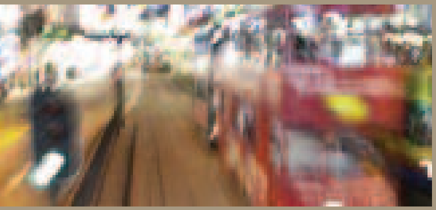

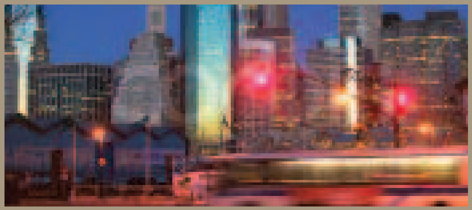


Transit Signal Priority (TSP):
A Planning and Implementation Handbook

May 2005 ✷ Funded by the United States Department of Transportation

Prepared by:

Harriet R. Smith
Brendon Hemily, PhD
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ITS AMERICA
Technology Transforming Transportation

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Table of Contents

Executive Summary

PART I | TSP PLANNING AND IMPLEMENTATION

Introduction

Our streets and highways are getting more congested as the population grows and more cars enter the transportation system. It is in the best interest of all to improve public transit service so that more travelers will utilize transit freeing up space on our streets, diminishing our dependence on fossil fuels, and improving air quality.

Transit Signal Priority (TSP) is a tool that can be used to help make transit service more reliable, faster, and more cost effective. TSP has little impact on general traffic and is an inexpensive way to make transit more competitive with the automobile. It is used extensively in other parts of the world, and is rapidly becoming more popular in the United States.

The U.S. Department of Transportation (U.S. DOT) has made it easier to choose TSP by financing workshops and documents to educate traffic engineers and transit planners on TSP implementation. This handbook is one of a series of documents created for that purpose. The first, entitled Overview of Transit Signal Priority, was a multi-year effort and was written entirely by volunteers under the leadership of ITS America. The volunteer authors included one traffic engineer and one transit planner for each chapter. Because it was co-authored by transit and traffic engineers, it was a ground-breaking effort that represented a new level of cooperation and consensus concerning the benefits of implementing TSP.

Capitalizing on the momentum created by the document, U.S. DOT financed a series of workshops to identify further research and educational needs and to reach out to the transportation community. Practitioners shared their experiences and worked with workshop participants to answer questions and build action plans for the participants' own communities.

The Overview of Transit Signal Priority was updated and expanded with information gathered from the workshops. The revised Overview of Transit Signal Priority was published in 2004 and is available on the ITS America Web site at http://www.itsa.org/tsp.html.

This handbook goes deeper into TSP and provides technical guidance. It does not repeat everything in the overview and is meant to be a companion document. The overview is a high-level document that explains what TSP is, why it is important, what the benefits are, and the important issues surrounding the topic. The handbook contains the steps one should follow to implement a successful TSP project. It relies heavily on eight case studies in which a great deal of information was gathered on topics related to planning, design, implementation, evaluation, technology, institutional issues, public reaction, and much more.

TSP projects are often complex enough to require professional engineering assistance. This handbook will help the public sector project manager provide better oversight. It explains a systems engineering approach with a logical sequence of steps that should be followed. It educates the reader on the inestimable benefits of working closely with stakeholders from day one to avoid problems later on. It equips the reader with vocabulary to communicate with both the transit and the traffic community. The handbook is a tool to help you navigate through a TSP project. Refer to it often. It is hoped that you will find in it the information you need to move you and your region toward TSP implementation.

Objectives

This handbook, prepared for the U.S. DOT, has four objectives:

- To outline a comprehensive process for planning and implementing TSP, based on a systems engineering approach, that identifies many of the issues that may need to be addressed in a TSP project
- To provide more extensive information on the current state of the practice of TSP in North America
- To document a number of case studies of communities that have implemented TSP in order to highlight the variety of issues that arise and solutions that have been developed
- To provide a number of resources to those interested in TSP, including primers on traffic control equipment and systems, on key concepts (e.g. simulation and optimization), as well as on traffic engineering and transit terminology, to assist transit planners and traffic engineers in understanding one another

Background on Transit Signal Priority (TSP)

TSP is an operational strategy that facilitates the movement of transit vehicles (usually those in-service), either buses or streetcars, through traffic-signal controlled intersections. Objectives of TSP include improved schedule adherence and improved transit travel time efficiency while minimizing impacts to normal traffic operations.

Examples of measured benefits:

- In Tacoma, Washington the combination of TSP and signal optimization reduced transit signal delay about 40% in two corridors.
- TriMet (Portland, Oregon) was able to avoid adding one more bus by using TSP and experienced a 10% improvement in travel time and up to a 19% reduction in travel time variability. Due to increased reliability, TriMet has been able to reduce scheduled recovery time.
- In Chicago, PACE buses realized an average of 15% reduction (three minutes) in running time. Actual running time reductions varied from 7% to 20% depending on the time of day.
- With the implementation of TSP and through more efficient run cutting, Pace (Chicago) was able to realize a savings of one weekday bus while maintaining the same frequency of service.
- Los Angeles experienced up to 25% reduction in bus travel times with TSP.

TSP is made up of four components. There is (1) a detection system that lets the TSP system know where the vehicle requesting signal priority is located. The detection system communicates with a (2) priority request generator that alerts the traffic control system that the vehicle would like to receive priority. There is software that processes the request and decides whether and how to grant priority based on the programmed (3) priority control strategies. And there is software that (4) manages the system, collects data, and generates reports.

There are a variety of technical approaches that can be used as control strategies. This handbook provides information on the control strategies.

A Systems Engineering Approach to TSP

This handbook encourages a systems engineering approach to implementing TSP. The steps include:

- Planning
- Design
- Implementation
- Operations and Maintenance
- Evaluation, Verification, Validation and Building on TSP

This is a logical approach that is essential for a successful engineering project. The process should proceed from plan to design and address operations and maintenance issues as part of the implementation. Evaluation helps to monitor results against objectives, and to subsequently refine the system. However, in complex projects is it easy to get lost in details and forget essential steps. Forgetting steps leads to cost overruns, miscommunications, and failed projects. Project managers who follow and communicate a clear systems engineering approach can stay on target and avoid unpleasant surprises. Each of the steps is discussed in the handbook.

Planning

TSP planning does not happen in a vacuum. TSP should be a response to a problem (such as buses experiencing delay at traffic signals) and should be consistent with regional and corporate goals (such as increased mobility). A TSP project is often the first opportunity to form a good working relationship between transit and traffic staff. It requires support from the traffic engineering office and the transit agency. One of the most important elements of the planning process is early identification and involvement of stakeholders. Stakeholders (internal and external to the transit agency) can provide support or create road-blocks. Good management will help lead to support.

During the planning process the stakeholders will identify project goals, and create a Concept of Operations (ConOps) which will help all partners understand and agree on what TSP will be able to do and how it should function.

Design

Project design will begin after a thorough planning process and will continue to involve stakeholders. The design will begin with data collection and will include a detailed design and engineering of each intersection and related road-side equipment; design and engineering of on-board equipment; optimization and preparation of signal timing plans; and perhaps modeling.

Implementation

Procurement is the first step of TSP project implementation. Most TSP procurements are handled through the RFP process. This handbook outlines a long list of elements that should be included in the RFP. After the vendors respond to the RFP and a selection is made, installation begins.

Installation

Installation involves managerial and technical staffs in various departments of the traffic engineering agency and the transit agency. A high level of cooperation is needed because most people are understandably uneasy about allowing others access to equipment for which they are responsible. If good relationships have been built among stakeholders through the planning process, equipment installation will go more smoothly. After equipment is tested and validated the system will be ready to "go live."

Operations and Maintenance

Most practitioners have found that operations and maintenance (O&M) of TSP has not been burdensome. Signal technicians add the on-street TSP technology to their maintenance program and the bus maintenance personnel add the on-vehicle equipment to their normal O&M. However, it is important that all impacted organizations have written agreements on who maintains (and upgrades) what equipment and software.

Lessons Learned from Practitioners

- Early stakeholder involvement is critical.
- Good communication among the stakeholders is important.
- One or more champions are needed to move the project forward.
- Demonstrations and pilot projects help test the TSP and build trust for full implemen tations.
- Good before and after studies can produce convincing evidence of benefits.
- Pitching the right ideas from the beginning can help ensure success.
- Interjurisdictional partnerships will help with coordination and implementation.
- It is important to keep the momentum going even when problems surface.
- Standardizing equipment will save time and money in the long run.
- Keep the project simple _ especially in the beginning.
- It helps to remember to keep TSP objectives simple and build incrementally.

PART II | STATE OF THE PRACTICE

A survey was conducted of TSP systems in North America with 24 agencies responding to full interviews. The interviews consisted of a standard questionnaire regarding the physical and operational characteristics of the transit route; the technical details of the traffic signal controllers, TSP software and vehicle detection systems; and other questions about the general details of the deployments (year deployed, number of signalized intersections, etc.).

The survey of the remaining 24 agencies demonstrates a wide variety of TSP applications. Several of the agencies indicated the use of very sophisticated TSP applications with advanced TSP hardware and software that utilize more sophisticated TSP strategies. At the same time, there are other agencies that are using TSP[1] in targeted applications. Additionally, three agencies reported the use of traffic signal pre-emption (rather than priority) strategies with their Light Rail Transit (LRT) and bus systems. Several agencies reported one or more routes/corridors with TSP systems currently in the deployment process that are not yet operational. The findings along with technical information about hardware and software are detailed in this document.

[1] Preemption requires terminating normal traffic control to provide the service needs of a special task such as a fire truck or railroad crossing.

Eight in-depth case studies were conducted in systems around North America. The systems ranged in size, application, and geographic location. Size varied from 15 to 654 intersections and from 12 to 1,400 buses. Some systems were centralized, some decentralized, and some distributed. Various methods were used for detection and communications. Two are integrated with AVL and five have some integration with Emergency Pre-emption. Costs for implementation and O&M varied and benefits were noted. All stated that the non-priority street impact was negligible.

This section includes a wide range of technical information to assist transit and traffic agency

PART III | TECHNICAL SUPPORT

staff planning TSP, including information about: TSP system architecture; traffic signal control equipment and software; and detection systems; communications systems.

Sections on traffic engineering terminology and key concepts are designed to help the transit planner understand and communicate better with traffic engineers. And a section on transit terminology is designed to help the traffic engineer communicate better with the transit planner.

Simulation and Optimization Tools for TSP

Some practitioners are strong proponents of using computer simulation to study and understand TSP before implementing it in the field. All agree that TSP works best when signal timing is optimized. One of the primary problems with the existing signal timing models is that they are designed solely for vehicular traffic rather than transit, pedestrians or freight. The implementation of TSP is an additional level of complexity that requires additional understanding of the signal controller's logic and even modification in some cases. Traffic simulation models provide an opportunity to assess the impact of transit signal priority. This document gives the reader a brief overview of these tools.

APPENDICES

In the appendices the reader will find a list of resources; a glossary; a full reporting of the eight case studies, and the detailed TSP survey forms.

Part I: Transit Signal Priority (TSP) gives transit vehicles a little extra green time or a little less red time at traffic signals to reduce the time they are slowed down by traffic signals. It is a cost-effective method to enhance regional mobility by improving transit travel times and reliability.

Part 1

TSP Planning & Implementation

1 INTRODUCTION

Objectives

Transit Signal Priority (TSP) gives transit vehicles a little extra green time or a little less red time at traffic signals to reduce the time they are slowed down by traffic signals. It is a cost-effective method to enhance regional mobility by improving transit travel times and reliability, thereby increasing the attractiveness of transit as an alternative to single-occupant vehicle travel. Its use is common in Europe, and is rapidly growing across North America. The growing interest in TSP led to the publishing of a document entitled, *An Overview of Transit Signal Priority*, which was a joint effort of the Advanced Traffic Management Systems Committee and the Advanced Public Transportation Systems Committee of the Intelligent Transportation Society of America (ITS America). Through the sponsorship of the U.S. Department of Transportation's Joint Program Office and Federal Transit Administration, dissemination concerning TSP was enhanced through the organization of several regional workshops and the updating of the overview document.

An Overview of Transit Signal Priority, available at http://www.itsa.org/tsp.html, provides a high-level introductory guide to implementing TSP and is a companion document to this handbook. While the overview does not have all the information one would need before embarking on a TSP project, it enables the reader to establish a basis of relevant knowledge and raises an awareness of many of the issues surrounding TSP planning, implementation and operation. It is intended as a first step for policymakers, managers, and technical staff with an interest in TSP.

Discussions among experts and interested parties identified a pressing need to assemble a more technically-oriented handbook, based on best available information and practices, to assist technical staff in the planning and implementing of a TSP project in their own community.

This handbook, prepared for the U.S. DOT, has four objectives:

- To outline a comprehensive process for planning and implementing TSP, based on a ***systems engineering approach***, that identifies many of the issues that may need to be addressed in a TSP project
- To provide more extensive information on the current state of the practice of TSP in North America
- To document a number of case studies of communities that have implemented TSP in order to highlight the variety of issues that arise and solutions that have been developed
- To provide a number of resources to those interested in TSP, including primers on traffic control equipment and systems, on key concepts (e.g. simulation and optimization), as well as on traffic engineering and transit terminology, to assist transit planners and traffic engineers in understanding one another

TSP can range from simple applications to very complex multi-technology and multi-jurisdictional programs. This handbook does not provide all of the technical solutions to actually carry out a do-it-yourself TSP project. An array of various kinds of technical expertise is needed to plan and deploy sophisticated technological solutions for integrating the simultaneous requirements of both transit and traffic engineering. However, the handbook does provide, based on best existing practice, extensive insight into the steps required and the issues that may need to be addressed during the planning and implementation of a TSP project or program.

PART I

1.2 Audience

This paper draws upon the existing body of knowledge embodied in the experiences and perspectives of practitioners. Anyone interested in TSP is encouraged to read the previously mentioned document, *An Overview of Transit Signal Priority,* to obtain an initial understanding of TSP. This handbook is intended for the more technically-oriented transit and traffic engineering management and staff members who wish to gain insight into the experiences with TSP in order to prepare for the planning and implementation of a TSP project or program.

TSP involves the development of a technical solution that includes both transit vehicles and systems, and traffic control equipment and their respective systems. In order to succeed, TSP must involve a partnership of transit and traffic engineering staff, and 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 more effective TSP initiatives.

USING THIS DOCUMENT: HOW TO AVOID BEING OVERWHELMED

This handbook is a reference that contains a large collection of information for a diverse audience. It is divided into three parts.

Part I – TSP Implementation – This part outlines the steps needed to implement a successful TSP project. It is based on a systems engineering approach which is straightforward and logical.

Part II – State of the Practice – This part describes what is actually in the field. Most of the information was gathered through extensive surveys and interviews.

Part III – Technical Assistance – This part provides good background information on traffic control equipment and software, and pertinent traffic and transit terminology.

The appendices contain a variety of valuable resources including:

- References
- Glossary
- Full case studies and surveys outlining TSP experience from across North America.

Throughout the document you will find boxes containing Key Questions. We hope these boxes will add to your knowledge base and will help you on your way to TSP implementation.

2 BACKGROUND ON TRANSIT SIGNAL PRIORITY (TSP)

2.1 What is TSP and What Are its Objectives?

TSP is an operational strategy that facilitates the movement of transit vehicles (usually those in-service), either buses or streetcars, through traffic-signal controlled intersections. Although signal priority and signal pre-emption are often used synonymously, they are in fact different processes. While they may utilize similar equipment, signal priority *modifies* the normal signal operation process to better accommodate transit vehicles, while pre-emption *interrupts* the normal process for special events such as an approaching train or responding fire

NTCIP[2] STANDARDS DEFINE TRAFFIC SIGNAL PREEMPTION AND PRIORITY AS FOLLOWS:

Preemption: Per NTCIP 1202 Version 2, the transfer of the normal control (operation) of traffic signals to a special signal control mode for the putttrpose of servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage, and other special tasks, the control of which requires terminating normal traffic control to provide the service needs of the special task.

Priority: The preferential treatment of one vehicle class (such as a transit vehicle, emergency service vehicle or a commercial fleet vehicle) over another vehicle class at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations. Priority may be accomplished by a number of methods including the beginning and end times of greens on identified phases, the phase sequence, inclusion of special phases, without interrupting the general timing relationship between specific green indications at adjacent intersections.

[2] National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP)

engine. Objectives of emergency vehicle pre-emption include reducing response time to emergencies, improving safety and stress levels of emergency vehicle personnel, and reducing accidents involving emergency vehicles at intersections. Light rail systems are also often equipped with pre-emption at grade crossings or intersections to reduce accidents. On the other hand, objectives of TSP include improved schedule adherence and improved transit travel time efficiency while minimizing impacts to normal traffic operations.

2.2 TSP Benefits and Costs

Expected benefits of TSP vary depending on the application, but include improved schedule adherence and reliability and reduced travel time for buses, leading to increased transit quality of service. Potential negative impacts consist primarily of delays to non-priority traffic, and these delays have proven to be minimal. Experiences from prior deployments generally indicate bus travel time savings on the order of 15% (depending on the exiting signal delay) with very minor impacts on the overall intersection operations. However, substantial variability exists in the nature of deployments and magnitude of impacts. At the end of this Handbook there are a number of case studies which demonstrate the commonalities and differences in TSP deployments. Costs are dependent on the configuration of the system, with somewhat higher costs associated with signal upgrades, equipment/software for the intersection, vehicles, or the central

Key Questions:

WHAT ARE THE QUANTIFIABLE BENEFITS OF TSP?

There are many. Case studies revealed the following:

- In Tacoma, WA the combination of TSP and signal optimization reduced transit signal delay about 40% in two corridors.
- TriMet (Portland, OR) was able to avoid adding one more bus by using TSP and experienced a 10% improvement in travel time and up to a 19% reduction in travel time variability. Due to increased reliability, TriMet has been able to reduce scheduled recovery time.
- In Chicago PACE buses realized an average of 15% reduction (3 minutes) in running time. Actual running time reductions varied from 7 to 20% depending on the time of day.
- With the implementation of TSP and through more efficient run cutting, Pace (Chicago) was able to realize a savings of one weekday bus while maintaining the same frequency of service.
- Los Angeles experienced up to 25% reduction in bus travel times with TSP.

HOW DO WE DEAL WITH POTENTIAL DISRUPTION OF TRAFFIC AND SYNCHRONIZATION?

Most agencies will not grant TSP at the same intersection in which TSP has just been granted until the signals are back in synchronization. That usually takes one or two cycles. Some agencies report that synchronization is never disrupted because TSP steals a small number of seconds from the non-priority street green and therefore stays in sync with the corridor.

It was uniformly reported that the impact to the non-priority street flow was extremely small or imperceptible. The number of seconds taken from non-priority street green is so small, it is rarely noticed.

management system. Many TSP systems have been implemented without costly upgrades. Because costs can be substantially affected by the desired functionality, comparisons with other TSP systems with different capabilities should be considered with caution.

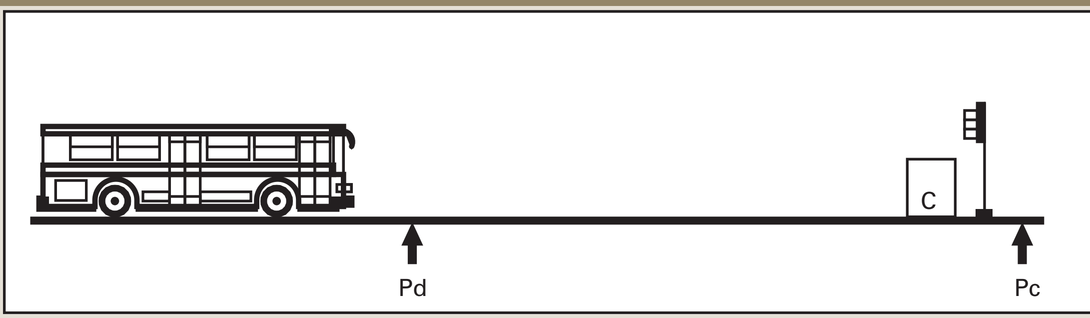
Given these excellent benefits, one might wonder about potential detriments. Does TSP cause problems and disruptions? That, in fact, is a key question, especially for traffic engineers who are rightly concerned about potential negative impacts on the traffic system. TSP deployments from around the country report uniformly that there is very little disruption to traffic flow. In fact, because so many cities included signal re-timing in their TSP projects, traffic flow became smoother and delays were reduced.

