.
- **Traffic Controllers and TSP: Technical Requirements for Alternative TSP Strategies and Inventory of Traffic Controllers and Technical Characteristics**
  To define technical capabilities required of traffic controller equipment under different TSP strategies, and to inventory and evaluate existing controller equipment according to these technical requirements.
- **Cost-Effective Approaches for Time Stamping Traffic Controller and Transit Data for TSP Applications**
  To explore the most cost-effective approaches to time stamping traffic controller and transit data for TSP applications, in which accuracy and synchronization are paramount concerns.
- **Archiving TSP Data: Potential Uses of Archived TSP Data, and Data Collection Requirements and Data Definitions**
  To explore the potential uses of archived TSP data to improve transit planning and operations, or traffic control, and to provide guidance on the technical requirements for collecting and archiving such data (e.g., data elements and definitions, data messaging protocols, database structures, etc.).
- **Development of Next-Generation Controller Software for More Effective TSP: Alternatives to the Dual Ring Barrier Controller Software Logic**
  To build on the findings of NCHRP Project 3-66 of next generation controller software, in order to develop more effective TSP systems, and overcome limitations imposed by dual-ring barrier logic.

IMPLEMENTING TSP IN A TRANSIT AGENCY

- **Technical Integration of TSP in New ITS Transit Systems: Applicable Standards and Technical Requirements**
  To provide guidance with respect to applicable standards and functional requirements for including TSP in new ITS Transit systems (e.g., AVL, APC with GPS, etc.) being planned and/or procured.

- **Technical Feasibility of Retrofitting TSP into Existing AVL Systems: Critical Factors and Cost-Effectiveness**
  To explore technical requirements, technical feasibility and cost-effectiveness of retrofitting a TSP application to legacy AVL systems.
- **Artificial Intelligence and TSP: Application for Bus Arrival Predictions, Dwell Time Predictions, and Effective Conditional TSP**
  To explore the potential use and effectiveness of applying artificial intelligence techniques to various aspects of TSP (e.g., bus arrival predictions, dwell time prediction, cost-effective conditional priority, etc.)
- **Designing TSP-Based Operational Control Strategies**
  To develop operational control strategies (e.g., deadheading, closed door runs, holding, short-turns, etc.) for surface transit, that maximize the potential benefit from TSP systems.
- **TSP and Transit Scheduling: Best Practices for Maximizing the Benefits of TSP under Different Conditions.**
  To develop improved transit scheduling methodologies under different TSP conditions.
- **Incorporating TSP into the Transit Capacity Manual**
  To review how the TCRP Transit Capacity Manual should be modified to include TSP conditions.
- **Development of a TSP-Based Route-Level Demand Forecasting Model**
  To develop a TSP-based route-level demand forecasting model, that reflects best knowledge of the ridership impacts of deploying TSP under various conditions.
- **Institutional, Organizational, and Labor-Related Experience and Issues in Planning and Implementing TSP**
  To explore current experience and identify the range of institutional, organizational, labor-related, and operator training issues that may result for transit agencies, as a result of the deployment of TSP systems.

TSP AND BRT

- **The Role of TSP in BRT System Design, and in BRT-Specific Planning Tools**
  To isolate TSP among the many elements of BRT system design, to evaluate the specific contribution of TSP to BRT system performance, to explore the interactions between TSP and other BRT strategy elements, and to develop analytic approaches for incorporating TSP in BRT-specific planning tools (e.g., SmartBRT).
- **System-wide TSP and BRT: Priority Conflict Resolution for Multiple BRT Corridors**
  To explore the application of TSP in a multi-corridor BRT network, and to develop strategies for resolving potential conflicts that might arise.
- **Bus-Only Crossings: Experience, Traffic and Safety Impacts, and Related Issues**
  To explore the issue of bus-only crossings, such as BRT deployments in former rail right-of-ways, and to review related experience, traffic and safety impacts, and other related issues, including the need to incorporate this emerging situation in the MUTCD.

SPECIAL APPLICATIONS OF TSP AND OTHER

- **The Role of TSP in Emergency Preparedness and the Design of TSP-Based Emergency Traffic Corridor Plans**
  To explore the potential contribution of TSP systems to emergency preparedness, and to develop TSP-based emergency traffic corridor plans to be used for purposes of enhancing evacuation effectiveness.
- **The Potential Use of TSP Data for Real-Time Transit Customer Information Systems**
  To explore the potential use of TSP data in corridor applications with predicted downstream arrivals at intersections, for providing real-time transit customer information at bus/LRT stops.
- **The Potential Use of TSP for Paratransit Services: Options, Technical Implications and Cost-Effectiveness**
  To review the potential use of TSP in non-fixed route paratransit services, from the point of view of technical feasibility, potential benefits, and cost-effectiveness.
- **Security of TSP Systems and Potential Risk for Misuse**
  To explore the security of TSP systems, under different technological approaches, and the potential risk for misuse or criminal abuse of the TSP system.
- **The Impact of Bus Operator Behavior on Transit Schedules Under TSP**
  To explore how bus operator behavior might affect transit schedules under different TSP deployment scenarios.

