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)

FINAL DRAFT July 11, 2002

Forword

Foreword

This overview of Transit Signal Priority (TSP) was 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. This resource is also being made available electronically through the ITS America web site at *www.itsa.org*.

Acknowledgment

Acknowledgment

ITS America expresses gratitude to the following professionals who generously shared time and expertise in creating this document.

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Executive Summary

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 <u>modifies</u> the normal signal operation process to better accommodate transit vehicles, while preemption <u>interrupts</u> 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. Negative impacts consist primarily of impacts to other traffic, generally on cross streets, which face the potential of increased delays at signals. Impacts are often difficult to measure, especially with small changes and difficulties in controlling before and after conditions. Experiences from prior deployments generally indicate bus travel time savings on the order of 15% and only minor impacts on the cross street traffic; however, substantial variability exists in the nature of deployments and magnitude of impacts. Information on costs is also limited, and are also difficult to compare. Depending on the configuration of the system, more equipment costs may be associated with equipment/software for the intersection, vehicles, or the central management system. The costs can be substantially affected by the desired functionality, so 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.

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, type of transit system, transit stop location, 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. 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. 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 type 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/Recommendations

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.
- Establish a multi-department team of leaders with responsibility to carry out the project.
- Establish the goals and objectives. Set measurable levels of performance in these goals.
- Make sure all of the partners have been identified who will be impacted by the project
- 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

Introduction

1.0 Introduction

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.

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.

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 along with recommendations.

Overview Fundamentals

2.0 Overview of Transit Signal Priority Fundamentals

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.

TSP Fundamentals

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 preemption1 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.

Traffic 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, 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