2.3 Key Components of TSP System

TSP systems may involve the interaction of four major elements, the transit vehicle, transit fleet management, traffic control, and traffic control management. These four sub-systems are then enhanced with four functional applications of vehicle detection, priority request generation (PRG), priority request server (PRS), and TSP control. Or more specifically:

- Detection - A system to deliver vehicle data, (location, arrival time, approach, etc.) to a device that is routed to a Priority Request Generator.
- Priority Request Generator/Server - A system to request priority from the traffic control system and triage multiple requests as necessary.
- Priority Control Strategies - A traffic control system software enhancement (ideally more versatile than pre-emption) that provides a range

FIGURE 1: TRANSIT PRIORITY AT TRAFFIC SIGNALS – A SIMPLIFIED REPRESENTATION



The general steps involved in providing priority are as follows:

- The bus approaching the intersection is detected at some point **Pd** upstream of the intersection (various detection methods exist).
- The Priority Request Generator unit is notified of the approaching bus and alerts the traffic control system that the vehicle would like to receive priority. The system processes the request and decides whether to grant priority based on defined conditions. The traffic controller **C** then initiates action to provide priority based on the defined priority control strategies. Typically, if the intersection signals are already displaying a green phase for the approach being used by the bus, the controller will extend the length of the green phase to enable the bus to pass through the intersection on that phase. If the intersection signals are displaying a red phase on the bus approach, the controller will shorten the green phase on the cross street (e.g., truncate the red phase) to provide an earlier green phase for the bus approach.
- When the bus passes through the intersection, clearance is detected by the bus detection system **Pc** and a communication is sent to the traffic controller that the bus has cleared the intersection.
- On being notified that the bus has cleared the intersection, the controller C restores the normal signal timing through a predetermined logic.

Derived from O'Brien, W. "Design and Implementation of Transit Priority at Signalized Intersections: A Primer for Transit Managers and a Review of North American Experience". Canadian Urban Transit Association STRP Report 15, Toronto, Canada, 2000, p.31.

"TSP Control Strategies" that address the functional requirements of the traffic jurisdiction.
- TSP System Management – Incorporates both traffic and transit TSP functions in both the transit management and traffic control management that can configure settings, log events, and provide reporting capabilities.

The concepts of Priority Request Generator (PRG) and Priority Request server (PRS) and their various configurations in a system architecture are discussed in more detail in Part III.

2.4 Potential TSP Control Strategies

Transit Signal Priority can be implemented in a variety of ways including passive, active and adaptive priority treatments as discussed below:

2.4.1 Passive Priority

Passive priority does not require the hardware and software investment of active and adaptive priority treatments. Passive priority operates continuously, regardless, based on knowledge of transit route and ridership patterns, and does not require a transit detection / priority request generation system. In general, when transit operations are predictable with a good understanding of routes, passenger loads, schedule, and/or dwell times, passive priority strategies can be an efficient form of TSP. One such passive priority strategy is establishing signal progression for transit. In this application, the signal timing plan would account for operational characteristics such as the average dwell time at transit stops, or considering that dwell times are highly variable, use as low a cycle length as possible. For example, in Denver the signal system uses cycle lengths based on the travel speed of the buses on the Denver Transit Mall so that the buses can stay in sync with the signals and so that the cross streets can be coordinated across the mall.

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, reducing cycle lengths, or coordinating signals on a corridor, may improve traffic flow and reduce transit travel time as well. Simply timing the intersection to minimize person delay, as opposed to vehicle delay, would be considered a passive strategy.

2.4.2 Active Priority

Active priority strategies provide priority treatment to a specific transit vehicle following detection and subsequent priority request activation. Various types of active priority strategies may be used if available within the traffic control environment.

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*** 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.

Generally early green and green extension strategies are available together within TSP enhanced control environments but are not applied at the same time. By definition[3] a "TSP" capable signal controller providing an early green or green extension will not negatively effect coordination.

The following Active strategies are generally available in most traffic control environments and may

[3] NTCIP 1211 Definition of Priority

not require a sophisticated "TSP enhanced" controller per NTCIP 1211[4] definition.

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

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

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.

2.4.3 TSP Operating in Real-Time

There are subtle differences between TSP with Adaptive Signal Control Systems and Adaptive Signal Priority, as described below. These are very sophisticated and complex systems and therefore not yet common. They provide a level of traffic control beyond what most of us experience today, but they are possibly the wave of the future.

Although an Adaptive Signal Priority built on top of an adaptive signal control system may offer more benefits, Adaptive Signal Priority does not have to be built on top of an adaptive signal control system. The work conducted in NCHRP Project 3-66[5] shows that Adaptive Signal Priority can be achieved upon the closed-loop system, although additional efforts are needed to address the insufficiency, incapability or inflexibility of traffic detection means, communication and signal controllers employed in the closed-loop system.

The priority strategies such as early green, green extension and phase insertion listed under the category of Active Priority apply to adaptive systems as well.

2.4.3.1 TSP with Adaptive Signal Control Systems

TSP with Adaptive Signal Control Systems provides priority while simultaneously trying to optimize given traffic performance criteria. Adaptive Signal Control Systems continuously monitor traffic conditions and adjust control strategies. When using Adaptive Signal Control Systems, it is possible to take into account person delay, transit delay, vehicle delay, and/or a combination of these criteria. To take advantage of Adaptive Signal Control Systems TSP would 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 combined with TSP also may 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.

[4] See NTCIP Standards Bulletin B0096 from the Joint AASHTO/ITE/NEMA Committee on the NTCIP, dated August 16, 2004 and found at http://www.ntcip.org/new/NTCIP_1211_SB.pdf#search='ntcip%201211

[5] National Cooperative Highway Research Program – Project 3-66, FY 2002, Traffic Signal State Transition Logic Using Enhanced Sensor Information: http://www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+3-66

2.4.3.2 Adaptive Signal Priority

Adaptive Signal Priority is a strategy that takes into consideration the trade-offs between transit and traffic delay and allows graceful adjustments of signal timing by adapting the movement of the transit vehicle and the prevailing traffic condition.

Typically, an adaptive TSP needs to have the following components: 1) a detection means that allows accurate prediction of bus time-to-arrival to the intersection in real-time when vehicle is within a specified range 2) traffic detection system; 3) a signal control algorithm that adjusts the signals to provide priority while explicitly considering the impacts on the rest of the traffic and ensuring pedestrian safety; 4) vehicle to infrastructure communication links; priority request generator(s) (PRG), a priority request sever (PRS) and a control system with real-time signal timing strategies to facilitate adaptive TSP.

The rest of the Handbook will focus on the application of active priority systems to transit vehicles in mixed traffic.

3 A SYSTEMS ENGINEERING APPROACH TO TSP

3.1 Systems Engineering Approach

TSP projects range significantly in their level of complexity. At their simplest, one can implement the insertion of a left-turn phase, actuated by a bus loop, that helps bus turning movements. At their most complex, a TSP program may involve the following: technological integration with a comprehensive transit ITS project (e.g. GPS, AVL, customer information systems, etc.); technological integration with EMS pre-emption; sophisticated conditional priority based on varying conditions of schedule adherence, complex communications from transit vehicle to controller via both the transit and traffic centers; multiple technological controller interfaces; and implementation involving a multiplicity of jurisdictions. It is clear that the project management requirements for a TSP project will vary greatly between these two extremes.

Irrespective of the size and complexity of the TSP project, it is important to use a systematic approach to the planning and implementation process. This Handbook recommends an approach that is consistent with good systems engineering, and is required by U.S. DOT for any federally funded ITS project[6].

The proposed steps are:

1. Planning
2. Design
3. Implementation
4. Operations and Maintenance
5. Evaluation, Verification, Validation and Building on TSP

Each of these steps is discussed in the following sections focusing in particular on the TSP-specific aspects of each of these standard systems engineering steps. The issues identified are based on information gathered from the in-depth case studies of successful TSP implementations in North America and from telephone interviews (full text is found in the Appendices), as well as from multiple discussions with experts.

3.2 Simplified Process for TSP at Isolated Intersections

The discussion of the steps involved in the planning and implementation of TSP, and the issues that may arise, has been structured to be as comprehensive as possible. It is worth noting however that a simple form of TSP can be used very effectively to address significant bus delay at isolated intersections. Examples include:

- The insertion of left-turn phases, actuated by bus detection, at major arterial intersections,
- The use of green extension or red truncation, actuated by buses emerging from minor cross streets (such as from residential subdivisions) onto major arterials, where standard timings for

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[6] For those interested in more information on ITS Systems Engineering, the ITS Professional Capacity Building (PCB) Program of the U.S. DOT has initiated a curriculum, entitled the ITS/SE Series, which is comprised of systems engineering courses designed for professionals involved in the implementation of advanced technologies for transportation: http://www.pcb.its.dot.gov/brochures/ITS_SE.htm

Another useful reference is entitled Building Quality Intelligent Transportation Systems Through Systems Engineering, prepared by Mitretek Systems Inc. for the ITS Joint Program Office of US DOT in 2002: http://www.its.dot.gov/JPODOCS/REPTS_TE/13620.html

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Key Question:

WHAT ARE THE STEPS FOR PLANNING AND IMPLEMENTING A TSP SYSTEM?

TSP Project Planning

- Needs Assessment [Why TSP?]
- Stakeholders: Roles and Responsibilities [Who is to be involved?]
- Concept of Operations (ConOps) and Requirements Document [What will TSP do?]
- Corridors and Intersections [Where will TSP be implemented?]
- Technology Alternatives Analysis and System Architecture [How will TSP work?]

TSP Project Design

- Detailed Data Collection and Inventory of Traffic Control System
- Detailed Design and Engineering for Central Control and Communications
- Systems Components
- Detailed Design and Engineering by Intersection Detailed Design and Engineering of On-Board Equipment
- Optimization and Preparation of Timing Plans
- Use of Micro-Simulation Model to Design TSP Control Strategy in Special Cases

TSP Project Implementation

- Procurement
- Installation
- Verification and Validation

Operations and Maintenance

- Ongoing Performance Monitoring and Management
- Procedures to Ensure System is Operating
- Maintenance

Evaluation, Verification, Validation and Building on TSP

- Evaluation Study
- Ongoing Data Collection
- Building on TSP Benefits through Transit Scheduling

low volume minor streets results in excessive delay for buses,
- The insertion of special bus-actuated bus-only turning phases for buses entering or exiting off-street terminals, etc.

In such cases, if the existing controller has the capability, the inclusion of relative simple TSP functionality actuated by simple bus detection (e.g. embedded loops in left-turn lanes or strobe emitters) can be a relatively straightforward initiative, not requiring consultant involvement or lengthy process for planning, procurement, installation, etc.

4 TSP PROJECT PLANNING

4.1 Introduction to TSP Project Planning

Transit Signal Priority (TSP) is a tool, and how it is applied can vary tremendously:

- It can be used as a straightforward tool to address significant delay experienced by transit vehicles at isolated intersections.
- It can be used to improve transit travel times and reliability along an entire corridor.
- It can be combined with other tools, procedures, and technologies to create a whole new

Key Question:

HOW DOES TSP RELATE TO AND ENHANCE BRT?

BRT is generally associated with a whole package of improvements including the combining of physical and signal priority measures (e.g. reserved bus lanes and TSP) with modified service attributes, such as increased stop spacing, enhanced stop design, level boarding, increased frequency of service, enhanced customer information (both on-board and at stops), new service control procedures (e.g. headway management rather than scheduled time points), attractive branding, exclusive lanes, etc. TSP is just one component in this toolbox. If traffic signals are slowing buses, TSP is an obvious tool for speeding them up. Although many cities have implemented TSP without BRT, few have implemented BRT without TSP.

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transit product line, as in the case of Bus Rapid Transit (BRT).

- It can be integrated system-wide with other ITS systems to deploy region-wide conditional TSP and pre-emption for EMS vehicles.

4.1.1 Regional and Corporate Goals

To create a well functioning transportation system, all transportation projects should be consistent with regional goals. Isolated projects can actually disrupt the transportation system and confuse drivers and transit passengers who have expectations of a smooth and seamless transportation system. As a practical point, a project that is consistent with regional and corporate goals is an "easier sell." In the absence of the support that consistent goals lend, it is hard to get a project off the ground.

Regional transportation goals are established by the local Metropolitan Planning Organization (MPO), Council of Government (COG), traffic agency or other regional or local authorities. They should be listed in regional planning documents, the Regional Transportation Plan, the Transportation Improvement Program, the regional ITS architecture, etc. If you are uncertain of what the regional transportation goals are, or where they can be found, you may be able to find them with a web search using keywords like regional+transportation+goal+yourcity or yourcounty, or by contacting the agencies listed above.

If you want to champion a TSP project and you are in a region that does not have "Transit First" or transit-friendly goals, you may want to work to establish more transit-friendly goals in your region. However, a web search of regional transportation goals revealed that virtually every region has stated some transit-friendly goals such as:

- Minimise adverse environmental impacts
- Provide adequate mobility for all persons
- Be cost-effective
- Provide for efficient travel
- Integrate various modes of travel

These goals as well as broad and sweeping goals like "improving air quality" or "increasing mobility" (to which it is difficult to imagine opposition) can be the basis for initiating a TSP project. TSP projects (when applied to corridors or intersections in which transit vehicles are experiencing delays due to traffic signals) are proven to improve transit service, which leads to increased mobility and improved air quality.

Key Question:

HOW DOES TSP FIT IN WITH REGIONAL INTEGRATION AND PLANNING?

TSP should fit into the goals and objectives that have been outlined for your region. If improving mobility through bus service is a priority for your region, you will want to conduct a study (which could be an in-house study) to determine what you need to do to improve bus service. If you would like to decrease transit travel times or increase transit reliability, and you determine through a Needs Assessment that traffic signals are slowing down your bus service, you will want to consider implementing TSP. As you begin to plan for TSP you will need to engage the regional stakeholders. You, along with your regional stakeholders, will work together to ensure that TSP is integrated into regional plans.

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In addition to helping to meet regional goals, TSP projects should be consistent with corporate goals. That is to say the TSP projects should be consistent with the goals of the transit agency, traffic agency, and the affected jurisdictions. Consistency with these goals is needed for the same reasons as the consistency with regional goals. This consistency will help produce a smoother transportation system and will make the TSP project a much easier sell. Hopefully, the traffic agencies and jurisdiction have adopted transit-friendly goals similar to the goals mentioned above. Again, remember that a simple goal such as "increased mobility" is a transit-friendly goal. More specific goals such as "reduce intersection delay," "improve corridor travel time," "reduce transit operating cost" are especially supportive of TSP. These goals can be met with a number of objectives such as reducing travel time, improving reliability, staying on schedule, maintaining transit headways, improving efficiency, and improving person throughput.

It is therefore important, prior to launching a TSP project, to identify pertinent regional and corporate goals in the local context, and to assess to what extent they support TSP, and alternatively to what extent TSP addresses these goals.

4.1.2 TSP as it Relates to the Regional ITS Architecture and Other Transit ITS Projects

TSP can be a stand alone system, or it can be integrated with a wide variety of other ITS projects (e.g. transit AVL, EMS pre-emption, etc.) As a result, the regional ITS architecture is an important resource and

Key Questions:

ARE THERE EXISTING PLANS FOR AN AUTOMATIC VEHICLE LOCATION (AVL) SYSTEM, AND IF SO, IS TSP TO BE INTEGRATED WITH THE AVL SYSTEM, AND THE ITS REGIONAL ARCHITECTURE?

There are many potential advantages for integrating the TSP and AVL systems. For example, this enables the possibility for lateness conditionality, as mentioned before. It opens up an expanded set of technological possibilities for the PRG/PRS system and for data collection, which is a major concern for TSP systems. However, it also greatly increases the complexity of the project, and will inevitably introduce major delays for TSP deployment. There are many facets to this question that need to be assessed based on local considerations:

- the urgency of implementing TSP,
- the status of the AVL project,
- the stated ITS priorities within the regional ITS architecture,
- the relative risks associated with stand-alone versus integrated projects,
- technological options available under different timeframes,
- the ability to integrate an existing TSP system into a future AVL system, etc.

The question of integrating TSP and AVL is very complex and all transit systems considering both AVL and TSP will need to grapple with it. The outcome of this process should then be incorporated into the ITS regional architecture.

ARE THERE PLANS TO PROVIDE EMS VEHICLES WITH SIGNAL PRIORITY/PRE-EMPTION?

Although the connection between AVL and TSP is obvious to transit agency staff, it is equally important to ascertain whether EMS pre-emption/pre-emption is being planned and whether any transit TSP project will need to be integrated with any existing or planned EMS initiative. This needs to be determined at the outset because it will affect objectives, stakeholders to be involved, technological choices, and design engineering.

The regional ITS architecture may provide an answer to this question, or it may have to become a key point of discussion in defining the TSP project's goals.

it will be important to review this document. If this document has been fully developed, it should provide guidance on numerous pertinent issues, including:

- the role of TSP and its priority,
- the stakeholders that will need to be involved,
- the status of other transit ITS, traffic engineering, and EMS pre-emption projects,
- funding priorities,
- projects in the pipeline,
- etc.

If it does not address these issues, the updating of the regional ITS architecture will need to be included as a task in the TSP project.

4.1.3 Regional and National ITS Architecture Conformity

The National ITS Architecture was developed to provide a unifying framework for ITS infrastructure deployment to ensure that technologies can work together smoothly and effectively. The National ITS Architecture and Standards Final Rule issued on January 8, 2001 requires that ITS projects funded by the Highway Trust Fund and the Mass Transit Account conform to the National ITS Architecture, as well as to U.S. DOT adopted ITS Standards.[7] Specifically, most State departments of transportation and metropolitan areas are required to develop a regional ITS architecture using the National ITS Architecture as a resource and to use a systems engineering approach for developing ITS projects. The deadline for completing a regional ITS architecture is April 8, 2005.[8]

The National ITS Architecture and Standards Final Rule means that:

- Regions *currently* implementing ITS projects must have a regional ITS architecture in place in four years. Regions *not currently* implementing ITS projects must develop a regional ITS architecture within four years from the date their first ITS project advances to final design.
- ITS projects funded by the Highway Trust Fund and the Mass Transit Account must conform to a regional ITS architecture.
- Major ITS projects should move forward based on a project level architecture that clearly reflects consistency with the National ITS architecture.
- Projects must use U.S. DOT adopted ITS standards as appropriate. To date, the U. S. DOT has not adopted any ITS standards, and a formal rulemaking process will precede any U.S. DOT ITS standard adoption.
- Compliance with the regional ITS architecture will be in accordance with U.S. DOT oversight and Federal-aid procedures, similar to non-ITS projects.

4.1.4 Standards (NTCIP and TCIP)

The transportation industry has recognized a need to provide voluntary standards to help reduce costs and decrease risk in TSP implementations. Without standards public agencies are sometimes hesitant to purchase equipment because they are not sure if it is compatible with existing equipment and software and because they might be "locked into" the same vendor in the foreseeable future. Standards will allow procurements of TSP hardware and software without concern for compatibility and will help open the market place for competition and price reduction.

The ITS traffic standards come under the umbrella of National Transportation Communications for ITS Protocol (NTCIP). From www.ntcip.org we find:

> The NTCIP is a family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. The NTCIP is the first set of standards for the transportation industry that allows traffic control systems to be built using a "mix and match" approach with equipment from different manufacturers. Therefore, NTCIP standards reduce the need for reliance on specific equipment vendors and customized one-of-a-kind soft-

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[7] US Department of Transportation, Federal Highway Administration, ITS Architecture Implementation Program, web page http://www.ops.fhwa.dot.gov/its_arch_imp/asflyer.htm as of March 9, 2005.

[8] Source: US Department of Transportation, Federal Highway Administration, Facilitating Intelligent Transportation Systems Deployment, web page http://ops.fhwa.dot.gov/aboutus/one_pagers/its_deploy.htm as of March 9, 2005.

ware. To assure both manufacturer and user community support, NTCIP is a joint product of the National Electronics Manufacturers Association (NEMA), the American Association of State Highway and Transportation Officials (AASHTO), and the Institute of Transportation Engineers (ITE). The NTCIP originated as the National Transportation Communications for Intelligent Transportation System (ITS) Protocol (NTCIP).[9]

This NTCIP data dictionary defines the management information base for Signal Control and Prioritization (SCP) systems through parameters that represent the configuration, status, and control information. NTCIP 1211 defines the functional entities of a Priority Request Generator and a Priority Request Server, which respectively originates and performs triage on requests. After performing triage in terms of importance and priority, the requests are sent to the Coordinator entity in a Traffic Signal Controller.