DISSEMINATION

- **Incorporation of TSP into All Relevant Transportation Manuals**
  To review the implications of TSP for transportation manuals including: the Manual on Uniform Traffic Control Devices (MUTCD), the Highway Capacity Manual (HCM), and the Transit Capacity Manual (TCM), and to develop a process for incorporating knowledge related to TSP best practice into these manuals.
- **Transit Planning for Traffic Engineers: Development of a Professional Development Curriculum**
  To develop a professional development curriculum of transit planning concepts for traffic engineers in order to facilitate the dialogue between local traffic and transit agency staff.
- **Traffic Engineering Concepts for Transit Planners: Development of a Professional Development Curriculum**
  To develop a professional development curriculum of traffic engineering concepts for transit planners in order to facilitate the dialogue between local transit and traffic agency staff.
- **Practical Approaches to Maximizing the Use of Traffic Controller Hardware for TSP Traffic Control Algorithms: Development of a Professional Development Curriculum**
  To develop a professional development course on the technical aspects related to the effective use or modification of traffic controller hardware for TSP applications.
- **Mobility-Based Approaches to Intersection Capacity and Road Level of Service Analysis: Current State of the Art and Practical Experiences**
  To review existing methodologies for analyzing intersection capacity and road levels of service from a person mobility, as opposed to vehicle-based perspective, and to explore alternative approaches.
- **Balancing Auto and Transit Capacity Requirements in Capacity-Constrained Corridors: A n Exploration of Strategic Options and Issues**
  To explore strategic options for balancing auto and transit capacity requirements in capacity-constrained corridors, and to identify issues and effectiveness of these options in meeting different objectives.

APTA—America Public Transportation Association

ATC—Advanced Transportation Controllers—a type of traffic signal controller

AVL—Automatic vehicle location often, but not always, utilizing global positioning satellites (GPS)

BRT—Bus Rapid Transit – BRT combines the quality of rail transit and the flexibility of buses. It can operate on exclusive transitways, HOV lanes, expressways, or ordinary streets. A BRT system combines intelligent transportation systems technology, priority for transit, cleaner and quieter vehicles, rapid and convenient fare collection, and integration with land use policy. *<http://www.nbrti.org/>*

CUTA—Canadian Urban Transit Association

DSRC—Dedicated Short Range Communications

FHWA—Federal Highway Administration

FTA—Federal Transit Administration

GPS—global positioning satellites often used for automatic vehicle location

IR detectors—Infrared detectors

ISTEA—Intermodal Surface Transportation Efficiency Act (of 1991)

ITS—Intelligent Transportation Systems—the integrated application of advanced computer, electronics, and communications technologies to increase the safety and efficiency of surface transportation.

LRT—Light Rail Transit

MPO—Metropolitan Planning Organization

National ITS Architecture—provides a framework for planning, defining, and integrating ITS. *<http://itsarch.iteris.com/itsarch/>*

NEMA—National Electrical Manufacturers Association

NEMA controllers—a type of traffic signal controller

NTCIP—National Transportation Communications for Intelligent Transportation Systems Protocol *<http://www.standards.its.dot.gov/standards.htm>*

NTCIP Standard 1211, "Object Definitions for Signal Control and Prioritization", describes the interfaces with the signal control system *<http://www.standards.its.dot.gov/standards.htm>*

PRG—Priority Request Generator

PRS—Priority Request Server

Regional ITS Architecture—Regional ITS architectures help guide the integration of ITS components. During a regional architecture's development, agencies that own and operate transportation systems cooperatively consider current and future needs to ensure that today's processes and projects are compatible with one another and with future ITS projects. Federal rules and policy require development of regional ITS architectures that conform with the National ITS Architecture, to which subsequent federally-funded ITS projects must adhere.

TCIP—Transit Communications Interface Profile *<http://www.standards.its.dot.gov/standards.htm>*, *<http://www.ite.org/standards/tcip.asp>*

TCIP TWG 10—a standard concerning transit signal priority *<http://www.standards.its.dot.gov/standards.htm>*

TEA-21—Transportation Equity Act for the 21st Century (of 1998)

TSP—Transit Signal Priority—an operational strategy that facilitates the movement of in-service transit vehicles, either buses or streetcars, through traffic-signal controlled intersections.

Transit Signal Preemption—differs from Transit Signal Priority in that signal priority modifies the normal signal operation process to better accommodate transit vehicles, while preemption interrupts the normal process for special events (e.g., train approaching a railroad grade crossing adjacent to a signal, emergency vehicle responding to an emergency call).

Type 2070—a type of traffic signal controller

Type 170—a type of traffic signal controller

USDOT—United States Department of Transportation

Notes

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