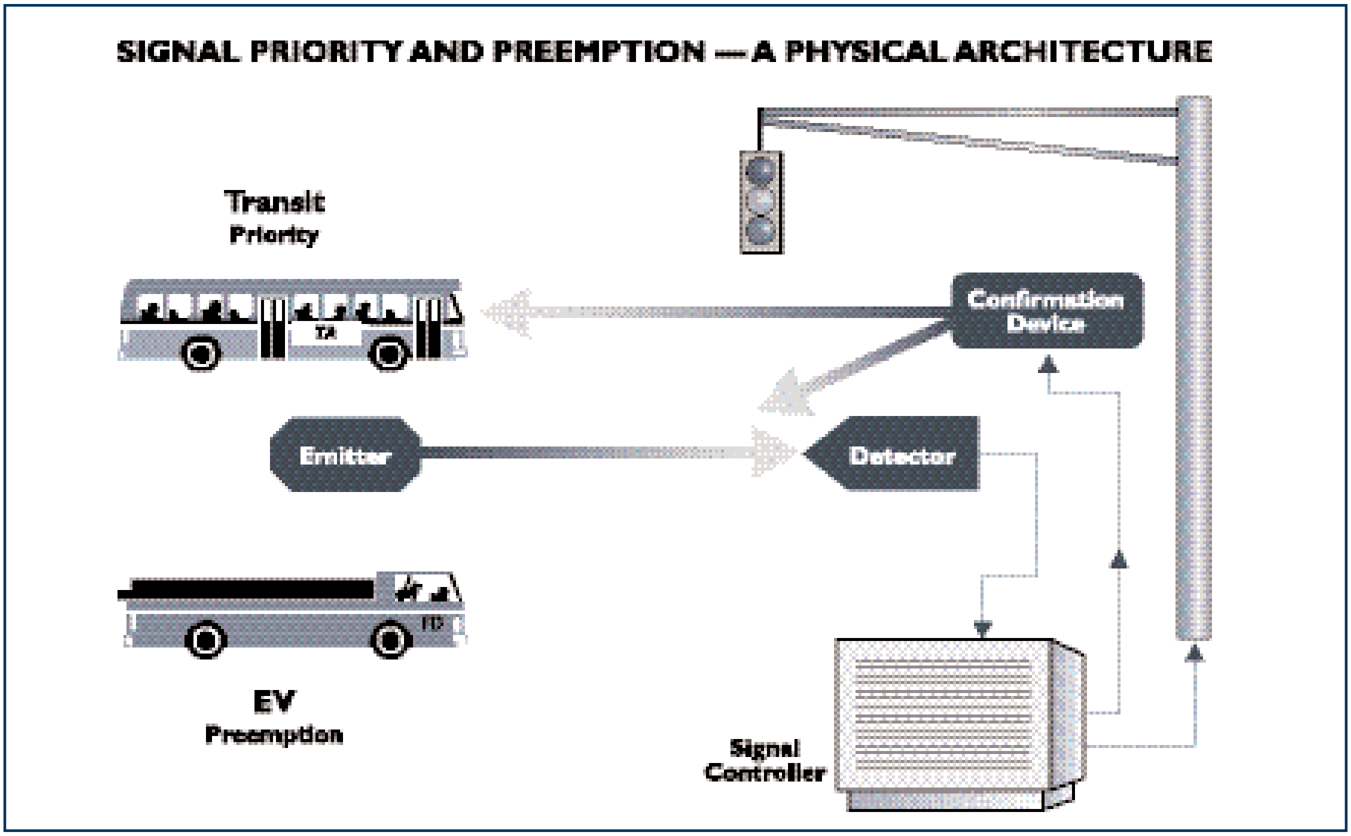

Figure 1: Priority and Preemption Example at Local Intersection Level 2

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.

Priority Treatments

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

- passive priority
- early green (red truncation)
- green extension
- actuated transit phase
- phase insertion
- phase rotation
- adaptive/real-time control

Passive priority operates continuously regardless of whether transit is present or not, and does not require a transit detection 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.

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.

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.

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/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 continuously optimize the effective timing plan based on real-time, observed data. 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.

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.

Local Intersection TSP vs. Street Network-based TSP

There are generally two different approaches to providing TSP. In its more basic form, TSP is accomplished at the local intersection level, by detecting the approaching transit vehicle upstream of the signalized intersection and sending a "check-in" 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. Depending on when the transit vehicle is detected 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.

A more sophisticated approach operates at the street network level by utilizing automated vehicle location (AVL) and control systems to determine if the transit vehicle is behind schedule before communicating to the traffic signal controller that priority is requested. This more sophisticated approach has recently appeared as a result of 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. This is called "selective priority" or "conditional priority". Although it may be viewed as preferable, it does require a more advanced (and more costly) AVL system and tight integration of system logic and equipment between the AVL and the traffic signal (or traffic management) system.

It should be noted that TSP implementations may utilize a combination of these approaches as well. For example, the Los Angeles TSP system uses a point detection system in conjunction with processing of priority requests at the traffic management center. The point detection system uses the traditional pavement embedded loop sensor along with a RF transponder on each bus that emits an identification code. The bus identification codes and locations are forwarded to the traffic management center, where centralized software implements the processing of priority requests and granting of preferential treatments. This hybrid approach permits relatively simple equipment to be used in the field, but centralizes schedule information so that changes (e.g. due to buses passing each other) can be made without needing to interact with each bus.

The Transit Vehicle Detection system is responsible for initiating requests for priority based on predefined criteria

System Components

There are three major components to a TSP system (see Figure 2):

Transit Vehicle Detection/ Priority Request System

The Transit Vehicle Detection system is responsible for initiating requests for priority based on predefined criteria, which may be static, e.g. priority automatically requested for all buses on certain routes, or dynamic, e.g. priority requested for buses behind schedule by more than 5 minutes. Depending on the approach selected[4], the detection 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.