NTCIP 1211:

- defines data elements used for information management and operations of signal control prioritization (SCP).
- organizes functional requirements and user requirements, and contains scenarios and use cases. The NTCIP SCP WG invented the functional entities of a "Priority Request Generator" and a "Priority Request Server," which respectively originates and performs triage on requests. After performing triage in terms of importance and priority, the requests are sent to the Coordinator entity in a Traffic Signal Controller.
- includes the management of multiple requests for priority or preferential treatment of different classes of vehicles, such as tran sit, emergency service, and commercial fleet vehicles. This SCP standard defines a method of granting priority to one signal while maintaining coordination with adjacent intersections.
- is intended to work in conjunction with the coordination object definitions and functions defined in NTCIP 1202, Object Definitions for Actuated Signal Controllers.
- The NTCIP 1211 was developed by the Joint NTCIP-TCIP Signal Control and Prioritization (SCP) WG. The WG is chaired by Ron Atherley (Seattle/King County Metro). The SCP Working Group purpose is to develop objects to control traffic signal systems in priority applications.[10]

In addition to NTCIP standards which are being developed for and by the traffic industry, Transit Communications Interface Profiles (TCIP) are being developed for and by the transit industry. One of the business areas of TCIP is TSP. A DRAFT report by the TCIP Technical Working Group on TSP states in part:

> As the public transit vehicle (PTV) operates on its trips it may encounter intersections that are equipped to provide priority treatment to PTVs (e.g. early green, extended green, phase rotation) to allow the PTV to operate more efficiently. Equipped intersections and agreeing on acceptable strategies for TSP requires extensive coordination between transit agencies, traffic management, and traffic engineering. Although a Priority Request Generator may request priority treatment; the traffic management system is not obliged to, and may not, grant it.
>
> Commentary: The TCIP TSP business area draws heavily from dialogs, data and concepts defined in NTCIP 1211. This includes the Priority Request Generator (PRG). Priority Request Server (PRS), and all items defined in TCIP beginning with 'SCP'. . .

[9] Source: The National Transportation Communications for ITS Protocol ONLINE RESOURCE… http://www.ntcip.org/info/default.asp as of May 24, 2005.

[10] Source: The National Transportation Communications for ITS Protocol ONLINE RESOURCE… http://www.ntcip.org/library/standards/default.asp?documents=yes&qreport=no&standard=1211 as of May 24, 2005.

Priority Request Generators may consider any or all of the following in creating a priority request (based on data available to the PRG at the time the request is generated):

- Business Rules
- Schedule Adherence Status of PTV
- Time of Day
- Equipment Type at Intersection
- Passenger Loading on PTV
- Scheduled time for PTV's current trip to arrive intersection (many agencies do not schedule to this level)[11]

The TCIP information above comes from a "draft Standard intended for review by the TCIP Technical Working Groups and other interested industry parties. It has not been approved and does not reflect APTA or U.S. DOT policy."[12]

All standards are voluntary but as stated above, the National ITS Architecture and Standards Final Rule issued on January 8, 2001 requires that ITS projects funded by the Highway Trust Fund and the Mass Transit Account conform to the National ITS Architecture, as well as to U.S. DOT adopted ITS Standards.[13]

Those who are interested in implementing TSP will want to stay abreast of the status of emerging NTCIP and TCIP.

4.1.5 Relations between Transit and Traffic Staff

TSP can only be implemented through a solid partnership of the transit and traffic agencies respective staff. This requires a continuous dialogue and solid working relationship. Unfortunately, it is all too common to observe a total lack of communications between transit and traffic agency staff, for a variety of reasons:

- Their institutional structures are often divergent with transit operating an independent (often regional) authority, and traffic staff being part of city, county or state departments, with few reasons to interact.
- Their focus is often different (vehicle versus people movement), as are their respective objectives. Some successful TSP implementation jurisdictions have reached agreement that greater people movement (transit) reduces vehicles (traffic) and therefore benefits both.
- Their training, common tools, and professional terminology are also different.

Nonetheless, to succeed, TSP requires a solid partnership. In many instances, the TSP projects represent the first time transit and traffic staff work together, and therefore require the cautious building of a relationship. The more solid the relationship is before the initiation of a TSP project, the easier it will be to pursue, as will other projects such as physical priority measures. Building such a partnership at the outset will help ensure the success of planning and implementing TSP

4.1.6 Traffic Engineering Support

TSP projects vary considerably in their complexity. However, with the exception of very simple deployments at isolated intersections, or in very large agencies with deep expertise in all areas, it is likely that external consultant expertise will be required at some point in the process of planning and implementing TSP. It may be valuable as part of the local "pre-planning" assessment to review what expertise exists locally, and where external expertise may be required.

Potential external support may involve one or more of the following activities:

- Needs Assessment
- Evaluation and recommendation of where to deploy TSP (e.g. specific corridors and intersections) to meet project criteria
- Baseline ("before") studies for general traffic and transit conditions and delay
- Detailed intersection inventory and assessment

[11] 5.3.4.2.6 Transit Signal Priority (TSP), APTA TCIP-S-001 D2.6.1, APTA DRAFT Standard for Transit Communications Interface Profiles. Document referenced May 25, 2005.

[12] Ibid.

[13] US Department of Transportation, Federal Highway Administration, ITS Architecture Implementation Program, web page http://www.ops.fhwa.dot.gov/its_arch_imp/asflyer.htm as of March 9, 2005.

- Pre-TSP signal optimization and development of signal timing plans
- Development/calibration of simulation models for special assessments
- Detailed TSP timing plans for each intersection
- Technical support for field equipment installation (PRG, PRS, controller upgrades, controller connections)
- "After" data collection
- Evaluation study
- Periodic reviews of performance

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4.2 TSP Project Planning

The first phase of the TSP project or program is *planning*. At its heart, this phase is designed to answer a number of key questions concerning the structuring of the project, including:

- ***Why*** TSP?
- ***Who*** is to be involved?
- ***What*** will TSP do?
- ***Where*** will TSP be implemented?
- ***How*** will TSP work?

4.2.1 Needs Assessment [*Why* TSP?]

The first step is to assess the need for TSP. There are a variety of methods for conducting the *Needs Assessment*, depending on local practices in project justification. A comprehensive *Needs Assessment* might provide an evaluation of:

- the potential benefits of TSP,
- an assessment of feasibility,
- an initial assessment of costs and budget requirements, and
- the potential business case (benefits versus costs) for a TSP project / program. This could include a Return on Investment (ROI) analysis.

It is clear that such an evaluation will depend on the information available. If there is considerable uncertainty concerning how to scope the project (both technologically and geographically) and who will be involved, or insufficient information to conduct a meaningful benefit / cost analysis; then it may be necessary to first perform a broad high-level *Needs Assessment*, and prepare a the business case later on the project, once the *Concept of Operations (ConOps)* has been structured, and technology choices have been made.

The following provides some thoughts about information needed for the *Needs Assessment*.

4.2.1.1 Potential Benefits: Traffic Signal Delay and its Impact on Transit Travel Times and Reliability

Benefits that are directly related to corporate goals can be measured and evaluated more easily than generic benefits. For example, if the corporate policy objective is to increase transit modal share, we know, based on industry experience, that by improving transit travel times (relative to car travel times) we will increase transit's modal share. If the primary objective is to decrease costs to the transit agency and/or taxpayer, we need to ask ourselves a question (create a goal) that will help yield a measurable benefit concerning costs.

We can begin our assessment of traffic signal delay and its impact on transit travel times and reliability by taking field measurements or analyzing appropriate reports. Most transit systems do not have good information on the impact of traffic signal delay on their operations.

Transit planners need to ask questions such as:

- Is there measurable delay or unreliability due to traffic signals?
- How much delay could we save on a particular route by providing TSP?
- Has the cost (capital and operating) of intersection delay and congestion to the transit system been calculated?
- Have transit schedulers been consulted about the locations and extent of intersection delay?
- Has data on intersection bus delay already been collected?
- If not, are alternative approaches/sources available to collect time-distance data and measure intersection delay (for example, current AVL/APC systems can provide distribution of running times by route segment, by time of day, and day-of-week that can be used to measure vehicle speed and intersection delay)?

Answering these questions and assessing the magnitude of intersection delay will be the basis for assessing the potential benefits that may be derived from TSP. Posing the questions in a quantifiable format will make it possible to measure the benefits.

4.2.1.2 Transit and Traffic Data Collection

At the same time, in order to assess the costs of a TSP project and its feasibility, background information will need to be collected concerning the traffic control systems in pertinent jurisdictions. Examples of information to collect include:

- Initial survey of applicable traffic control and communications systems
- Characteristics of traffic control systems by jurisdiction (e.g. centralized, distributed, coordination, communication links, use of loops, EMS pre-emption, etc.)
- Types of controllers in use (or planned) by jurisdictions (and prevailing standard if any), and TSP compatibility
- Status of optimization of timing plans (time of day, areas, peak direction)

In addition, data related to bus operations will need to be collected, including:

- Capacity/level of service by time of day for major intersections along bus corridors
- Identification of any saturated intersections along major bus corridors
- Data on extent and impact of intersection delay on buses

At some point, detailed traffic data on intersection delay and queues will have to be collected. For the purposes of this model process, this data collection effort can take place during the "before" study of the Design phase. However, if the scope and location of the planned TSP deployment is known from the outset, then it may be feasible (and cost-effective) to collect that data during the initial Needs Assessment step.

Depending on the scope of the TSP project, it may be feasible to collect the background information through an in-house study in which technicians or planners observe and record pertinent information. There is no magic formula for the number of days this information should be collected or the times of day, but it is generally agreed that traffic data should be collected at high traffic times. Therefore, the best days of the week are usually Tuesday through Thursday and best times might be AM and PM peak hours. This depends on local circumstances.

4.2.1.3 TSP Project/Program Costs - Preliminary Assessment

The next step is to use the background information on the traffic control system as a basis for estimating the costs of implementing TSP. The background information will indicate whether existing traffic control software and controllers are TSP-compatible or not. The need to upgrade or replace traffic software and controllers is a critical issue to consider, since it represents the most significant cost items in the observed TSP projects. If existing software and controller equipment can be used, costs can be under $5,000 per intersection but rise to $20,000-$30,000 per intersection if traffic control equipment and/or systems need to be replaced.

Key Question:

ARE THERE PLANS TO UPGRADE OR REPLACE THE TRAFFIC CONTROL SYSTEM AND/OR TRAFFIC CONTROLLERS?

TSP by definition involves the integration of vehicle detection and action taken by the traffic control system. A major hurdle identified in many case studies was the inadequacy or lack of capability of the traffic controllers and/or of the traffic control software to actually receive priority requests and to be able to grant priority. The review of traffic equipment and software in Part III illustrates the complexity of this issue. In many cases, TSP can only be implemented by upgrading or replacing traffic control software and/or conrtoller equipment. It is critical that transit system staff interested in implementing TSP make themselves aware of the status of any plans related to the various traffic control systems in pertinent jurisdictions, so that the efforts can be integrated. This might include development of a standardized contoller for the region that may be initiated by the state DOT (e.g. Portland). I may be difficult or cost-prohibitive to introduce TSP after the fact.

The more specific the scope of the TSP project is from the outset, the more realistic can be the estimate of costs. Major cost elements include:

- Equipment - Detection/PRG (on-board or wayside)
- Equipment (PRS/interface to controller) and controllers (if required)
- Equipment - Communications
- TSP software (and traffic control system software if required)
- Installation and construction (if required)
- Traffic Engineering (traffic data collection, simulation, optimization, timing plans)
- Evaluation Studies (Before/After)
- Development Work (if required)

The costs can vary dramatically depending on the type of project and the extent to which field equipment must be upgraded. The traffic engineering staff should be able to give the team a good idea of the cost of upgrading the traffic equipment, if upgrading is required.

If the scope of the project is not yet determined, then the cost analysis can only be done at a high level, using ballpark assumptions. [The case studies in the Appendices provide some insights into actual experience with TSP costs.]

4.2.1.4 TSP Project/Program – Needs Assessment and Business Case

The above information on benefits and costs can in turn be used to assess the benefit cost ratio, return on investment, or other methodology used locally to evaluate capital investment decisions. The previous estimate of costs also provides a first cut at budgetary requirements. This can then be used to assess potential sources of funding, and to develop the necessary process for budgeting, programming, and securing funding.

4.2.2 Stakeholders: Roles and Responsibilities [*Who* is to be Involved?]

4.2.2.1 Identifying Stakeholders

The stakeholders will become the team that makes the TSP project happen. The old adage "a stitch in time saves nine" applies well to the stakeholder process. In the early stages of project development, it seems unnecessary and counter-productive to involve all the stakeholders. After all, it is much easier to accomplish any task in which there are no differing opinions. But later in the process, the value of early stakeholder involvement will become patently obvious. Stakeholders represent areas in which help is needed throughout the planning, design, procurement, installation, operation, and maintenance periods. Stakeholders also represent groups that can assist or bog down and even stop a project. The best way to ensure full implementation and operational success is to involve all the stakeholders in the beginning. Stakeholders who help define a project possess the irreplaceable feeling of ownership, and usually become the "Champions" of TSP for their agency.

The stakeholders will include representatives from the traffic departments of every jurisdiction in which you wish to have TSP, and representatives from every transit agency that will participate in TSP if it is a regional initiative. If you wish to integrate with EMS, you will need to bring in stakeholders from fire, emergency medical services, and police agencies as well. Many agencies have found that it is helpful to include representatives from the state and county departments of transportation, and metropolitan planning organization(s) (MPO) or councils of government (COG), in particular if they are the stewards of the regional ITS architecture. The extent of your stakeholder involvement will depend on the scope of your project and the players necessary to ensure funding, implementation, and maintenance.

Stakeholders internal to the transit agency include one or more representatives from planning, scheduling, administration, equal opportunity, contracts and procurement, risk assessment, quality assurance, operations, maintenance, finance and budget, engineering, IT, training, public affairs, and any other department or division that may be impacted by the project, or involved in its procurement. It may be useful to create in some cases sub-committees in order to focus the energy and involvement of some internal stakeholders on specific issues (e.g. procurement, training, publicity). Early involvement helps shape the project in ways that encourage stakeholders to find value in it and that allow stakeholders to understand the project and their role in it.

The importance of this early involvement really cannot be overstated. Many projects stumble or fail because of internal misunderstandings and turf battles. These stumbling blocks often can be avoided with early stakeholder involvement.

If the TSP project is complex, in addition to gathering the local stakeholders, it may be advantageous to create a peer review team from around the country. U.S. DOT will provide assistance to grantees, and ITS America will help members create such a team. The lead agency could use resources listed in this book including the case studies and the transit survey forms to form a team. The peer review team can help review RFP's, bids, proposals, and also answer questions by phone and e-mail.

4.2.2.2 Managing Stakeholders

The first step in managing stakeholders is to identify the players and invite them to a meeting. You may have a high response rate right from the beginning. If you do not get a good response, you may need assistance. You will know better how to make that happen in your region. Perhaps you can enlist the help of regional players who have some influence. The president of your ITS State Chapter or your local ITE Section may be able to help. To get the interest of the traffic department, you may have to offer an incentive such as the potential for upgraded or new traffic signal controllers for the department.

Generally, internal and external stakeholder meetings will be held separately because the two groups have a different focus. The first meeting of the stakeholders groups will set the tone for future meetings. As with all well planned meetings, invitations should be sent several weeks in advance clearly stating:

- Meeting purpose
- Meeting location with directions
- Agenda
- Start and end time

Key Question:

WE HAVE TO DEAL WITH MANY JURISDICTIONS. HOW DO WE GET THE STAKEHOLDERS TOGETHER?

There is no one way to build the professional relationships necessary to get the stakeholders to the table. In some areas, other projects have paved the way for cooperation. In other areas, the TSP champion had to start from scratch – trying to establish relationships between and among agencies that have historically been antagonistic because they have competed with one another for funding. Some have found that building relationships through local organizations such as ITE Sections and ITS State Chapters has helped bring people together for a common goal. Some organizations have hired professional facilitators to help lead visioning and/or planning sessions. One TSP champion says, "Never underestimate the power of stopping by the traffic engineer's office with a box of doughnuts."

In order to get "buy-in" from the traffic department, the transit agency may have to offer an incentive such as offering to fund a traffic study involving the re-optimization of signal timings, or upgrading or buying new traffic signal controllers for the department.

In other words, building relationships for the purpose of completing TSP projects is no different from building relationships in all other aspects of life. It takes a willingness to step forward and offer the hand of cooperation for the greater good. If all else fails, the ITS architecture points out that all stakeholders need to be at the table to discuss ITS project implementation. You may be able to get some support or ideas from your Metropolitan Planning Organization (MPO), Council of Government (COG), federal DOT representative, or ITS America.

Check the case studies at the end of this book to see how other implementers answered the question, "What were the institutional barriers?" and "How did you overcome them?"

* Any materials or preparation needed
* Contact information for the person setting up the meeting
* A request to respond to the invitation

The meeting should start and end on time, begin with a statement of purpose and introductions of all participants, and end with action items, next steps, and the date for a follow-up meeting if necessary. A signup sheet should be circulated and someone should be assigned the responsibility for taking notes. Action items should be assigned to specific participants with specific deadlines. If a meeting ends without any action items, it is a good indication that the meeting was unnecessary and could have been handled with a mailing (e-mail or other form); or that the meeting was not conducted well and therefore was not concluded as planned. Following the meeting, notes or minutes should be distributed to all participants and should reiterate action items, deadlines, next steps, and the next meeting date and location.

These ideas are presented to make the planning easier, not to add complication. Use your own judgment and remember that all is not lost if the above outline is not followed.

4.2.2.3 Project Management

Regional TSP projects are often made complex because of the multiple jurisdictions and agencies that need to be involved. The more complex the institutional setting for the project, the more critical is the project management function. Some of the issues that will need to be addressed include:

* Identification of Project Lead (champion)
* Definition of TSP planning project team and respective roles, responsibilities, and expectations
* Management of communications among stakeholders
    * Ground rules for communications, including roles for dissemination of internal information to an agency's non-project team members.
    * Meeting frequency
    * Notification of operating changes
    * Milestones
* Memorandum of Understanding / interagency agreements for planning, funding, installation, and ongoing maintenance (routine and non-routine). Agreements should also state when, how, and how much priority will be granted.
* Integration with regional transportation planning and planning requirements
* Linkage to the Regional ITS Architecture
* Linkage to other Transit ITS projects
* Integration with traffic control system upgrades
* Identification of pertinent experience with TSP in the region, state, or nationally on which to draw
* External consultant support requirements (what, when, and how?)

Depending on the complexity of the project, you may want to bring in more engineering expertise at any point along the way in the planning or design process. Some TSP projects can be completed using only in-house expertise with assistance from stakeholders. Other projects may require hiring outside expertise early on.

4.2.3 Concept of Operations (ConOps) and Requirements Document [*What* will TSP do?]

With an understanding of regional and corporate goals, and an understanding of the need for and benefits of TSP, the stakeholders can develop a *ConOps*, which defines what the TSP system will do.

4.2.3.1 TSP Project Goals, Objectives, and Vision

The first step is to have the stakeholder team define the goals and objectives of the proposed TSP project.

* Goals that have been stated in various TSP projects include:
* Improve travel times or reliability system-wide.
* Improve air quality by encouraging modal shift
* Improve travel time along strategic corridors through the combined use of different priority measures
* Create new BRT product line

Examples of more specific *objectives* include:

* Reduced excessive transit delay at particular intersections
* Reduced excessive transit delay along particular corridors

Key Question:

ARE OTHER PRIORITY MEASURES TO BE EVALUATED AND IMPLEMENTED ALONG WITH TSP?

If a goal is to improve transit travel times, a variety of other measures could be considered, evaluated, and possibly simultaneously implemented along with TSP, including:

- Increased bus stop spacing
- Updating signal timing plans
- Passive priority (retiming for signal progression for transit vehicles)
- Physical priority in traffic flow (separated bus lane)
- Reserved bus lanes
- Parking removal or prohibitions
- Turning prohibitions for general traffic with exemptions for transit
- Queue jumps
- Bus Bulbs (for stopping in-lane)
- Yield-to-Bus legislation
- Off-board fare collection
- Use of low floor buses
- Raised platforms for level boarding

In Europe and New Zealand, one frequently observes the combination of various priority measures (physical and signal) along strategic corridors that are renamed as "red routes" or "green routes". In other communities (e.g. Ottawa), a systematic effort is made to reduce transit delays at intersections by all measures short of signal priority, before introducing TSP. The transit system needs to assess to what extent a combination of measures can be implemented in an integrated fashion because this would be more effective overall, but would also change the nature of a TSP project or program.

- Improved reliability (schedule adherence or headway management)
- Improved efficiency (reduction in buses and labor required)
- Improved person throughput (person vs. vehicle-based philosophy)
- Improve signal timings for main street general traffic
- Minimize impact on general traffic on intersecting streets

Having defined the goals and objectives, it may be useful to define a TSP Program Vision Statement that can help articulate the reasons for implementing TSP and the scope of the program. It is also helpful in labeling, defining, and communicating the program.

The amount of potential funding will determine the extent and scope of the project. The vision may call for a much larger project than that which can be funded. In that case the project can be implemented in phases as funding becomes available. The case studies that are included in this handbook will give you an idea of what size project can be funded with the amount of money available.

Frequently, the vision and scope statement are crafted by the project champion or a task force formed from the stakeholders. The scope and vision would then be brought to the larger stakeholder groups for consensus. The funding agency will have final authority, but consensus among stakeholders can help move the project more smoothly.

4.2.3.2 Measures of Effectiveness (MOE) Resulting from Objectives

Using the revised objectives, the stakeholder team can identify the MOEs related to the objectives. The MOEs will be important later on, when the project is evaluated. You want to choose MOEs that are meaningful and that help you determine whether you have met your stated goals. To find that a project is not meeting the goals you had hoped to meet is not necessarily a failure, but

Key Question:

WHAT IS MORE IMPORTANT FOR THE TRANSIT SYSTEM TO OBTAIN THROUGH TSP: IMPROVED TRAVEL TIME OR IMPROVED SERVICE RELIABILITY?

To the extent that improved service reliability is a critical objective, and that the variability entails both early and late running buses, then priority should only be granted "conditionally" based on vehicle schedule adherence (or headway interval). This serves to assist late buses and reduce the variability of buses running 'hot'.

However, a requirement to grant priority based on a determined lateness condition requires a mechanism for continuously monitoring schedule adherence (or headway interval in cases where "headway management" is the basis of service control). An Automatic Vehicle Location (AVL) system can perform this function (e.g. Portland or Vancouver), or it can be structured through a sophisticated central traffic control system (e.g. Los Angeles). The information on conditionality will also need to be conveyed to the PRG/PRS system, increasing the communications requirement. In any case, a requirement for a "lateness conditionality" will result in a more sophisticated system and have strategic implications for the structuring of the TSP project/program.

On the other hand, if the goal is to simply decrease travel time, the system can grant priority to each bus that arrives at an equipped intersection within certain parameters. Those traffic system-related priority request criteria (e.g. recovery) allow the engineers to be more aggressive with the signal timing, since each bus is not requesting priority. Recovery generally takes one or two cycles. After the signals have recovered, they will grant priority to the next bus that arrives. This type of priority can be handled with signal software and does not require AVL, and therefore is much simpler and less costly to implement.

rather a new understanding of what works in certain situations. No matter how well the project meets goals, a good evaluation will give you information to help you decide future actions.

MOEs that have been used in TSP projects include:

- Reduced travel time for buses
- Reduced stop and signal delay for buses
- Reduced variability in operations or schedule adherence for buses
- Reduced recovery time at end of run
- Fuel savings
- Air quality benefits
- Reduced operating resources required
- Number of signal cycles to clear a queue before/after granting TSP
- Reduced queue on mainline
- Minimal delay to other vehicles
- Reduced accidents (pre-emption)
- Decreased travel time of emergency vehicles (pre-emption)
- Public response

4.2.3.3 TSP Concept of Operations (ConOps)

Having defined the goals and objectives of the TSP project / program, and the MOE's that result from these objectives, the stakeholders will need to review, discuss, and define the actual *ConOps*. This will define what the stakeholders want the system to be able to do from the users' point of view, and how it should function. The *ConOps* will later be used to define functional requirements and guide the choice of technology.

The Concept of Operations will clarify what the system will do from the users' point of view, and how it will be used. This will include a description, at a high level, of the major entities within the TSP system, the flows of information among those entities and to entities external to the system, the high-level capabilities of the system, and the main daily operational occurrences for the system, in particular through the definition of operational scenarios. There are various approaches to articulating operational scenarios, including the use of flow diagrams, or a more narrative approach, as in a "day in the life of the system…"[14]

[14] Building Quality Intelligent Transportation Systems Through Systems Engineering, prepared by Mitretek Systems Inc. for the ITS Joint Program Office of US DOT in 2002: http://www.its.dot.gov/JPODOCS/REPTS_TE/13620.html

In order to define the *ConOps*, stakeholders will have to examine and decide on a wide range of elements of the system that will define the system and how it operates.

Examples of system elements that will need to be defined might include:

- Centralized versus distributed control
- Integration with EMS pre-emption (Yes/No)
- Request Generator (PRG) conditionality requirment (Yes / No)
- If required, basis of conditionality:
  - Type of service (express or local)
  - Schedule adherence
  - Headway management
- Active Priority strategy choices
  - green extension
  - early green (red truncation)
  - actuated transit phase (access, egress from off-street terminal)
  - phase insertion (e.g. queue-jump)
  - phase rotation
  - phase skipping
- TSP Control Strategy Parameters (by intersection)
  - Extension time
  - Truncation time
  - Phase insertion points
  - Intersecting transit corridors (and rules for PRG/PRS, if yes)
  - Ability to use different levels of "low" priority
- Detection distance capability
- Check-in / Check-out mechanisms
- Traffic control system conditions
  - Handling of coordination
  - Windows in cycles for priority requests – frequency and duration
  - Recovery process (e.g. lock out of requests, other)
  - Jurisdictional Rules
  - Data to be collected

Determining the actual combination of operational functionalities and characteristics that best meet local requirements of the stakeholders may take considerable discussion and iterations.

The *ConOps* should also include an explanation of how the TSP project will be integrated with any pertinent traffic systems and procedures and EMS pre-emption requirements, as well as with transit systems and procedures. As discussed, this should also include consideration of the relationship of TSP implementation to any existing plans to modify/ upgrade/replace traffic control equipment and systems.

Having decided on the above key elements of the TSP system, a *ConOps Document* can be prepared and describe, based on the decisions made by the stakeholders, the TSP system and how it will function, as well as the operational and support environments that complete the picture of the TSP concept of operations. Elements to be included in the document include *high-level* descriptions of:

Key Question:

HOW MUCH PRIORITY CAN BE GRANTED?

This depends on many variables, including cycle length, complexity of phases, traffic on intersecting streets, protection of minimum clearance times for pedestrians, accuracy of check-out mechanism, etc. This will be the subject of considerable discussion between stakeholders. In addition, standard times granted for extension/truncation will have to be tailored to the specific conditions at individual intersections. The case studies in the Appendices provide examples.

However, once agreed upon, it is important to have this agreement on how much priority is to be granted formally documented in the Memorandum of Understanding or Interagency Agreement. In some jurisdictions, the seconds of priority granted (mysteriously) diminish over time and the TSP project is left with granting little actual priority. This can be avoided by having a written agreement that will help clarify expectations for the transit agency and traffic engineers, combined with an ongoing data collection/monitoring system. These mechanisms will be especially valuable as original participants are replaced by newcomers over time.

- Operational procedures describing what the users, and system components are performing, and under which specific conditions, (i.e. the operational scenarios),
- Equipment necessary for the system to be operational (e.g. signal controllers, loops, vehicle detectors, on-board equipment, etc.),
- Hardware necessary for system deployment,
- Software necessary for system operations,
- Interfaces with other ITS systems,
- Personnel necessary to operate and maintain the system,
- Facilities necessary to meet the needs of the fully functional system, in particular if TSP is to be combined with other priority measures (e.g. relocated bus stops, bus bays, turn lanes, etc.),
- Other support necessary,
- etc.

4.2.3.4 Requirements Document

The *ConOps* defines the operations of the TSP system and the control strategies the TSP system should be able to perform. This can be used to define the requirements for the system from a technical point of view, which will in turn be used to select the most effective technological solution for the defined requirements. Requirements should be clear statements of *what* is desired.

Developing Functional Requirements for ITS (FHWA-OP-02-047. April 2002.) defines Requirements as being, "…statements of the capabilities that a system must have, geared to addressing the [needs] that a system must satisfy."

1. Scope.
System identification, purpose and overview. Contents, intention, and audience for OCD.

2. Referenced Documents.

3. User-Oriented Operational Devices.
How mission accomplished: strategies, tactics, policies, constraints. Who users are and what they do:
- When and in what order operations take place
- Personnel profile; organizational structure
- Personnel interactions; activities
- Operational process models; sequence, interrelationships.

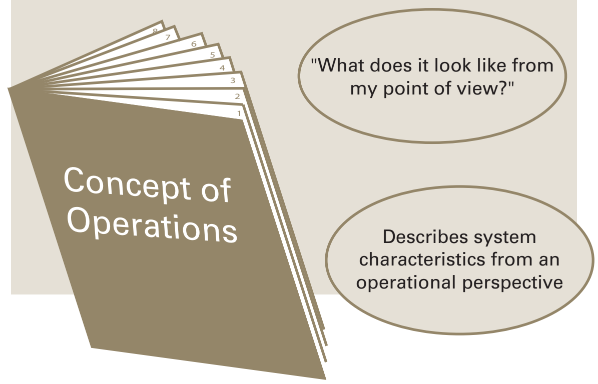
4. Operational Needs.
Mission and personnel needs that drive the requirements for the system.

5. System Overview.
Scope; users; interfaces; states and modes; capabilities; goals and objectives; system achitecture.

6. Operational Environment.

7. Support Environment.

8. Operational Scenarios.
Detailed sequences of user, system, and environmental events:
- Normal conditions
- "Stress conditions"
- Failure events
- Maintenance mode
- Handling anomalies/exceptions



Key Question:

WHAT SHOULD BE IN A CONOPS DOCUMENT?

In much of the literature on ITS systems engineering, the *ConOps Document* actually serves to summarize many of the decisions and core elements of the planning phase, including: scope, needs / justification, identified stakeholders, operational overview and scenarios, etc.. The ANSI/AIAA *Guide for the Preparation of Operational Concept Documents* (ANSI/AIAA G-043-1993) for example, provides a visual description of the core elements that might be contained in a ConOps document.

The specific contents of the ConOps document will likely vary from location to location, as well as over time, as experience with ITS systems engineering grows. What is most important is that there be a systematic process for answering the basic questions asked in this handbook, and that this be clearly docu mented.

Generally, there are two levels of Requirements: functional and non-functional Requirements. Requirements Engineering defines the difference as being, "…functional Requirements describe what the system should do and non-functional Requirements place constraints on how these functional Requirements are implemented." It is often the case, however, that these are combined into one general statement of overall system requirements.[15]

The *Requirements Document* will describe in much greater detail the concepts that were developed in the ConOps. The ConOps is for a general audience and the Requirements Document is for an engineering audience. It needs to contain sufficiently clear detail to allow the engineers to design, build, and operate a system. A Requirement is a statement of system functionality that conveys some task or objective that the system must perform or meet. Similar to the Concept of Operations development process, the Requirements development process is iterative.[16] As an example, the City of Seattle requires that controller software meet the following requirements for offering transit signal priority:

- Traffic signals shall extend their green interval for approaching priority vehicles
- Traffic signals shall shorten red displays for approaching priority vehicles

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Key Question:

WHAT ARE EXAMPLES OF TSP SYSTEM FUNCTIONAL REQUIREMENTS?

The following provides an illustration of *examples* of more specific types of requirements that may be outlined in the *Requirements Document*.

TSP Operation:

Two types of TSP operation shall be provided during both "Free" and "Coordinated" modes.

- TSP operation during "Free" operation shall increase the green time provided to transit phase/s and decrease the green time to the non-transit phase/s without interrupting the normal phase sequence.
- TSP operation during coordination shall increase the green time provided to transit phase/s and decrease the green time to the non-transit phase/s without adverse impact to signal coordination.

TSP Functional Features:

- TPR controller inputs shall be programmable to allow one or more phases to be selected for priority treatment.
- Any phase or compatible phase pair shall be programmable as the TSP phase(s)
- Provide capability to extend green intervals for the priority phase(s) (programmable by time-of-day)
- Provide capability to shorten green displays using programmable minimum phase duration for non-priority phases (programmable by time-of-day)
- Provide capability to retain normal vehicle and pedestrian clearance intervals. (programmable by time-of-day)
- Provide capability to serve all signal phases without changing phase sequencing.
- Provide transition back from priority mode that retains coordination.
- Provide override of priority input upon conflicting high-priority (emergency vehicle) call,
- Provide timer that prohibits the reservice of a priority treatment, (programmable by time-of-day)
- Provide delay timer that delays acting on the TPR input (programmable by time-of-day)
- Provide locking detection of TPR input, with release of lock upon serving priority phase
- Provide capability to operate during main street walk rest operation
- Provide a minimum of four (4) TSP Alternate Split Plans/TPR Input

These are merely examples provided for illustrative purposes, and the specific requirements in any given TSP implementation will need to be discussed and decided by the stakeholders.

[15] TMC Pooled Fund Study: Developing and Using Concept of Operations in Transportation Management Systems, Chapter 6. The Next Step: Using the concept of Operations to Drive Requirements, December 16, 2004, page 3. Found at http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/Chapter6_Final_Dec16_2004.doc May 26, 2005.

[16] Ibid.

- Traffic signals shall not shorten any minimum or clearance intervals
- Traffic signals shall not skip any phases
- Traffic signals shall not break coordination

It should be noted that the *ConOps* requirements might vary across different jurisdictions because of different traffic control software or controller equipment, or because of local policy. These variations will need to be reflected in the *Requirements document*.

PART I

4.2.4 Corridors and Intersections [*Where* will TSP be implemented?]

The next step is to define where TSP is to be implemented. This has been defined at a high level in the ConOps. (See "Boundaries on the Scope of the System.") The selection process depends on the vision and scope of the project. In some cases, the stakeholders can identify trouble spots immediately and the project can be structured to address these. In other instances, a corridor is pre-determined because it has already been chosen as a BRT corridor. Regardless, it may be necessary to perform an engineering analysis to prove to decision-makers and Board members that the project is warranted and likely to produce the desired results.

There may be opportunity for TSP deployment in conjunction with a new arterial management project or Transportation Management Center development. Stakeholders may be able to identify other projects in the region that will be complemented by or enhanced by TSP deployment.

The engineering analysis does not have to be an expensive endeavor. It is likely that the *Needs Assessment* that was done early on will suffice, since the data gathered may well match closely the first-hand knowledge stated by the stakeholders. But decision-makers often need documented evidence to back up funding decisions.

In some situations, such as the implementation of a TSP program in a large metropolitan region, it may be necessary to conduct a full-scale study in order to evaluate and select the most appropriate TSP corridors within the network. These studies may rely on various criteria (e.g. time savings benefits, service reliability benefits, transit use, transit potential based on census data, transit dependence, etc.). In some cases, specific evaluation tools have been developed to evaluate potential TSP deployment sites – such as King County Metro's TIM benefit / cost model or the Illinois RTA's regional assessment based on simulation tools.

4.2.5 Technology Alternatives Analysis and System Architecture [*How* will TSP work?]

The final step in the TSP planning phase is to select the most appropriate technology solution to meet the defined requirements, i.e. how the TSP system will work. This involves first defining a TSP system architecture, and then evaluating the alternative TSP technologies in light of the requirements and TSP architecture.

Key Question:

HOW DO WE PICK THE RIGHT SITES (INDIVIDUAL SITES, CORRIDORS, NETWORK) FOR TSP?

Picking the right sites relates directly to the goals and objectives of your project. Each intersection should present a problem (such as causing transit delay) that TSP can help resolve. Although every agency seems to have a slightly different set of criteria for picking TSP sites, nearly everyone agrees that you don't want to implement TSP at an intersection in which there is no delay caused by the traffic signal. Criteria listed by successful deployments vary widely and include: potential for bus rapid transit or express service; heavy traffic volume; number of passengers per hour; service frequency; amount of service disruption; level of transit use; transit potential based on census data; and transit dependence.

4.2.5.1 Definition of TSP System Architecture

Building on the *ConOps* and *Requirements* documents, the stakeholder team will need to develop the TSP System Architecture within which the technology will operate. A system architecture describes the overall framework of the system you are building. It refers to the physical system environment (hardware, networks, facilities) and the logical constructs (subsystems) that function in the pysical environment. It provides the blueprint on which to design the system[17].

For a TSP system architecture, this involves identifying the relationships between the vehicle, PRG, PRS, controller, and/or transit and traffic centers (as appropriate), as well as the required communications to link them.

The development of the architecture is likely to be an iterative process because it is co-related to the selection of the specific technologies for PRG/PRS and communications.

Figure 2 provides an illustration of one such architecture.

4.2.5.2 TSP Technology Alternatives Analysis

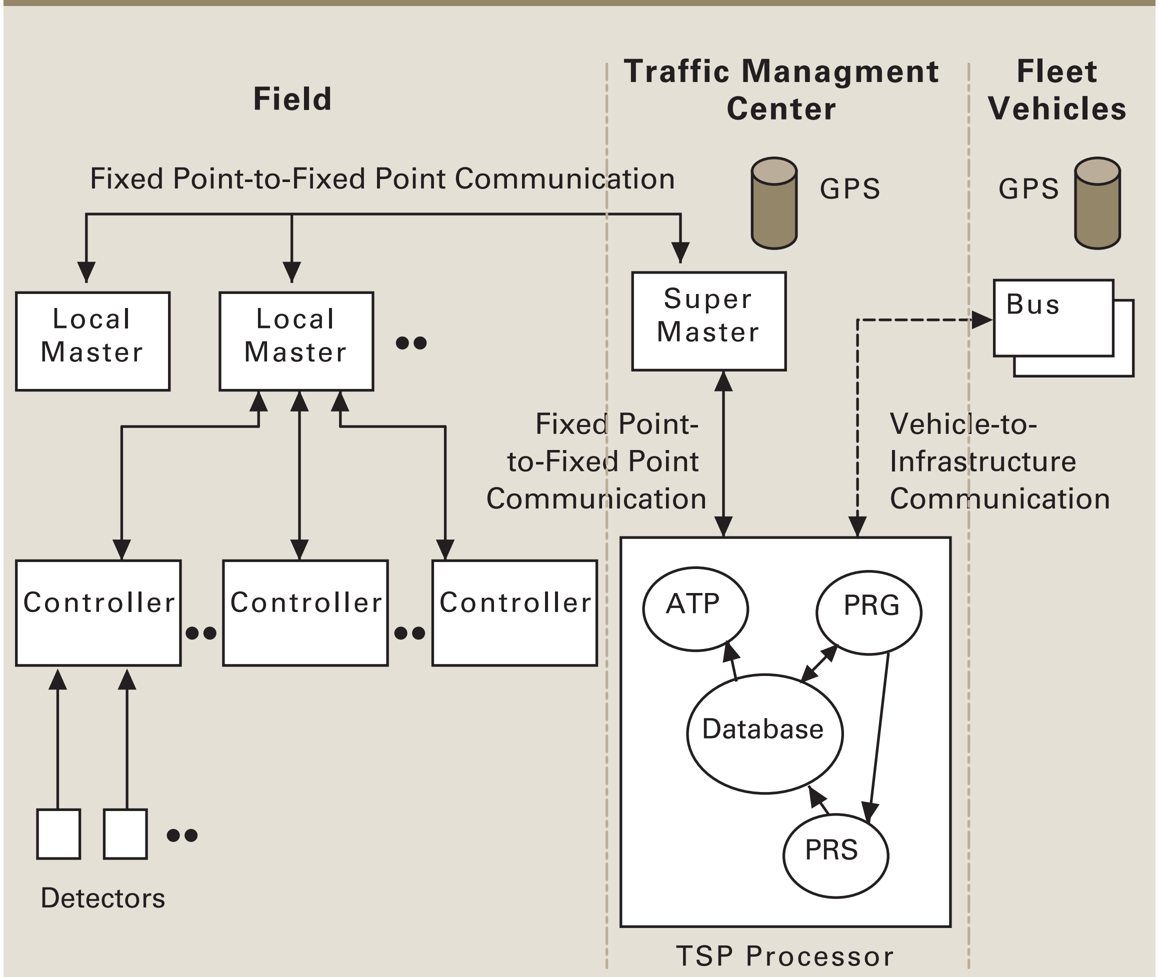
Special local conditions may affect the approach for selecting the TSP technology (including both PRG/PRS and communication links). For example, the technology selection process may be pre-determined in order to meet a constraining local requirement established by the stakeholders (e.g. integrate with existing EMS pre-emption system and equipment).