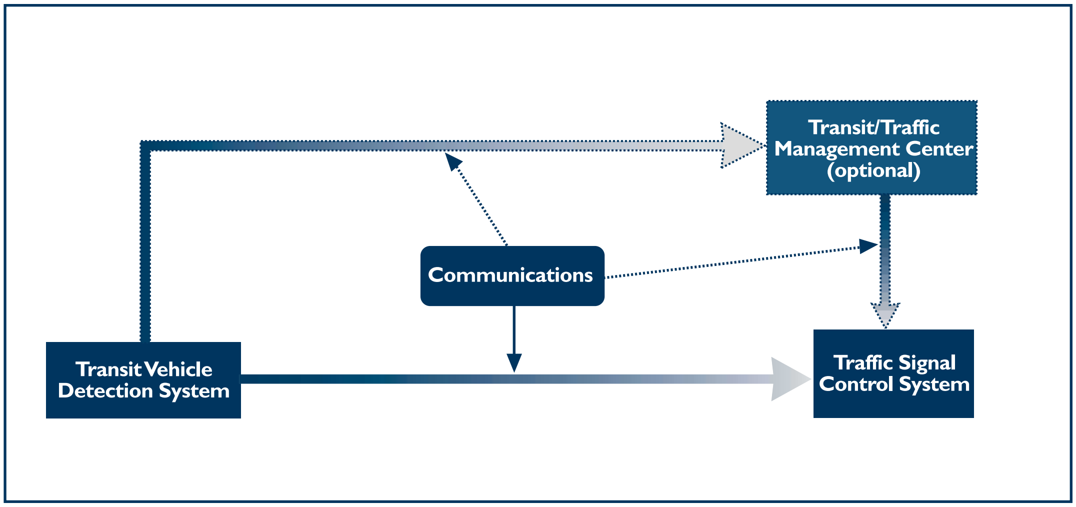

Figure 2: TSP Main Sub-Systems

Communicans System
The communications system for TSP includes the provision of detection information from transit vehicles to the local intersection or management center, and if a management center is used, from center-to-center and center-to-intersection as applicable.

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 will provide impetus to TSP initiatives. NTCIP Standard 1211 describes the interfaces with the signal control system. The NTCIP signal control prioritization working group will have their work available for draft user comments in the fall of 2002. NTCIP Standard 1409 covers the Priority Request Generator from a vehicle requesting priority. It is in the early phases of development.

Benefits & Costs

3.0 TSP Benefits & Costs

Benefits

Several benefits are anticipated from implementing a TSP system. These benefits typically include: improved transit schedule reliability, reduced transit travel times, 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 can also have negative impacts. One of the most commonly cited impacts is the potential increase in traffic delay.

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 3 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 6 to 42% reduction in transit travel time, with only 0.3 to 2.5% increases in auto travel time.

In North America, Toronto, Edmonton, Charlotte, Portland, Chicago, and Los Angeles, among others, have installations in place. Other cities, such as Albany, NY, have TSP projects in the development stage or that are being planned. In Toronto for example, average transit signal delay reductions of between 15 and 49% using TSP has justified expansion to over 300 signalized intersections (15% of total) along four bus and five streetcar routes, all in mixed traffic. Other TSP deployments include a 2-_ 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. Chicago Transit Authority and suburban PACE buses, using transponders and absolute TSP, realized an 8-minute trip time versus 12 minutes before TSP (a 33% reduction). In Los Angeles, two projects demonstrated application of TSP in conjunction with service restructuring (Metro Rapid) at approximately 100 signals along of each corridor (14-16 miles)[6]. Results indicated an average 8% decrease in overall bus running time, and a 35% reduction in bus delay at signalized intersections.

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.

Studies associated with the deployments[7,8] have shown that there has been little or no impact on the travel times of other motorists along streets operating with TSP. In fact, the operation of TSP may positively benefit vehicles traveling in the same direction of the transit vehicle by 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[9,10]. 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[11], 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, prompt arrival of data collection personnel) can substantially impact results. Simulation can reduce this risk.

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 (i.e., one bus and 100 signals or 100 signals and one bus). 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

➤ Type of roadside and on-board equipment

➤ 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[12] Tualatin Valley, Hwy.	Bus	10	early green, green extension	• Bus travel time savings=1.4 to 6.4% • Average bus signal delay reduction=20%
Seattle, WA[13] Rainer at Genesee	Bus	1	early green, green extension	• 50% reduction of signal related stops by prioritized buses • 57% reduction in average traffic signal delay for prioritized buses • 13.5% decrease in intersection average person delay • Average intersection delay did not change for traffic • 35% reduction in bus travel time variability through intersection • Side street effects were insignificant
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] Rainier Avenue (Midday Peak)	Bus	3	early green, green extension	• 24% average reduction in stops for TSP eligible buses • 8% reduction in travel times • When TSP has been granted to a bus that any side street delay does not cause the side street drivers to miss a green signal • 34% reduction in average intersection bus delay for TSP eligible buses
Portland, OR[17] Powell Blvd.	Bus	4	early green, green extension, queue jump	• 5 to 8% bus travel time reduction • Bus person delay had a general decrease • Inconclusive impacts of TSP on traffic
Sapporo City, Japan[18]	Bus	unknown	unknown	• 6.1% reduction in bus travel time • 9.9% increase in ridership
Route 36				• 7.1% reduction in bus stops at signals which resulted in a 20.8% reduction in stopped time
Toronto, Ontario[19]	Street car	36	early green, green extension	• 15 to 49% reduction in transit signal delay • 1 street car removed from service
Chicago, IL[20] 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[21]	LRT & Trolleys	16	early green, green extension	• 6 to 25% reduction in transit signal delay
Minneapolis, MN[22] 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]	Bus	211	early green, green extension, actuated transit phase	• 8% reduction in average running time • 35% decrease in bus delay at signalized intersections

Table 1: TSP Benefits and Impacts— Case Studies

4.0 Planning for Deployment of Transit Signal Priority

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, but 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.