Typical steps for this technology evaluation process might include:

- Structure the technology alternatives analysis process (steps, participants, etc.)
- Develop evaluation criteria based on the

PART I

FIGURE 2 EXAMPLE OF TSP SYSTEM ARCHITECTURE (CALTRANS/PATH PROJECT)



[17] Building Quality Intelligent Transportation Systems Through Systems Engineering, prepared by Mitretek Systems Inc. for the ITS Joint Program Office of US DOT in 2002: http://www.its.dot.gov/JPODOCS/REPTS_TE/13620.html

functional requirements and TSP system architecture
- Identify alternative TSP system technology solutions
- Obtain information (this may include literature searches, site visits, use of simulations, and/or local technology evaluation tests)
- Evaluate any implications of technology selected on the functional requirements
- Evaluate and select

The results from the technology evaluation process may conclude that no technology currently exists that fully meets all identified *ConOps* and TSP system architecture requirements. This might lead to reviewing/revising the project requirements. Alternatively, it may lead to initiating a research and development effort to develop and test new products or systems that meet the desired requirements, as discussed below.

5 TSP PROJECT DESIGN

The TSP Planning phase defined the broad characteristics of the TSP system, including the *Concept of Operations (ConOps)*, *Requirements Document*, *TSP System Architecture*, and technology solutions. The design phase reviews the generic choices in light of the specific realities in the field (in terms of actual equipment layout, specific intersection geometric design, local traffic conditions, etc.) and translates these choices in ways that can be implemented corridor-by-corridor and intersection-by-intersection.

In reality, this phase will be carried out in parallel with the procurement phase as an iterative process in order to ensure that the technology functional requirements are consistent with the realities emerging from the design phase, but also to ensure that the design engineering is modified to meet any requirements of the specific technologies that are actually acquired. For example, final engineering of equipment in the field, in the controller cabinet, or on-board the buses, cannot take place until a vendor has been selected, and the final design specifications have been developed.

The discussion below concerns only issues related to the design of the TSP system. It is important to note that the design process will become more complex if TSP is being implemented in conjunction with various physical priority measures (e.g. bus lane, bus bulbs, queue jump, etc.), or as part of a BRT project, or as part of a comprehensive Transit ITS initiative. In these cases, TSP is only a component of a much larger initiative. However, many of the issues identified in this report will still need to be addressed.

5.1 Detailed Data Collection and Inventory of Traffic Control System

Once the *ConOps* has been defined and the corridors and specific intersections where TSP will be implemented have been selected, it will be necessary to conduct a major data collection effort. Data needs to be collected on current traffic conditions in order to refine the design of the TSP strategies; to measure the "before" conditions for use in any evaluation studies; and to provide a complete inventory of intersection geometry, field equipment, cabinet location and layout, communication lines, power supply, etc. This detailed inventory is used for detailed engineering and preparation of equipment installation and construction if required. Some of this information may be available; but most agencies have found that a significant data collection and inventory effort is needed.

Traffic Data that may need to be collected includes:
- Traffic volumes and turning movements - AM peak / PM peak / mid-day / all day
- Pedestrian crosswalk volumes
- Speed & delay studies (general traffic and transit vehicles)
- Free flow (floating car) travel times / speeds
- Turn movements & volumes
- Level of Service
- Delays / queues

In addition, it may be valuable to collect bus data:
- "before" dwell time / travel time
- variability of travel time by time of day
- layover / recovery times at end of routes
- bus stop activity (ons / offs)
- transfers
- pedestrian movements of transit riders

In lower traffic the street network performs best. In high traffic there is often a breakdown in traffic flow at intersections. Signalized intersections constrain the traffic and then release it in platoons. In the best of circumstances, the platoon will proceed smoothly to the next intersection, reaching the signal just as it turns green. One reason traffic engineers sometimes have a bias against buses is that buses stop frequently making it relatively impossible to maintain a smoothly flowing platoon across lanes. But then all vehicles entering and exiting through curb cuts and stopping before turns to allow pedestrian movements interrupt the traffic flow. These disturbances are generally in the right hand lane. Sometimes turns are made into driveways from the left lane. Data should be collected in the lane(s) that best represents the general traffic flow.

5.2 Detailed Design and Engineering for Central Control and Communications Systems Components

Depending on the system architecture and technology solutions selected and procured, there may be required modifications to the central control system and to the communications network. Any modifications to these systems will need to be designed and engineered.

5.3 Detailed Design and Engineering by Intersection

Similarly, all installations in the field (new equipment, new connections, cabinet modifications, new loops, new detection equipment, etc.) will need to be designed and engineered, intersection-by-intersection. Although templates can be prepared in advance, there are always peculiarities in the field that will be encountered and that will need to be addressed case-by-case. This is a very labor-intensive effort.

As part of the TSP program, the option of relocating bus stops to the far side of the intersections should be investigated because of the previously mentioned benefits. The relocation of the bus stop will need to be assessed in light of various considerations, including: bus passenger activity and movement, traffic patterns, street geometry, pedestrian activity, community design, etc.

5.4 Detailed Design and Engineering of On-Board Equipment

Most TSP technologies involve the installation of on-board equipment. The installation of this equipment requires engineering; this is the case in particular, if the equipment is mounted externally and therefore vulnerable to damage from bus washers or road collisions, or if the technology requires line-of-sight accuracy for detection. Generally, such engineering needs to be done only once for every bus model.

Key Question:

IS A "FAR-SIDE" BUS STOP PLACEMENT POLICY FEASIBLE?

The near-side/far-side bus stop placement debate has existed within the transit industry from its very beginnings with strong arguments for each side. However, the placement of a bus stop on the far side of an intersection provides many advantages in the design of a TSP system. It will help disentangle the bus from conflicts with right-turning general traffic. It will simplify the green extension calculation and make the vehicle's "check-out" more accurate, thereby ensuring that the green phase is only extended as much as is really needed, rather than based on a prediction of stop dwell times. This should free up more green time for transit vehicles overall and reduce the need for recovery where subsequent buses are locked out from receiving priority. However, the decision to move well-established bus stops is a difficult one for transit systems, and may involve various ramifications, including stop/shelter relocation costs, conflicts with local residents and retail owners, and unintended or undesired pedestrian movements

5.5 Optimization and Preparation of Timing Plans

After installation of the TSP software, it will be necessary to optimize the traffic control system and prepare new signal-timing plans (see discussion of optimization in Part III). Where financial resources are constrained, signal plans may not have been reviewed or updated for years. In some of the case studies, the re-optimization of signal plans was in fact a major benefit to the general traffic, — including transit — that would not have occurred without the TSP project. In at least one case (i.e. Pierce Transit), these benefits were specifically documented through the evaluation process, by conducting two distinct "after" analyses, the first after general traffic optimization but pre-TSP installation, and the second after TSP installation and post-TSP optimization.

5.6 Use of Micro-Simulation Model to Design TSP Control Strategy in Special Cases

In some cases, TSP-compatible micro-simulation tools (such as VISSIM) are used to conduct more sophisticated analyses of a complex situation or to evaluate corridor impacts (see Part III for a description of these tools). These tools require more data and effort to calibrate than standard engineering models, but are sometimes useful because they specifically model the impact of TSP and the benefits to transit vehicles. In addition, they are visually stunning and provide valuable supports for presentations to decision makers.

5.7 Special Considerations

5.7.1 Developing and Deploying New or Enhanced TSP Technologies

TSP technologies are evolving rapidly. New approaches to detection and communication, including the combination of GPS and wireless communications, are being considered, developed, or deployed as part of more recent TSP technologies. New controller and ITS standards are being developed and deployed. New approaches to ITS data collection, transmission, and archiving are also emerging. This evolving situation offers great opportunities to develop increasingly more sophisticated technical solutions to address the limitations of older approaches. It also means that there are fewer off-the-shelf technical solutions. The case studies highlight several instances where transit and traffic agencies became involved in development efforts to create a more flexible controller interface (e.g. King County Metro) or a system for collecting data (e.g. Pierce Transit).

You may have the opportunity to be on the leading edge and chose to develop or deploy a new and unproven technology as part of your TSP project. If you have funds for research and development, it is laudable to advance the state of the technology. This may yield a more effective solution to meet your local requirements and is good for the industry, but is higher risk than implementing an older proven technology with limitations. One should weigh the options carefully.

The decision to embark on a "development" effort will need to be carefully integrated into the overall TSP project, and will need to address such issues as:

- Funding sources and implication (e.g. supplemental evaluations studies)
- Related risks and their impacts on project management (e.g. schedule)
- Process for managing the required R&D
- Specific requirements related to acceptance testing (for hardware and software)
- Ownership of intellectual property
- Procurement costs for distributing the products developed under this initiative to other potential jurisdictions in the region

5.7.2 Integration with Planned Transit ITS Project

The potential integration of a TSP project into an overall transit ITS project has been identified as a strategic consideration. Some of the specific design-related issues include:

- Sequencing / phasing of design and engineering activities
- Degree of modularity of the TSP component within the overall ITS project
- Design of process for assessing defined "conditions" and the generating of priority requests based on these conditions
- Archiving of PRG request data

5.7.3 Integration with EMS Pre-emption

Similarly, it may be necessary to analyze the implications of integrating TSP with EMS pre-emption. Issues to consider include:

- Integration of legacy EMS pre-emption system with TSP
- EMS services to receive priority (e.g. fire department vehicles only?, or all EMS vehicles?, necessary approvals (e.g. state legislative requirements), and implications for project management
- Implications for TSP priority strategy choices and parameters, especially if TSP and EMS pre-emption are not simultaneously implemented in the same jurisdictions
- Resolution of conflicts between different levels of priority (e.g. priority vs. pre-emption)
- Upgrades for existing EMS vehicles

6 TSP PROJECT IMPLEMENTATION

6.1 Procurement

6.1.1 Project Management – Procurement and Deployment

After the TSP system has been planned and designed it will move into the procurement and deployment stage. Throughout the procurement and deployment process the lead agency will have the responsibility to maintain documents in an orderly manner so they can be retrieved in the future to use as a model, settle disputes, or to build upon the existing system.

In addition, it may be valuable, if this has not yet been done, to develop more formal Memoranda of Understanding or Interagency Agreement documents to clearly state financial, operating, and maintenance obligations as well as ownership of equipment. This becomes more important once financial resources are to be committed to ensure there are no misunderstandings that could become serious conflicts between stakeholders down the road.

6.1.2 Procurement Strategy

At this point the project manager will either be happy he/she has included someone from the contracts and procurement office as an internal stakeholder, or be woefully sorry she or he has not. Each agency has rules about procurement that cannot be sidestepped. Having a procurement officer on the team early on helps assure that the procurement office has some understanding of the project planning and design and will work with the project manager to create a smooth procurement process. If no one from that office was involved in the early stages, the project manager must now brief the office and bring them up-to-speed. The procurement office needs to understand the intent of the project as well as the technical aspects.

The method of procurement will most likely be either by bid or by RFP. If the design process has resulted in a bid document, the procurement will be a bid. In a bid process responders state that they will meet the design exactly as specified and give the cost.

If the design process resulted in functional specifications, then an RFP should be created. This appears to be the more common approach for TSP, given the complexity and potential design variations that are inherent in TSP projects.

An agency would chose to use the bid process if the agency has available (either in-house or hired) the expertise to write a detailed design document; that specifically outlines the required technical solution, to the exclusion of potential other approaches. It also assumes that there is no uncertainty as to the ability of the required technology to meet the *ConOps requirements*. Sometimes the design is dictated by other actions already taken in the region, and a bid document makes sense. Once the design is complete, the bid process is straightforward and does not require intense involvement of the stakeholders.

An agency might chose the RFP process if they are know what functions they want but are looking for alternative approaches to meeting a diverse set of requirements. The RFP process also allows responders the opportunity to be creative with solutions that the client may find more attractive than their own ideas.

PART I

The stakeholder team will need to decide what procurement strategy to pursue and carefully lay out the procurement process, including milestones, communications managements, evaluation process and criteria, approvals requirements from the various jurisdictions, etc. All agencies have experience with their own procurements processes; the main issue in a TSP procurement is that it involves multiple stakeholders who most likely have not worked together previously in a joint procurement, and likely operate under different procurement rules and processes. It is helpful if all differences in stakeholder procurement processes are discussed and clarified prior to starting the process so that there are no surprises later on.

6.1.3 Preparation of RFP's and/or Bids (Procurement Documents)

Generally it is a good idea to create a functionally-based RFP to allow responders to tell you how they would address the issues you state, and encourages creative solutions. The responder(s) will respond to an RFP with a design the responder believes will meet the client's needs. It will explain the proposed technology and how it will meet the functions requested. It will also include cost information. The response may state certain assumptions about the existing situation and equipment at the agency saying that based on these assumptions, the cost would be X dollars. The RFP process allows responders the opportunity to be creative with solutions that the client may find more attractive than their own ideas, and it may recommend technological solutions that the agency hasn't even considered.

The RFP may be prepared in-house if the agency has sufficient expertise. This is not an area in which an agency wants to scrimp. Poorly prepared RFP's and bid documents cause misunderstandings and destroy credibility. They rarely result in useable proposals, so they waste valuable time for the requesting agency and those who propose. If in-house expertise is not available, the agency will want to contract with someone who is experienced in writing RFP's for TSP. In finding the right person or firm to do this work, the agency can follow normal contracting procedures. Most agencies will want to be sure to ask for a list of successful projects that resulted from the contractor's RFP writing. It is also a good idea to follow up on references by contacting someone at each agency listed to be sure the contractor actually did the work that is claimed and that the RFP resulted in practical proposals.

The RFP or bid documents should require:

- All functions the agency wants performed including an explanation of how the responder's TSP solution will handle the:
    - Planned control strategy
    - TSP control strategy parameters
    - Circumstances (conditions) under which priority is to be granted
    - Detection distances required and to be used
    - Check-in / check-out mechanism
    - Required accuracy of detection mechanism
    - Technological approach to detection / Priority Request Generator (PRG)
    - Technological approach to Priority Request Server (PRS)
    - Data collection at PRS and at the controller, and archiving process
    - Interfaces with on-board ITS systems (if required)
- A listing of any data the transit agency or traffic engineering office wants collected
- A listing of any reports the transit agency or traffic engineering office wants created with collected data
- Access to data and the ability to create future reports
- Compliance with specified ITS standards
- A listing of special considerations for any tech logical interfaces (e.g. AVL, TMC, traffic controsytem upgrade)
- A description of compliance with open/nonpropretary hardware and software requirements, or software escrow requirements
- Required design and engineering for installation at intersections
- Required design and engineering for installation / interface with central control and communications systems
- Creation of a process for testing and proving

pre-defined reliability and acceptability of all equipment before it is installed in the field (this may include inspection at the fabricator's facility before shipment)

- Completion of the pre-installation testing process before installation
- A clear description and schedule of any installation of equipment and software required of the supplier by the RFP
- A clear description and schedule of when and where equipment will be installed on buses (The transit agency may need to provide garage space for the installers to work on buses. Be aware of conditions such as weather and lighting that need to be clarified.)
- A clear description and schedule of when and where equipment will be installed in the field. (The traffic engineering office will be intensely involved in this process because field installation has the potential of disrupting traffic. Consideration must be given to time of day, day of week, placement of installation equipment, signal disruption, and potential traffic hazards.)
- Clear delineation of responsibility for obtaining any right-of-way and electrical permits if supplier is to be involved in installation
- Post-installation testing of all installed equipment and software
- Documentation of equipment installed, which might include:
    - Wiring diagrams
    - Installation drawings
    - Detailed description of timing plan adjustments made by priority type
    - Documentation for any special equipment, cards, and/or relays
    - Catalog cuts and shop drawings of equipment stating specifications for each piece of equipment
    - Manuals for maintenance and operations
    - Equipment warranty information
- Development of training documents for operation and maintenance personnel including bus operators, mechanics, and field technicians who will deal with any and all TSP equipment
- Performance of training for operation and maintenance personnel including bus operators, mechanics, and field technicians who will deal with any and all TSP equipment
- Warranty period including any additional training that may be required

6.1.4 Vendor Selection Process

After bid documents or RFP's are distributed, it is often good to have a Pre-Bid (or Pre-RFP) Conference where any potential bidders or responders are invited to ask questions about the project in a forum where all can hear the questions and the answers.

In a bidding-process selecting the winner is fairly simple. Based on the criteria used by the agency, such as low bid, the winner will be identified.

The RFP selection process is more involved. Most agencies create a team to review proposals and select a vendor. The team will be drawn from the already-identified stakeholders. If there are questions as to the meaning of statements in the proposals, the team may want to have a meeting with each vendor to clarify all issues in the proposals. If that occurs, there will be another round of "best and final offers." (Most TSP projects are not so complicated as to require this second round.) The review team will examine all proposals based on a list of criteria the team has created. Usually points are allocated to each criterion. Examples of criteria may include: response to technical specifications, experience and responders' record of on-time completion, financial resources, price, meeting equal opportunity goals, etc. These are just *examples* of criteria. Your criteria will relate to the mission and goals of your organization. After adding and averaging points, the winning responder will be identified.

After the stakeholder team has selected the successful responder and informed all respondents as to their selection or non-selection, there may be further negotiations and clarifications with the successful responder/vendor. Good communication with the vendor at this point can prevent lost time, misunderstandings, future change(s) of scope, and in extreme cases — lawsuits.

6.2 Installation

6.2.1 Equipment Installation

After the vendor is chosen and contracts are finalized the equipment installation process can begin. The lead agency must provide one point-of-contact for the contractor so that there is no danger of scope modification by someone in the agency who is not authorized to modify the contract. The point-of-contact will be the only person who can authorize a change in scope, schedule or payment. The lead agency will be responsible for overseeing step-by-step every aspect of the contract and, through the point-of-contact, will give the vendor/installer feedback along the way to avoid surprises at the end of the contract.

To avoid large-scale headaches, all equipment should be pre-tested and proven before installation. The stakeholders representing risk assessment and quality control will want to be sure all equipment functions properly and may have a process in place to ensure quality of equipment. The vendors generally have standard tests to demonstrate the proper function of the equipment including software, hardware, and the PRG/PRS systems. If the vendor does not have a standardized test, then the vendor will be required to create a test as was stated in the procurement documents.

6.2.1.1 Installation of Bus Equipment

The stakeholders in bus operations — who have been involved since the beginning of this process – will move into a more active role to oversee equipment installation on buses. The transit agency will have to make buses available to the contractor for installation. This is an important consideration because buses may have to be taken out of service during installation. Some vendors will install at night but they may charge a higher fee for night work. These issues will be handled easily with good communication. If possible, these installation conditions should have been specified in the procurement documents. Bus maintenance is not unusual for transit agencies; and vendors understand the problem of taking buses out of revenue service. The important issue is that agreement is reached early on to avoid unpleasant surprises.

6.2.1.2 Installation of Field Equipment

The case studies illustrated that one of the most labor-intensive aspects of any TSP project is the installation of equipment in the field. This may involve any or all of the following tasks:

- Installation of detector/PRG units on arm masts or utility poles
- Connection to power lines
- Installation of PRS unit, sometimes within controller cabinet or nearby
- Connection of PRS to power and communication lines and controller
- Cutting of new embedded loops in pavement
- Replacement / relocation of controller cabinet and possible construction of new concrete pad and connections
- Remote or on-site downloading of software and/or new signal settings to controller

The traffic engineer(s) representing the jurisdiction(s) in which field equipment will be installed will need to oversee installation of field equipment and connection to controllers and power. The traffic engineering office will have to coordinate with the vendor and/or engineering consultant for field installation, and the vendor will have to conform to the traffic engineering office's accepted procedures for field installation to reduce liability. Consideration must be given to time of day, day of week, placement of installation equipment, signal disruption, and potential traffic hazards. Construction contractors may also be required in some cases (e.g. loop installation, relocation of controller cabinets), or if TSP project involves reconfiguring road geometry (e.g. queue jump).

If the TSP program involves bus stop relocation, the transit system will need to develop a parallel but coordinated process to address repositioning stops and shelters.

The stakeholders from the respective IT departments can help oversee the installation of any central software.

6.2.2 Training

The RFP/bid documents should require the vendor to:

- Develop training documents for operations and maintenance personnel including field technicians, bus mechanics, bus operators, etc., who will deal with any and all TSP equipment
- Perform training for operations staff and bus operators
- Perform training of transit maintenance personnel including mechanics
- Perform training of field technicians who will deal with any TSP equipment in the field and/or connections to controllers

Many agencies have found that the "train the trainer" technique works best. In other words, the vendor will train a smaller numbers of personnel who will then train others. Regardless of whether the agency requires the vendor to train all or a portion of pertinent positions, the agency needs to develop a plan for training new hires in the future. This can be accomplished by adding the TSP training to the standard training for bus operators, mechanics, and field technicians.

Many agencies do not feel that any TSP-specific training is needed for bus operators. If the operators have no control over the TSP equipment, they simply obey traffic signals. If the drivers have any role to play in testing equipment, turning it off or on, or reporting problems, then some training should be provided.

6.2.3 Internal Communications

There is an observed tendency for TSP projects to be carried out by the dedicated staff in relative isolation of other internal transit staff. This is a natural occurrence because the TSP functionalities do not significantly impact ongoing transit operations and maintenance activities. Most TSP systems today do not require bus operator involvement and require minimal maintenance of on-board equipment. In addition, the most active dialogue is with external stakeholders (traffic engineers and consultants / suppliers). This typically provides the TSP Project Manager with considerable autonomy, but also makes more difficult cooperation with other departments that are not actively involved. It has been previously argued that internal stakeholders (e.g. scheduling, procurement, operations, and maintenance) need to be included from the outset. Given the nature of TSP projects, and the relative isolation within the transit agency, it will be important for the Project Manager to strive for the proper balance in internal communications: to keep internal stakeholders and decision makers (e.g. management, Board) informed of progress without creating an onerous task.

One point may be worth highlighting. As the TSP system is being installed and starts to generate results and data, this may be the appropriate time to enter into a more active dialogue with staff from

Key Question:

HOW WILL THE TRANSIT SYSTEM TAKE ADVANTAGE OF ANY TRAVEL TIME SAVINGS CREATED BY THE TSP SYSTEM?

The transit system's scheduling department should reflect on this issue to ensure that any travel time savings are not just lost in increased time spent by the vehicle and the operator sitting at the end of the route. This creates several requirements. First, the transit system will need to have a mechanism for continuously monitoring running times so that the improvements in travel time and the reduction in their variability, created by the TSP system, can be identified. State-of-the-art APC or AVL systems are well geared to provide such information, or the TSP system itself may be structured to gather this information. Some transit agencies use personnel (ride checkers) to gather running time information, but this approach will require a concerted effort to concentrate the use of the checkers on the TSP routes to gather sufficient data on the post-TSP running times. Second, this issue requires ongoing internal discussion and coordination from the very beginning between the planning staff installing the TSP and the staff responsible for preparing the schedules. Third, it will require an assessment of the scheduling process and system itself; many experts with TSP experience have suggested that one needs to be able to distinguish between "layover time" as required in the labor contract versus "recovery time" that is added to address the variability in running times. The transit system needs to be able to reduce the "recovery" portion as travel times and reliability improve. This is sometimes difficult for larger transit systems.

the scheduling department. This dialogue is needed in order to raise awareness, and to start developing the process by which savings in travel time and improved reliability (resulting in the reduction of l required scheduled recovery time) can be gradually worked into the schedule, thereby resulting in increased efficiency. This can be a complex discussion and will require time, especially given the long time-horizons between successive schedules (typically prepared only three to four times a year).

6.2.4 Publicity

Depending on the regional and agency goals, the agency may or may not choose to have a media campaign advertising the TSP installation. Some agencies use the TSP project as a way to inform the public of the importance of transit in a region and as a demonstration of regional cooperation and problem solving. Some agencies include a brief mention of TSP as part of other more comprehensive efforts (e.g. launching of a new BRT service). Some agencies turn-on the TSP system without any fanfare to avoid anticipated adverse publicity or reaction. Decision makers in the transit agency and impacted jurisdiction(s) should reach agreement about publicity before anyone takes action in this area.

6.3 Verification and Validation

6.3.1 Testing of Equipment

Once all equipment has been installed, verification and validation begins.

The procurement documents laid out several steps in this respect, including:

- Creation of a process for testing and proving acceptability of all equipment before it is installed in the field,
- Completion of the testing process before installation (pre-testing)
- Testing of all installed equipment and software (post-installation acceptance testing)

6.3.2 Testing of System

Traffic engineering departments are likely to have their own testing / acceptance procedures for traffic control software and controller upgrades. Testing and acceptance procedures from the multiple jurisdictions will need to be discussed and agreed upon by the stakeholder team prior to procurement.

Once totally installed, procedures should be followed to test, verify, and validate the TSP system in its entirety.

6.3.3 Validation of Detection Distances and Accuracy

One specific issue raised during the case studies related to the validation of detection equipment, both optical and RF-based. In many cases, this required careful attention and/or attenuation. Generally each intersection presents slightly (or vastly) different geometric designs that may require different detection distances and/or zones. The procedures for verification and validation will vary depending on the detection technology chosen. With optical detection some agencies choose to set up equipment with standard settings and later readjust settings and equipment placement if buses aren't detected properly. Others have installed equipment on a truck to simulate a bus, and then installed detection equipment on the mast arm while the truck is in the spot in which they want the bus detected. With loop detection, the loops will be installed at a distance from the intersection that is based on an assumed speed at which the bus will be traveling. Verification would consist of running a vehicle with a detector over the loop to determine if a signal is sent to the receiver.

7 OPERATIONS AND MAINTENANCE

7.1 Ongoing Performance Monitoring and Management

Ongoing performance monitoring and management of a TSP system requires data collection. This represents an area of weakness in most current technologies. Although some PRG systems (especially if they are integrated with on-board AVL) incorporate a mechanism for logging when requests have been generated, by which bus, and under what con-

Key Question:

HOW DO WE HANDLE MAINTENANCE AND WHAT IS THE COST?

Surprisingly this is not as big an issue as one might imagine. In most cities the transit agency handles maintenance of all equipment on the bus during routine maintenance, and the traffic agency handles all equipment on the street or signal during routine maintenance. The various technologies and equipment seem to be robust enough to have caused few problems. Although the maintenance issues are not huge issues, it is very important that agreement be reached before implementation on how maintenance will be handled so that it does not create a misunderstanding or become a big issue.

dition, data collection from the PRS and controller remains problematic. Many PRS and controllers cannot store data, or if they do, they do so only on-site, and this data can only be obtained by manually downloading it in the field. Therefore, in many cases, one does not know if the system is operating correctly and granting priority, and cannot monitor what priority action is being used, for what bus, and under what circumstances. This is a major issue that future TSP projects will have to grapple with.

Ideally, one would want to collect various data:

- time call was requested,
- vehicle number,
- high or low level priority,
- specific priority routine invoked,
- range and intensity of detection signal,
- when call was dropped,
- call duration period,
- priority request disposition (e.g. not granted, why not granted, when granted, etc.)

To address the issue of lack of data, current TSP deployment sites have had to develop their own solutions. Pierce Transit has developed a stand-alone system for retrieving data at the controller and transmitting the data via cellular communications to an internet-accessible archived database, which can be used to verify operational status and perform various types of analyses. King County Metro has developed a sophisticated unit capable of interfacing with different types of controllers, but also capable of logging data on PRS and controller activity.

In the future, the lack of data collection / monitoring should be less of a concern: centralized TSP system architectures automatically incorporate data archiving capabilities, and the TSP technologies currently under development are increasingly sophisticated and should be more capable of addressing this weakness. In the mean-time, agencies will need to identify means to collect data for purposes of ongoing monitoring, management, and analysis, and to ensure that the TSP system is operating properly.

For those systems where data is available, travel times and signal timing can be calculated from collected data. If the transit agency or traffic engineering office would like to collect and use data created by the TSP system, that should be made clear in the procurement document.

There should be an agreement among the stakeholders (preferably with a memorandum of understanding or inter-agency agreement) concerning what data will be collected and how it will or will not be distributed and shared.

7.2 Procedures to Ensure System is Operating

Both the transit agency and the traffic engineering offices will need to have some procedures to ensure that:

- the TSP system is operating properly
- the PRG is generating priority requests
- the PRS is processing the requests and communicating them to the controller, and that
- the controller is granting the appropriate priority action for the circumstances.

With respect to on-board equipment, some agencies have a short test bed that each bus runs through in the morning as it leaves the garage in order to validate that the on-board TSP equipment is working. This approach can work with loops, optical systems, radio frequency system (RF) tags, etc.

Unfortunately, on the street, it is often difficult to determine if the PRS and controller are not responding. A few signal systems actually have monitoring technology, and some centralized signal systems have monitoring capability (e.g. Los Angeles), but many do not. In addition, most TSP systems modify the signal timing in such a small and subtle way that the bus operator won't immediately notice that the signal is not responding. It is only over a period of time that added seconds make an impact. Sometimes over the course of an operator's shift, he or she will notice that the signal has not been responding properly and will report it. This is a haphazard approach to ensuring ongoing proper functioning, and better mechanisms will need to be developed in the future as well as improved data monitoring capabilities.

There should be agreements in place so that if a signal is not responding, there are procedures for having it fixed.

7.3 Maintenance

TSP maintenance seems to be an insignificant issue in many cases. Both on-board and field equipment seem to be reliable, requiring little maintenance. However, agreements need to be in place for the occasions in which maintenance is required.

The policy in most areas is that transit agencies maintain whatever is on the bus and that traffic engineers maintain field equipment, incorporating maintenance tasks into standard maintenance activities. This is another reason why it is important for traffic engineering and bus operations and maintenance to be part of the stakeholder team. As mentioned, it is useful to have agreements stating the maintenance and ongoing financial policies to avoid misunderstandings or changes in attitude in case of personnel changes.

Maintenance procedures should be spelled out by the equipment supplier in the provided maintenance documents. Stakeholders will need to agree on the level of spares to be initially acquired and for the ongoing financial responsibility for acquiring additional replacement components and future upgrades.

8 EVALUATION, VERIFICATION, VALIDATION AND BUILDING ON TSP

8.1 Evaluation Study

It is important to evaluate the impact of TSP for a number of reasons. First, in several of the case studies, the evaluation study of the demonstration / pilot project helped to document the benefits derived from TSP while confirming the minimal impact on non-priority street general traffic. This is a basic concern from all traffic engineering staff, and the evaluation study serves to allay those concerns. If the evaluation study illustrates that the benefits are positive and the impacts on general traffic are acceptable, then the trust between stakeholders is reinforced. This in turn facilitates the next step of wide-spread implementation of TSP across the region.

A good evaluation will also help determine the future direction of TSP in the transit agency. Because most transit agencies are strapped for funds, it is important to know what programs are cost effective. An evaluation with positive results will justify the TSP implementation(s), and an evaluation with negative results will raise important red flags and help guide future decisions.

In addition, the evaluation study may clarify the specific conditions under which TSP is most cost effective. If financial resources are highly constrained, this knowledge may help guide the choice of corridors or intersections for future TSP implementation.

In order to evaluate a project in a meaningful way, one needs Measures of Effectiveness (MOE) that relate to the objectives of the project. Examples of MOEs used by various agencies include:

- Reduced travel time for buses
- Reduced stop and signal delay for buses
- Reduced variability in operations or schedule adherence for buses
- Reduced recovery time at end of run
- Fuel savings
- Air quality benefits
- Reduced operating resources required
- Number of signal cycles to clear a queue before/after granting TSP

Key Question:

HOW DO WE EVALUATE THE PROJECT TO SEE IF WE HAVE MET OUR GOALS?

A successful project will follow the standard systems engineering approach (recommended in this document) that begins with a needs assessment and concludes with an evaluation. If a project is warranted (which will be determined through a needs assessment), and good planning procedures are followed, the after-study will show impressive results. The results are important in justifying the expenditure of funds and in making future plans. Most agencies have found that comprehensive before and after studies were very worthwhile. In many cases, it may be possible to simulate the before study by collecting data with the TSP turned off for a short period of time. This approach reduces impacts on analysis by utilizing data with the same operational impacts (weather, transit driver, seasonal ridership, etc.).

- Reduced queue on mainline
- Minimal delay to other vehicles
- Reduced accidents (pre-emption)
- Decreased travel time of emergency vehicles (pre-emption)
- Public response

Creating MOEs for your TSP project was suggested as a useful step in the planning phase. If the MOEs relate to the project objectives, before and after measurements will determine project success. At the least, you will want to determine through objective measurements the impacts on traffic and person movements.

A record of comments from transit users, general traffic users, and drivers will help demonstrate the success as well. All of the gathered information can help the agency prioritize future TSP deployments.

In at least one of the case study sites, evaluation studies were deemed critical to the ongoing cooperation of the stakeholders, and were carried out systematically:

- Data was collected before TSP implementation on a corridor
- A first evaluation was then conducted after general traffic optimization but pre-TSP installation
- A second evaluation was then conducted after TSP installation and post-TSP optimization

This process was conducted on a number of TSP corridor installations.

In another case study site, an innovative approach to pre- and post-TSP impacts was implemented. Because there is a lot of variability among transit ridership, transit operators, weather, and public driving patterns, it was determined that pre- and post-analysis would be most accurate if the variability could be reduced. Therefore, during a very limited data collection period, data was collected for half of the time with TSP enabled, and the remaining half of the time with TSP disabled. This allowed a more accurate comparison of the impacts of TSP implementation.

8.2 Ongoing Data Collection

A previous section discussed the difficulties of collecting data on an ongoing basis with current TSP and controller technologies. Collecting data on an ongoing basis would be valuable not only to monitor the proper operation of the system, but also because the data potentially represents a valuable source of information for analysis purposes.

Data collected from the TSP/controller system along an entire corridor might yield a variety of valuable information. This data is typically collected from transit's AVL. Examples include:

- Travel times (especially their variability) by time of day, day of week, and season
- Schedule adherence
- Scheduled layover and recovery time

From this data one can determine:

- Impact and effectiveness of alternative TSP control strategies
- Impact of different "conditions" on priority and running times
- Impact of stop dwell time on priority requests
- Impact of bus operator driving behavior, etc.

8.3 Building on TSP Benefits through Transit Scheduling

By reducing time lost at traffic signals, you can reduce bus running time; and with conditional priority one can reduce the variability in the running time. To capitalize on TSP benefits, the transit agency needs to revise transit schedules to reflect the new understanding of running time. This issue requires ongoing internal discussion and coordination from the very beginning between the planning staff installing the TSP and the staff responsible for preparing the schedules. The scheduler who was identified early on as a stakeholder can take the lead in this process.

The transit system will need to have a mechanism for continuously monitoring running times so that the improvements in travel time created by the TSP system can be identified. State-of-the-art APC or AVL systems can provide such information, or the TSP system itself may be structured to gather this information. Some transit agencies use personnel (ride checkers) to gather running time information, but this approach requires a concerted effort to concentrate the use of the ride checkers on the TSP routes to gather sufficient data on the post-TSP running times.

Revising the schedules will require an assessment of the scheduling process and system itself. Many experts with TSP experience have suggested that one needs to be able to distinguish between "layover time" as required in the labor contract versus "recovery time" that is added to address the variability in running times. The transit system needs to be able to reduce the "recovery" portion as travel times and reliability improve.

Many agencies have found that it is easier to rework schedules in small increments. If the recovery time is cut too much, the operators will not be able to match the schedule, and everyone – including passengers – will be upset. If the time is cut too little, the benefit is not maximized. Cutting a small amount from each schedule markup period may be the least dramatic and least painful way to adjust the schedules until an optimal schedule is defined.

8.4 Fine-Tuning TSP Design

Finally, the transit system may want to fine tune the TSP design over time using an iterative process alternating small schedule adjustments with fine tuning TSP design. An initial fine tuning of the settings might be the contractor's last task based on the observations when TSP has been fully implemented.

The initial TSP strategies and settings are typically a compromise between what the transit system would desire and what the traffic engineers feel is acceptable. However, this initial compromise is made before the system is implemented and before any data on impacts exists. One should develop a process for systematically collecting data on the TSP actions taken by the controllers, and comparing it to the time benefits for buses and the impacts on general traffic vehicles. Over time, as data is accumulated and analyzed, and experience grows, it should be feasible to refine the TSP strategies and settings, or even incorporate new strategies or technological solutions currently under development in the research community. This will require the development of ongoing data collection systems as well as processes for periodically reviewing the TSP system.

9 KEYS TO SUCCESS

TSP projects vary in complexity and scope, but there are some common themes and lessons learned that apply across the board. Listed below are lessons learned from recent successful TSP implementations. Some were common to all projects and some were unique. They can provide value to anyone who is considering TSP.

PART I

Early Stakeholder Involvement

A TSP project by its nature involves multiple jurisdictions and agencies and multiple departments in the transit agency. Getting representatives to the table from all impacted areas can be difficult and cumbersome, but in the long run, it is the only way to implement a TSP project. Nearly every implementer interviewed listed early stakeholder involvement and communication as the keys to success. Success requires a good team effort. Get the team on board early and keep it engaged. Consensus among stakeholders will give the project the energy and support it needs to move to successful implementation.

Good Communication

Good communication among agencies, consultants, internal stakeholders, and all partners is critical. Communication can lead to cooperation and is needed throughout a project to keep the project moving forward and to prevent unpleasant surprises. Without good communication, cooperation is non-existent or is lost.

A Champion

Someone has to get the ball rolling. The champion can come from any agency or jurisdiction, but it is unlikely that anything will happen without a champion to nudge it along. Enthusiastic support of at least some of the agencies involved will go a long way to helping the project move forward. It is desirable, if possible, to get a champion from each involved agency.

Demonstration / Pilot Project to Test TSP and Build Trust

The vast majority of TSP deployments have begun with an initial demonstration or pilot project. This served three different purposes. First, this allowed for a test of the technical systems and equipment to ensure that they were all meeting their functional requirements. Second, it provided a basis for measuring the benefits and impacts of applying TSP. Finally, it provided a way to test TSP on a limited basis and thereby allay the concerns from traffic engineering staff. This in turn built a level of mutual trust that would enable further implementation of TSP across a region.

Convincing Evidence

Good before-and-after studies can demonstrate the benefits of TSP and ? more importantly ? the lack of negative impact on traffic. If studies provide measurable and quantifiable project results and outcomes, they can present the evidence needed to convince all stakeholders that TSP is a cost effective, beneficial plan for traffic and transit. It helps to verify operational benefits in accordance with local jurisdictions' traffic engineering requirements. This puts the information in a language understandable to the people most impacted. If the traffic engineers and the transit planners all agree that the studies show benefit to the entire transportation community, the next project should be easier and faster to implement.

Pitching the Right Ideas

Pitching the right ideas from the beginning can be a key to success. The important issues are (1) people throughput, and (2) passenger wait time (as opposed to passenger load), which includes impacts on transit passengers not yet on board a bus. We know that high variability creates anxiety in passengers who feel they have to arrive at a bus stop early. With TSP one can reduce passenger wait time and increase people throughput.

Partnerships

Developing strong jurisdictional partnerships for project coordination and implementation is helpful. These partnerships are the direct result of stakeholder involvement. If there is a way, through agreements, to formalize the partnerships, that can help keep the project moving even when there is staff turnover.

Momentum

It is critical to keep the TSP project moving ahead despite the obstacles. This responsibility will be incumbent upon the "champion" and will require solid project management to maintain momentum.