Planning the Transit Signal Priority System

This section looks at lessons learned in the following areas related to transit implementation planning:

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

Stakeholders: Roles & Responsibilities

Issue: 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, 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.

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.

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.

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. This package could 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.
- 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.

Regional Management and Coordination of TSP Issues

Issue: 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 criteria23 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.

Implementation Planning

Issue: 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.

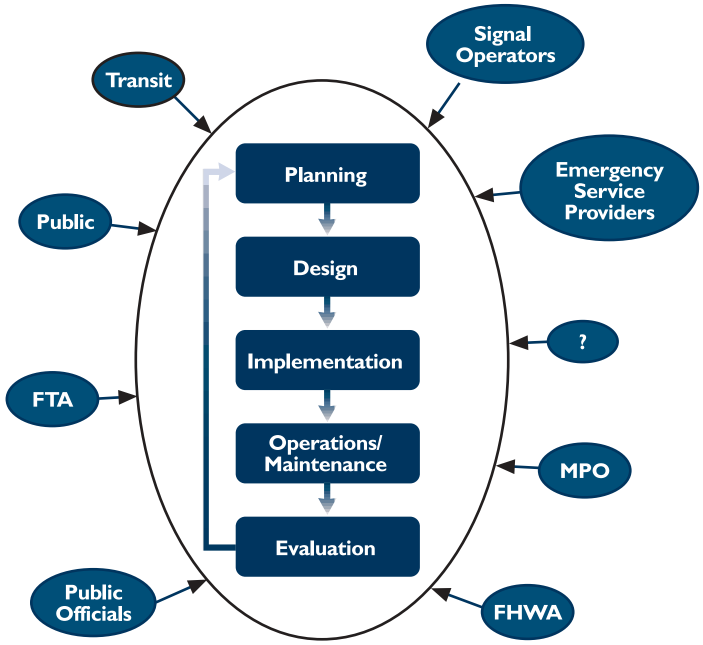

Figure 3: Steps and Stakeholders in TSP Deployment

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, design, implementation, operations and maintenance, and evaluation. 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, and developing functional specifications. Many other processes then 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 *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 *www.incose.org* for further information.

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 *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 *www.its.dot.gov*.

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.

Procurement

Issue: 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: the intersection equipment, the bus equipment, the communication system between the vehicle and intersection equipment, the central traffic signal management system, and the 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[24]. These include fixed-price; time and materials; and cost-plus contracts. One or more contract types used in combination refer to a contracting approach[12]. 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[25], Report No. FHWA-JPO-98-036. This 214-page paper can be downloaded from the USDOT Electronic Document Library (*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).

Design/
Implementation

5.0 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.

TSP Implementation Parameters

There are many factors that affect the implementation of a TSP system. The following sections identify some of these factors. 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).

Although traffic volumes vary constantly in any area, peak hours seem to be the most important time intervals to evaluate TSP.

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.

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

- Type of transit system
- Transit stop location
- 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. 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[26]. 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.

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.

Transit Vehicle Detection 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, GPS/AVL, and Radio Frequency 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, IR, 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 following criteria:

- What kind of information is important for the operations and management of a TSP system?
- What are the existing systems (detection, communications)?
- 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[27] 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.

It is important to keep in mind that the expected impacts of signal priority vary by deployment[26].

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,

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

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.

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, such as cellular data (CDPD) 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, IR have been used to communicate 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. Other 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. This approach is generally felt to be less reliable and has not been applied in many systems.

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 of 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.

A variety of strategies 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. Adaptive/real-time traffic signal control generally requires more detectorization, communications, and processing capability than actuated signal control.

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.

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.

Operations & Maintenance

6.0 TSP Operations and Maintenance Issues

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?

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.

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.

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.

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.

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.

Future Direction/ Recommendations

7.0 Future Direction/Recommendations

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.

There have been significant advances in transit signal priority including understanding of the issues—both technical and political, and the development of valuable experiences. Based on this knowledge and experience, the following recommendations are proposed for agencies considering a TSP project:

- Identify a champion.
- Establish a multi-department team of leaders with responsibility to carry out the project.
- Establish the goals and objectives. Set measurable levels of performance in these goals.
- Make sure all of the partners have been identified who will be impacted by the project
- 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

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