Standardization of Equipment

Standardized equipment can save money and time. Installation, operation, and maintenance are all easier on standardized equipment. In the presence of multiple jurisdictions, state or county-wide efforts to standardize TSP-capable controller equipment can be valuable. In any case, stakeholders should discuss the feasibility of increasing standardization of controller and TSP-related equipment.

Keep it Simple

It helps to remember to keep TSP objectives simple and build incrementally.

PART I

Part II presents extensive information on the current state of the practice of TSP in North America, Chapter 10 provides a broad survey of TSP systems and how they are being used, and Chapter 11 provides a summary from the eight in-depth case studies that were conducted for this project.

Part 2

State of the Practice

10 SURVEY ON TSP STATE OF THE PRACTICE

10.1 Introduction

This section highlights the state of the practice of Transit Signal Priority (TSP) in the U.S. and Canada. It contains a synthesis of TSP ßexperiences drawn from a review of existing literature and interviews with transit agency and traffic engineering personnel in areas in the United States and Canada where TSP and emergency vehicle pre-emption systems are operational. The literature review and interviews have been conducted in order to identify, inventory and classify TSP and emergency vehicle pre-emption systems currently in operation and an effort was made to contact as many agencies with TSP systems as possible in order to provide a broad background of the current status of TSP systems in North America.

10.1.1 Identification of Agencies/Cities with TSP and Emergency Vehicle Pre-emption

A list of 39 agencies/cities initially identified as utilizing TSP was generated from: (1) a literature review; (2) Advanced Public Transportation Systems (APTS) deployment publications; and (3) consultation with transit/traffic engineering professionals familiar with TSP in both the U.S. and Canada. The list only included those agencies/cities that were believed to have operational TSP systems when the report was prepared. Table 1 (see next page) contains the list of agencies generated as part of this project.

Since emergency vehicle pre-emption is built into traffic signal controller software, the capability to utilize this feature is directly linked to the existence of a vehicle detection system for emergency vehicles. The completion of this survey did not include in-depth contact with emergency response agencies to determine the existence of emergency vehicle priority detection systems. Rather, information on emergency vehicle pre-emption systems was obtained from contact with transit agency and traffic engineering personnel familiar with the signal controller hardware and software and vehicle detection equipment currently in operation in their cities.

10.1.2 Inventory and Classification of TSP Systems

The information necessary for the inventory and classification of TSP systems came from two primary sources: (1) published literature about the deployments and (2) interviews with the transit and traffic engineering personnel at the agencies/cities where the systems are deployed. Throughout the months of June, July, August and September 2004, representatives from the 39 agencies on the initial list were contacted by telephone to discuss the TSP deployments in their cities.

The interviews consisted of a standard questionnaire regarding the physical and operational characteristics of the transit route; the technical details of the traffic signal controllers, TSP software and vehicle detection systems; and other questions about the general details of the deployments (year deployed, number of signalized intersections, etc.). The completed survey forms are contained in the Appendices.

In the cases where contact was not possible by telephone, a written version of the questionnaire was e-mailed to the appropriate personnel. Thirty-one of the 39 agencies on the initial list were successfully contacted and surveyed by telephone and/or e-mail, which represents a response rate of

TABLE 1 List of Agencies Initially Identified as Utilizing TSP

MASTER LIST OF AGENCIES WITH TSP		
AGENCY	CITY	STATE
Alameda-Contra-Costa Transit District	Oakland	CA
Annapolis Transit	Annapolis	MD
Ben Franklin Transit	Richland	WA
Calgary Transit	Calgary	CAN
Centre Area Transit Authority (CATA)	State College	PA
Central Florida Regional Transportation Authority (LYNX)	Orlando	FL
City of Glendale	Glendale	CA
Charlotte Area Transit	Charlotte	NC
Colorado Springs Transit	Colorado Springs	CO
Greater Vancouver Transportation Authority	Vancouver	CAN
Honolulu Transit	Honolulu	HI
Houston Metropolitan Transit Authority	Houston	TX
Illinois DOT (Regional Transit Authority (RTA))	Chicago	IL
Jefferson Transit authority	Port Townsend	WA
King County Metro	Seattle	WA
Kitsap Transit	Bremerton	WA
LA County Metropolitan Transportation Authority	Los Angeles	CA
Maryland Transit Administration	Baltimore	MD
Metro Atlanta Regional Transportaion Authority	Atlanta	GA
Metropolitan Transit	Minneapolis	MN
Miami-Dade Transit Authority	Miami	FL
MUNI	San Francisco	CA
Napa County Transportation Planning Agency	Napa	CA
City of Ottawa	Ottawa	CAN
Pace suburban Bus Service	Arlington Heights	IL
Pierce Transit	Tacoma	WA
Phoenix Transit/ Valley Metro	Phoenix	AZ
Port Authority of Allegheny County	Pittsburgh	PA
Ride On	Montgomery County	MD
Sacramento Regional Transit District	Sacramento	CA
Sanat Clara Valley Transportation Authority (VTA)	San Mateo County	CA
Skagit Transit	Burlington	WA
Southeastern Pennsylvania Transportation Authority (SEPTA)	Philadelphia	PA
St. Cloud Metropolitan Transit Commission	St. Cloud	MN
Toronto Transit Commission	Toronto	CAN
Tri-county Metropoliatn Transit District (TriMet)	Portland	OR
Union City Transit	Union City	CA
Utah Transit Authority (UTA	Salt Lake City	UT
Washington Metropolitan Transit Authority (WMATA)	Washington	DC

approximately 80 percent. Of the 31 agencies that were surveyed, seven indicated that their agency had not yet deployed TSP or that their TSP deployment was no longer operational. Table 2 highlights the response rate achieved as part of this survey, and Table 3 summarizes the status of the TSP systems reported by the seven agencies that do not have operational TSP systems.

The information contained in this document regarding TSP and emergency vehicle pre-emption deployments was obtained from the interviews with the 24 agencies in the U.S. and Canada that reported having operational TSP deployments (or TSP systems currently being deployed) during the summer of 2004.

TABLE 2 Response Rate and Agencies Surveyed

	NUMBER	PERCENT OF INITIAL LIST
Initial List of Agencies With TSP	39	100%
Agencies Contacted/ Responded to Survey	31	80%
Agencies with Operational TSP Systems (Summer 2004)	24	62%

PART II

TABLE 3 Status of Agencies Reporting No TSP Systems

AGENCY	STATUS
Annapolis Transit - Annapolis, MD	No TSP implementations; pre-emption only
Centre Area Transit Authority - State College, PA	Currently planning for TSP deployment in late 2005
Maryland Transit Administration - Baltimore, MD	Planning on LRT TSP deployment
Miami-Dade Transit Authority - Miami, FL	TSP deployment discontinued
Napa County Transportation Planning Agency - Napa, CA	No TSP implementations; pre-emption planned
Phoenix Transit/ Valley Metro - Phoenix, AZ	No Information available
Ride On - Montgomery County, MD	TSP implementation discontinued

10.2 Summary of Findings on State of the Practice

The survey of the 24 agencies demonstrates a wide variety of TSP applications. Several of the agencies indicated the use of very sophisticated TSP applications with advanced TSP hardware and software that utilize more sophisticated TSP strategies. At the same time, there are other agencies that are using TSP in very targeted applications, such as the two agencies that are using TSP only on a limited number of intersections for left-turn movements only. The City of Ottawa utilizes a unique approach that includes several different TSP treatments, including T-intersection queue jump and left turn phase insertion. Additionally, three agencies reported the use of traffic signal pre-emption (rather than priority) strategies with their Light Rail Transit (LRT) and bus systems. Finally, several agencies reported one or more routes/corridors with TSP systems currently in the deployment process that are not yet operational.

10.2.1 General Findings

10.2.1.1 Type of Transit Application

Approximately two-thirds of the agencies indicated the use of TSP only for bus applications, and the remaining one-third of agencies reported the deployment of TSP for both bus and LRT applications. None of the agencies surveyed as part of this study indicated the use of TSP only for LRT deployments.

10.2.1.2 Year of Deployment

While two agencies reported a TSP deployment as early as 1985 and several agencies reported TSP deployments in the early 1990s, the majority of TSP deployments were completed in the late 1990s and after the year 2000. There were also several agencies that reported TSP systems that are currently in the process of being deployed, including the

TABLE 4 Year of TSP Implementation

YEAR OF TSP IMPLEMENTATION			
AGENCY	CITY	ST	YEAR
Alameda-Contra-Costa Transit District	Oakland	CA	2003
Ben Franklin Transit	Richland	WA	1995
Calgary Transit	Calgary	CAN	2000
Central Florida Regional Transp. Authority	Orlando	FL	1997
City of Glendale	Glendale	CA	2001
Charlotte Area Transit	Charlotte	NC	1985
Houston Metropolitan Transit Authority	Houston	TX	2004
Illionois DOT (Regional Transit Authority)	Chicago	IL	2003
Jefferson Transit Authority	Port Townsend	WA	1996
King County Metro	Seattle	WA	1999
LA County Metropolitan Transp. Authority	Los Angeles	CA	1990
Metropolitan Transit	Minneapolis	MN	2004
City of Ottawa	Ottawa	CAN	1990s
Pace Suburban Bus Service	Arlington Heights	IL	1985
Pierce Transit	Tacoma	WA	2002
Port authority of Allegheny County	Pittsburgh	PA	1995
Sacramento Regional Transit District	Sacramento	CA	2002
Santa Clara Valley Transp. Authority (VTA)	San Mateo County	CA	1990
Skagit Transit	Burlington	WA	1993
Southeastern Pennsylvania Transp. Authority	Philadelphia	PA	2002
St. Cloud Metropolitan Transit Commission	St. Cloud	MN	2002
Tri-County Metropolitan Transit District (TriMet)	Portland	OR	1987
Utah Transit Authority (UTA)	Salt Lake City	UT	planned
Washington Metro. Transit Authority (WMATA)	Washington	DC	planned

Washington Metropolitan Transit Authority (WMATA) and the Utah Transit Authority (UTA). This trend matches the information obtained from a review of the literature, in which approximately 70% of transit agencies with over 100 vehicles reported either implementing or planning TSP in a 2000 survey[18]. Table 4 shows the year of implementation reported by the 24 agencies with TSP systems.

10.2.2 Route Characteristics of TSP Applications

10.2.2.1 Route Type

The most common bus TSP application is a system that operates in mixed traffic on four- to six-lane arterials. Very few agencies reported bus TSP applications in an exclusive bus or bus rapid transit (BRT) lane. On the other hand, the LRT applications were almost exclusively deployed on dedicated right-of-way (ROW) separate from vehicular traffic flow. The exception to this trend is streetcar systems, such as in Philadelphia, that operates on roadways with mixed traffic flow.

10.2.2.2 Number of Routes

Most trnsit agencies reported TSP deployments along one or two routes, and only a few agencies indicated that TSP was deployed on more than six routes. A number of the deployments were demonstration projects, which limited the deployments to one or two routes. A number of agencies reported that additional routes were planned for future deployment.

TABLE 5 Number of Signalized Intersections with TSP

NUMBER OF SIGNALIZED INTERSECTIONS WITH TSP			
AGENCY	CITY	ST	SIGNALS
Alameda-Contra-Costa Transit District	Oakland	CA	62
Ben Franklin Transit	Richland	WA	31
Calgary Transit	Calgary	CAN	67
Central Florida Regional Transp. Authority	Orlando	FL	19
City of Glendale	Glendale	CA	17
Charlotte Area Transit	Charlotte	NC	17
Houston Metropolitan Transit Authority	Houston	TX	1563
Illionois DOT (Regional Transit Authority)	Chicago	IL	84
Jefferson Transit Authority	Port Townsend	WA	2
King County Metro	Seattle	WA	26
LA County Metropolitan Transp. Authority	Los Angeles	CA	420
Metropolitan Transit	Minneapolis	MN	22
City of Ottawa	Ottawa	CAN	40
Pace Suburban Bus Service	Arlington Heights	IL	12
Pierce Transit	Tacoma	WA	110
Port Authority of Allegheny County	Pittsburgh	PA	5
Sacramento Regional Transit District	Sacramento	CA	600
Santa Clara Valley Transp. Authority (VTA)	San Mateo County	CA	77
Skagit Transit	Burlington	WA	80
Southeastern Pennsylvania Transp. Authority	Philadelphia	PA	61
St. Cloud Metropolitan Transit Commission	St. Cloud	MN	89
Tri-County Metropolitan Transit District (TriMet)	Portland	OR	370
Utah Transit Authority (UTA)	Salt Lake City	UT	12
Washington Metro. Transit Authority (WMATA)	Washington	DC	N/A

[18] O'Brien, W. "Design and Implementation of Transit Priority at Signalized Intersections: A Primer for Transit Managers and a Review of North American Experience." Canadian Urban Transit Association STRP Report 15, Toronto, Canada, 2000.

PART II

10.2.2.3 Number of Signalized Intersections

The number of signalized intersections with TSP functionality ranged widely, from two intersections utilizing only a transit left turn phase strategy to over 1,500 intersections in a bus TSP deployment in a large metropolitan area (Houston). Most of the transit agencies reported having TSP operational at 10 to 80 signalized intersections. Table 5 shows the number of signalized intersections reported by each agency with TSP deployments.

10.2.2.4 Location of Bus Stops

The survey indicated a mixture of near- and far-side bus stop locations. Most of the agencies reported utilizing both far-side stops and near-side stops. The survey also provided clear evidence that agencies with TSP strongly prefer far-side stops and the trend is to relocate existing near-side stops to far-side stops wherever possible. The main reason for this preference is that far-side stops eliminate the difficulty of accurately predicting transit vehicle arrival at an intersection, and thereby reduces the amount of green extension required and facilitates "checking out" the bus.

10.2.2.5 Peak Hour Headways

The headways reported by the transit agencies ranged from 90 seconds to over 30 minutes on routes using TSP. During the peak hour, most agencies reported headways from five to 30 minutes, depending on the route and type of service (bus, LRT, express, etc.).

10.2.3 Hardware for TSP Deployments

10.2.3.1 Traffic Signal Controllers

More than 40% of the transit agencies surveyed reported the use of NEMA traffic signal controllers, which are currently the most widely deployed type of signal controller in the United States. Nineteen percent of agencies reported the use of Type 170 and 23% for Type 2070 controllers. Figure 3 shows the traffic signal controller hardware by type; and Table 6 shows the traffic signal controller hardware used by each agency surveyed.

10.2.3.2 Vehicle Detection Systems

Approximately two-thirds of the agencies reported the use of optical vehicle detection systems. Approximately one-third of transit agencies indicated the use of a loop-based detection system, which uses an inductive loop embedded in the pavement and a transponder mounted on the underside of the transit vehicle to distinguish the transit vehicle from other vehicular traffic. Only three agencies reported using other types of detection systems, including Global Positioning Satellites (GPS) and radio frequency (RF) systems.

The predominance of the optical detection system for TSP is generally attributed to the wide-spread existing use of optical detection for emergency vehicle pre-emption systems. Since the emergency vehicle pre-emption systems are far more common than TSP systems, many transit agencies found that the signalized intersections along their transit routes were already equipped with optical detection systems at the time of planning/deployment of the TSP system. The use of optical detection for TSP allows transit agencies to use an existing field detection system installation, allows for cost savings in terms of equipment procurement, installation, and ongoing maintenance costs, and eliminates the need to have two different vehicle detection systems deployed at each intersection.

10.2.4 Software for TSP Deployments

As previously stated, more than 40% of the surveyed transit agencies reported the use of NEMA traffic signal controller hardware. This type of controller is generally provided with signal control software from the controller manufacturer. Nearly all of the transit agencies that reported the use of NEMA controllers also indicated the use of the controller manufacturer's software with TSP functionality. A small number of agencies reported using customized controller software with TSP functionality with their NEMA controllers.

A small number of transit agencies reported the use of third-party TSP software packages that generally offer more flexibility than the TSP software provided with NEMA controllers. These software packages include BiTran, Wapiti, NextPhase,

FIGURE 3 Traffic Signal Controller Hardware by Type

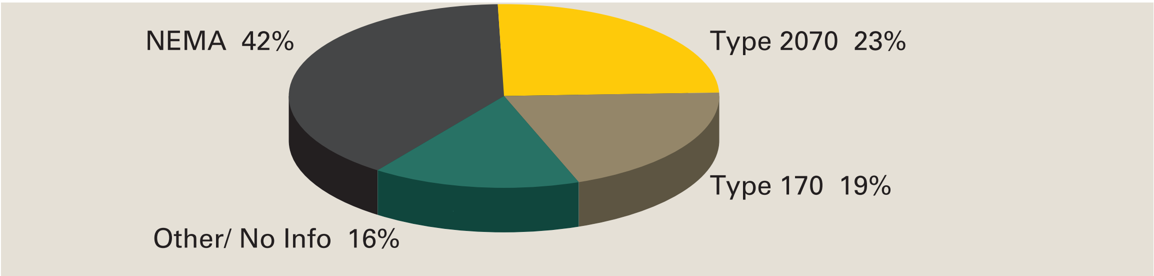


TABLE 6 Traffic Signal Controller Hardware by Agency

Legend: NEMA | Type 170 | Type 2070 | Other | Info Not Available

TRAFFIC SIGNAL CONTROLLER HARDWARE BY AGENCY			
AGENCY	**CITY**	**ST**	**HARDWARE**
Alameda-Contra-Costa Transit District	Oakland	CA	Type 170
Ben Franklin Transit	Richland	WA	NEMA
Calgary Transit	Calgary	CAN	NEMA
Central Florida Regional Transp. Authority	Orlando	FL	NEMA
City of Glendale	Glendale	CA	Type 170
Charlotte Area Transit	Charlotte	NC	NEMA
Houston Metropolitan Transit Authority	Houston	TX	Type 2070
Illionois DOT (Regional Transit Authority)	Chicago	IL	NEMA, Type 2070
Jefferson Transit Authority	Port Townsend	WA	Info Not Available
King County Metro	Seattle	WA	NEMA, Type 2070
LA County Metropolitan Transp. Authority	Los Angeles	CA	Type 170, Type 2070
Metropolitan Transit	Minneapolis	MN	Info Not Available
City of Ottawa	Ottawa	CAN	Info Not Available
Pace Suburban Bus Service	Arlington Heights	IL	NEMA
Pierce Transit	Tacoma	WA	NEMA
Port Authority of Allegheny County	Pittsburgh	PA	Type 170
Sacramento Regional Transit District	Sacramento	CA	Type 2070, Other
Santa Clara Valley Transp. Authority (VTA)	San Mateo County	CA	NEMA
Skagit Transit	Burlington	WA	Info Not Available
Southeastern Pennsylvania Transp. Authority	Philadelphia	PA	Type 170
St. Cloud Metropolitan Transit Commission	St. Cloud	MN	NEMA
Tri-County Metropolitan Transit District (TriMet)	Portland	OR	Type 170
Utah Transit Authority (UTA)	Salt Lake City	UT	Type 2070
Washington Metro. Transit Authority (WMATA)	Washington	DC	NEMA, Type 170

Caltrans' C-8, and City of Los Angeles' custom TSP software. Since the transit agencies' choice of TSP software is limited by the type of signal controller already in use at the signalized intersections, a number of agencies are not able to utilize these third-party TSP software products or are required to invest in traffic control system and/or equipment upgrades in order to do so. As advanced signal controllers such as the Type 2070 controllers become more prevalent in traffic signal control applications, it is anticipated that transit agencies will begin to utilize these third-party TSP software products that are capable of running on the advanced controllers. At the same time, there has also been significant progress with the advancement of TSP software for NEMA controllers, which will offer transit agencies the benefits of improved TSP functionality while still utilizing their existing NEMA controllers.

Readers are encouraged to monitor the progress of signal control hardware and TSP software since there are continuous advancements that affect TSP functionality. Also, developments within NTCIP will continue to impact TSP hardware and software development, particularly NTCIP 1211, the evolving standard that addresses signal control and prioritization.

Figure 4 shows the TSP software by type, and Table 7 shows the TSP software used by each agency surveyed.

FIGURE 4 TSP Software by Type (percent of total software)

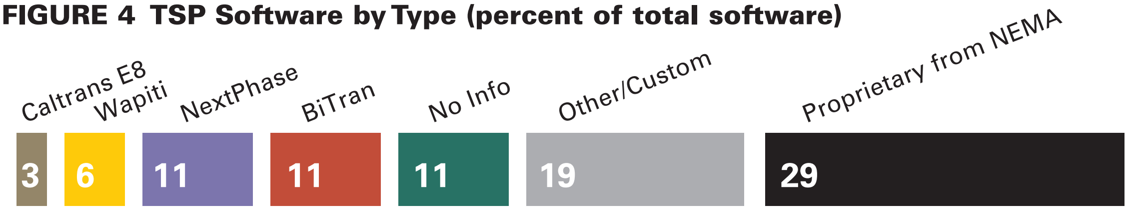


TABLE 7 TSP Software by Agency

TRAFFIC SIGNAL CONTROLLER SOFTWARE BY AGENCY			
AGENCY	CITY	ST	SOFTWARE
Alameda-Contra-Costa Transit District	Oakland	CA	
Ben Franklin Transit	Richland	WA	
Calgary Transit	Calgary	CAN	
Central Florida Regional Transp. Authority	Orlando	FL	
City of Glendale	Glendale	CA	
Charlotte Area Transit	Charlotte	NC	
Houston Metropolitan Transit Authority	Houston	TX	
Illinois DOT (Regional Transit Authority)	Chicago	IL	
Jefferson Transit Authority	Port Townsend	WA	
King County Metro	Seattle	WA	
LA County Metropolitan Transp. Authority	Los Angeles	CA	
Metropolitan Transit	Minneapolis	MN	
City of Ottawa	Ottawa	CAN	
Pace Suburban Bus Service	Arlington Heights	IL	
Pierce Transit	Tacoma	WA	
Port Authority of Allegheny County	Pittsburgh	PA	
Sacramento Regional Transit District	Sacramento	CA	
Santa Clara Valley Transp. Authority (VTA)	San Mateo County	CA	
Skagit Transit	Burlington	WA	
Southeastern Pennsylvania Transp. Authority	Philadelphia	PA	
St. Cloud Metropolitan Transit Commission	St. Cloud	MN	
Tri-County Metropolitan Transit District (TriMet)	Portland	OR	
Utah Transit Authority (UTA)	Salt Lake City	UT	
Washington Metro. Transit Authority (WMATA)	Washington	DC	

10.2.5 TSP Strategies

The most commonly used TSP strategy for buses operating in mixed flow was green extension and early green (red truncation). This strategy is typically available on the NEMA-based proprietary software packages, which are used by over 40% of the surveyed agencies. Several agencies that reported using more advanced signal controllers and TSP software packages indicated the use of additional strategies, including predictive priority, conditional priority (only applied to buses running behind schedule), and phase skipping.

Two agencies (Jefferson Transit Authority and Port Authority of Allegheny County) reported the use of a very targeted TSP strategy of providing a left turn transit phase for buses to make left turn movements at a limited number of intersections, or to accelerate access/egress into off-street terminals. These agencies were not using TSP strategies such as green extension or early green (red truncation) at any other signalized intersections along the bus corridors.

The City of Ottawa's unique approach to TSP includes several different applications. One application utilizes queue jumps at T-intersections, where buses arriving on the side street are provided a queue jump for making a left turn onto the main arterial. Another approach is the use of left turn phase insertion for buses at signalized intersections. A third TSP application involves the use of a semi-signalized intersection, where the traffic on the main street has a signal head and the side street traffic has Stop signs. The main street traffic always has a green light until a bus is detected on the side street or a pedestrian call is received.

LRT and bus systems that operate on exclusive ROW or in dedicated bus or bus rapid transit (BRT) lanes were reported to be using pre-emption strategies more often than priority strategies. Charlotte Area Transit, Metropolitan Transit and Central Florida Regional Transportation Authority all reported the use of pre-emption (rather than priority) strategies for their bus TSP systems. Table 8 indicates the TSP strategies reported by each of the surveyed agencies.

TABLE 8 TSP Strategy by Agency

EG = Early Green (red truncation) GE = Green Extension
PI = Phase Insertion PR = Preemption O = Other

TSP STRATEGY BY AGENCY			
AGENCY	CITY	ST	STRATEGY
Alameda-Contra-Costa Transit District	Oakland	CA	EG, GE
Ben Franklin Transit	Richland	WA	EG, GE
Calgary Transit	Calgary	CAN	EG, GE
Central Florida Regional Transp. Authority	Orlando	FL	PR
City of Glendale	Glendale	CA	EG, GE
Charlotte Area Transit	Charlotte	NC	PR
Houston Metropolitan Transit Authority	Houston	TX	EG, GE, O
Illinois DOT (Regional Transit Authority)	Chicago	IL	EG, GE, O
Jefferson Transit Authority	Port Townsend	WA	PI
King County Metro	Seattle	WA	EG, GE
LA County Metropolitan Transp. Authority	Los Angeles	CA	EG, GE, PI
Metropolitan Transit	Minneapolis	MN	PR
City of Ottawa	Ottawa	CAN	EG,GE,PI, O
Pace Suburban Bus Service	Arlington Heights	IL	EG,GE
Pierce Transit	Tacoma	WA	EG,GE,O
Port Authority of Allegheny County	Pittsburgh	PA	PI
Sacramento Regional Transit District	Sacramento	CA	EG, GE
Santa Clara Valley Transp. Authority (VTA)	San Mateo County	CA	EG,GE,PI,O
Skagit Transit	Burlington	WA	EG, GE
Southeastern Pennsylvania Transp. Authority	Philadelphia	PA	EG, O
St. Cloud Metropolitan Transit Commission	St. Cloud	MN	EG, GE
Tri-County Metropolitan Transit District (TriMet)	Portland	OR	EG, GE, O
Utah Transit Authority (UTA)	Salt Lake City	UT	EG, GE
Washington Metro. Transit Authority (WMATA)	Washington	DC	EG, GE

10.2.6 Challenges and Lessons Learned

10.2.6.1 Use of Existing Signal Controller Systems

The deployment of TSP systems is very dependent on the existing signal controller hardware and software systems. Currently, over 40% of TSP systems are utilizing NEMA traffic signal controllers, which are typically utilized with the TSP software provided by the controller manufacturer. The trend in the traffic industry is to upgrade existing hardware and software but this involves considerable expense and the timeframe for upgrades may not always satisfy TSP implementation requirements. Additionally, the availability of centrally controlled traffic signal systems allows for more TSP possibilities and it is expected that a number of the agencies with a large number of signalized intersections will migrate to centralized traffic signal control. All of these changes and migrations in traffic signal control equipment will affect the TSP systems already deployed or being deployed in those locations.

10.2.6.2 Coordination with Traffic Engineers

Many of the transit agencies attributed the success of their TSP programs to early and continuous coordination with local traffic engineers. Some agencies reported the use of tools such as Memorandums of Understanding (MOUs) or Memorandums of Agreement (MOAs) to aid in building consensus among stakeholders. This type of coordination was particularly important where TSP was implemented along corridors crossing several jurisdictions, with several different groups of traffic engineers responsible for the signalized intersections. The agencies reported very few complaints from motorists regarding additional delay on the TSP corridors, and many reported improved levels of service as a result of the TSP implementation.

10.2.6.5 Measures of Success

While several agencies have been able to measure and quantify the benefits of their TSP deployments with demonstrated time savings and improved transit service, a number of agencies lack the resources to perform such analyses. Also, some of the agencies reported that the measure of success for their TSP programs was simply that it was implemented and operated effectively without any complaints from motorists. Another measure of success is whether TSP can reduce variability, which improves transit attractiveness and can lead to a reduction in layover time, which will provide for a decrease in the overall running time on the transit vehicle's route. This reduction in layover time, when combined with a reduction in running time, could lead to the elimination of a transit vehicle from the route while maintaining the same level of service (or the provision of a better level of service with the same number of transit vehicles).

10.2.6.4 Traffic Signal Warrants for Busways

Several agencies reported that traffic signal warrants (which have traditionally been based on volume) do not take into account busways, where the volume of buses is typically low and only warrants a stop sign control for the intersections. The agencies indicated that a revision of the traffic signal warrants could result in recommendations for signalized intersections at busway locations that would otherwise not meet the volume-based criteria for a traffic signal. The use of signalized intersections along busways would better serve the busway, while also maintaining an acceptable level of service for the cross streets.

11 CASE STUDIES SUMMARY

Eight case studies were conducted in North American communities with TSP, to explore their experiences and highlight the issues that arise, as well as solutions. Understanding derived from the case studies allowed discussion of the planning and implementation process presented in Part I. Detailed case studies can be found in the Appendices. The table on pages 56-57 summarizes findings from the case studies to supplement the portrait of the State of the Practice discussed previously.

12 FUTURE DIRECTIONS

The National Intelligent Transportation Systems Program Plan: A Ten-Year Vision stated in part:

The ITS vision is to ensure that:

- *Future transportation systems will be managed and operated to provide seamless, end-to-end intermodal passenger travel regardless of age, disability, or location and efficient, seamless, end-to-end intermodal freight movement.*
- *Public policy and private sector decision-makers will seize the opportunity to make ITS a vial driver in achieving the vision of the transportation system for the 21st century.*
- *Future transportation systems will be secure, customer oriented, performance driven and institutionally innovative, enabled by information from a fully integrated spectrum of computing, communication and sensor technologies.*[19]

This vision points to a future in which traffic and transit agencies work together to create the best transportation system possible. Passengers do not care who is providing the transportation system. They want a system that works – that conveniently and quickly takes them to work, home, and play. The future vision fits perfectly with a well-executed TSP system. As has been discussed at length in this document, TSP is a cost-effective tool that can help make transit service more reliable and therefore, more desirable. It takes advantage of, and indeed requires, cooperation among agencies and jurisdictions. The cooperation established in TSP implementation can be a first step toward creating a seamless transportation system.

What will TSP look like in 10 years? Because there are two main components to TSP we can look at them separately. There is (1) technology on the bus and (2) technology on the street.

First, with respect to bus technology, a 2000 report[20] stated that by 1999, 61 transit agencies operated AVL systems and 93 were installing or planning such systems. The majority of the planned systems would be GPS-based systems. This indicates that transit agencies will rely more heavily on ITS in the future and that AVL systems will become more common. With wider application of AVL systems, there is more opportunity to implement more sophisticated TSP systems. AVL-based TSP systems can track vehicle location and compare it with scheduled bus times and provide “conditional” priority that will make bus systems more reliable.

A more advanced application for transit involves real-time customer information and moves completely away from schedules. With heavy reliance on real-time information, buses could move as quickly as possible through traffic (utilizing TSP). Real-time arrival times could be provided directly to customers through beepers, pagers, e-mail, cell phones, PDAs and so on. With cell phones and PDAs becoming ubiquitous and AVL being rapidly deployed, this scenario does not seem far away.

Second, with respect to technology on the street, traffic signal systems are becoming more sophisticated, complex, and adaptive. With the exception of older electromechanical controllers, all modern traffic signal controllers utilize some type of software to execute all traffic signal control and, where applicable, transit signal priority. Modern traffic control systems can monitor traffic more efficiently. Future traffic control systems will adapt to shifts in traffic and will change signal timing to meet demand. As traffic controllers and software acquire higher functionality, and wireless and fiber communications systems expand, it becomes more feasible for the transportation systems to track and provide priority to public transit vehicles, and therefore move more people more rapidly through the transportation system.

Taking into account the preponderance of regions throughout the country that state “more mobility” as a transportation goal, it is easy to understand the high level of interest in TSP. It works well now and promises to work even better as bus systems and traffic systems become more sophisticated.

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[19] The National Intelligent Transportation Systems Program Plan: A Ten-Year Vision, January 2002, Intelligent Transportation Society of America and United States Department of Transportation, page 3.

[20] Advanced Public Transportation Systems: State of the Art Update 2000, Report Number FTA-MA-26-7007-00-1, September 2000, Federal Transit Administration and Volpe National Transportation Systems Center, page 2-30.

TABLE 9 Case Studies Summary

Brief Summary of Case Study Interviews	AC Transit, Oakland, CA	King County Metro, Seattle, WA	MTA, Los Angeles, CA	PACE, Chicago, IL, Carmak Road
# Corridors Involved	1	3	9	1
# Intersections Equipped	62	28	654	15
# Buses Equipped	21	1400	283	125
Priority for Late Buses Only	Yes	No	Yes	No
System Setup	Decentralized	Distributed	Centralized	Decentralized
Detection Technology	Encoded Infrared	Passive RF	Loop Detection	Loop Detection
AVL-Integrated?	No	No	No	No
TSP Integrated with EMS Pre-emption?	Yes	Not integrated where it exists	At some locations	No
Cost of *Implementation	$25K cost to AC Transit to purchase/ install transmitters. Approx. 300K cost to ACCMA to purchase/ install TSP components.	$2.5M for Phase 1. $155K for Phase 2 hardware upgrades.	$10M.	$732K
Cost of Maintenance		$1K per intersection per year.	No itemized costs; traffic equipment and loops maintained by the city. MTA maintains bus equipment. Failures are not common.	IDOT doesn't pay additional costs because TSP loops and equipment are included as part of their normal maintenance.
Benefits	Extrapolation of data from 8 Caltrans intersections indicates approx. 9% time savings.	25-34% reduced ave. intersection delay for eligible buses. 14-24% reduced stops at intersections. 35-40% reduced trip travel time variability. 5.5-8% reduced travel time along corridors during peak hour.	19-25% reduced travel times. 1/3 savings = TSP; 2/3 savings = headway based service, fewer stops, and shorter dwell times. Ridership Metro Rapid lines up 4-40% depending on the line. 1/3 are new transit riders.	Average 15% (3 minutes) reduced running time. Saved one weekday bus through TSP and more efficient run cutting.
Impact on Non-Priority Street Traffic	Infinitesimal	Minimal	Typically one second delay per vehicle per cycle	Impact studies show little impact. Not aware of any complaints received by IDOT.

* Read the full case studies in the Appendix to understand what is included in the cost estimates.

PART II

Brief Summary of Case Study Interviews	Pierce Transit, Tacoma, WA	TransLink, Vancouver, BC	TriMet, Portland, OR	Virginia Route 1
# Corridors Involved	6	2	8	1
# Intersections Equipped	110	59 on B-Line and 4 on Willingdon	250	25
# Buses Equipped	245	28	650	12
Late Bus Priority?	No	Yes	Yes	No
System Setup	Decentralized	Distributed	Decentralized	Decentralized
Detection Technology	Encoded Infrared	Infrared emitters on Bline corridor. Visual recognition tech. on Willingdon bus lane.	Encoded Infrared	Encoded Infrared
AVL-Integrated?	No	Yes	Yes	No
TSP Integrated with EMS Pre-emption?	Yes	No	Yes	Yes
Cost of Implementation	$2.7M.	TSP budget was CD $1.3M (US $860K at the time) for hardware and software	$5.8M.	$220K for equipment only, for 25 intersections + 12 buses
Cost of Maintenance	None discernable because technicians clean detectors while they are cleaning the signal heads.	CD $24K (US $20K) per year	650 buses - 0.2 FTE - signals warrantied for 5 years. No additional cost for signal maintenance.	Currently being discussed with Fairfax County.
Benefits	Improved speed and reliability. TSP and signal optimization reduced transit signal delay about 40%. Project also resulted in economic benefit to the general public. (GP): $14.2M/year for 6 corridors from signal coordination after TSP. Ave. total signal delay on S.19th down 18-70% (GP) and 5-30% (transit). On Pacific Ave: 30-65% (GP) and 18-21% (transit).	98 B-Line reduced travel time in the corridor from 100 to 84 minutes. Resulted in a 23% modal shift from auto to transit in the corridor. Net benefit of the BRT line: CD $2.9M (US $2.4M). Main TSP benefit: significant reduction (40-50%) in travel time variability.	Reduced recovery time; increased reliability. For Line 4 in Nov. 2000, TriMet was able to avoid adding one more bus. which means savings. There are also benefits to emergency response and on-time performance for transit vehicles.	Improved travel for buses. Added emergency responder confidence.
Impact on Non-Priority Street Traffic	Very little impact.	No noticeable impact.	Very little.	TSP impact not yet assessed. Additional delay caused by EMS pre-emption is small.

PART II

Part III presents a wide range of background information to assist transit and traffic staff who are exploring TSP implementation.

Part 3

Technical Support

Part III presents a wide range of background information to assist transit and traffic agency staff that are exploring the implementation of TSP. TSP requires a strong partnership of both transit and traffic agency technical staff to ensure its success. However, the research for this study showed over and over that the differences in training, methodologies, and even technical language for traffic engineering and transit planning, was often an important barrier to cooperation and understanding between transit and traffic staff.

As a result, it appeared valuable to provide in this handbook, a range of technical information that could be drawn upon in the pursuit of TSP. In particular, technical information concerning traffic equipment and systems, terminology, and pertinent concepts is provided for the benefit of transit planners working on TSP. Similarly, information concerning transit terminology and concepts is provided for the benefit of traffic engineers.

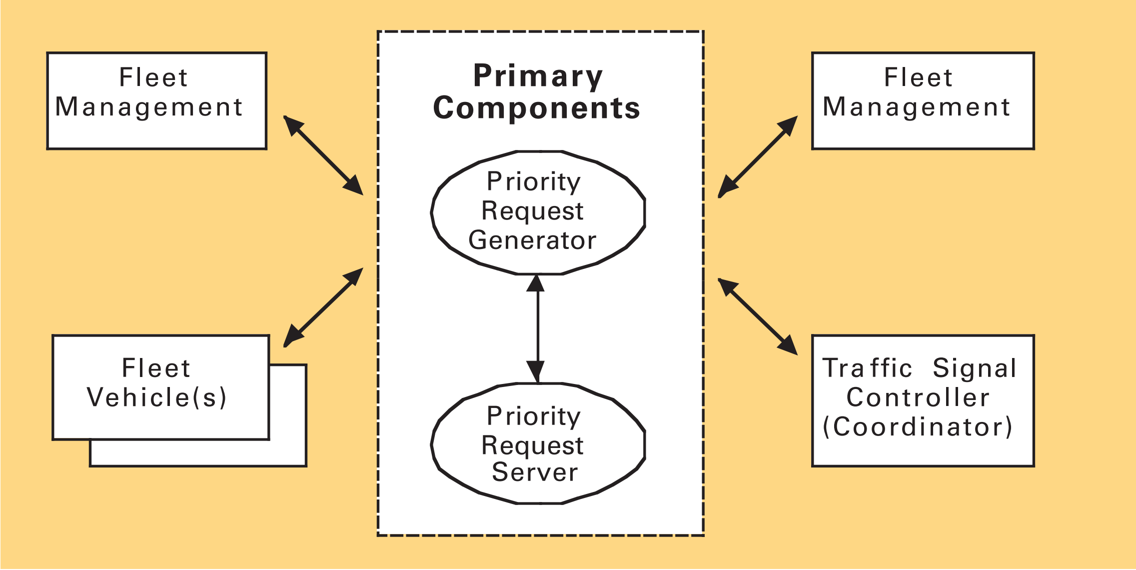
Part III covers the following topics:

- TSP System Architecture, Equipment, Software and Communications
- Traffic Engineering Terminology
- Simulation and Optimization Tools for TSP
- Transit Terminology
- References for Part III

13 TSP SYSTEM ARCHITECTURE, EQUIPMENT, SOFTWARE, AND COMMUNICATIONS

This section will provide transit and traffic engineering professionals a general understanding of the architecture and components of TSP and their respective range of functionalities. The information provided in this section covers systems and subsystems that are currently in use or available for use in the United States and Canada. When considering a complex implementation of a TSP system, it is important to consult an experienced TSP professional who is familiar with the latest TSP systems and technologies available on the market. In addition, it is important to recognize that no two TSP systems are the same and that TSP equipment and software varies for every application. A thorough design effort needs to be completed for each TSP application to ensure the most effective TSP system, given the individual characteristics of each application and the functionalities that are required by each agency.

FIGURE 5 TSP Architecture Elements [based on NTCIP 1211]



PART III

13.1 TSP System Architecture

Initial implementations of TSP projects were technologically simple, involving some mechanism for detecting the transit or EMS vehicle, using embedded loops or optical strobe systems. The detection of a vehicle would then initiate a process within the phase selector and/or controller to grant priority (or not) based on fairly simple criteria.

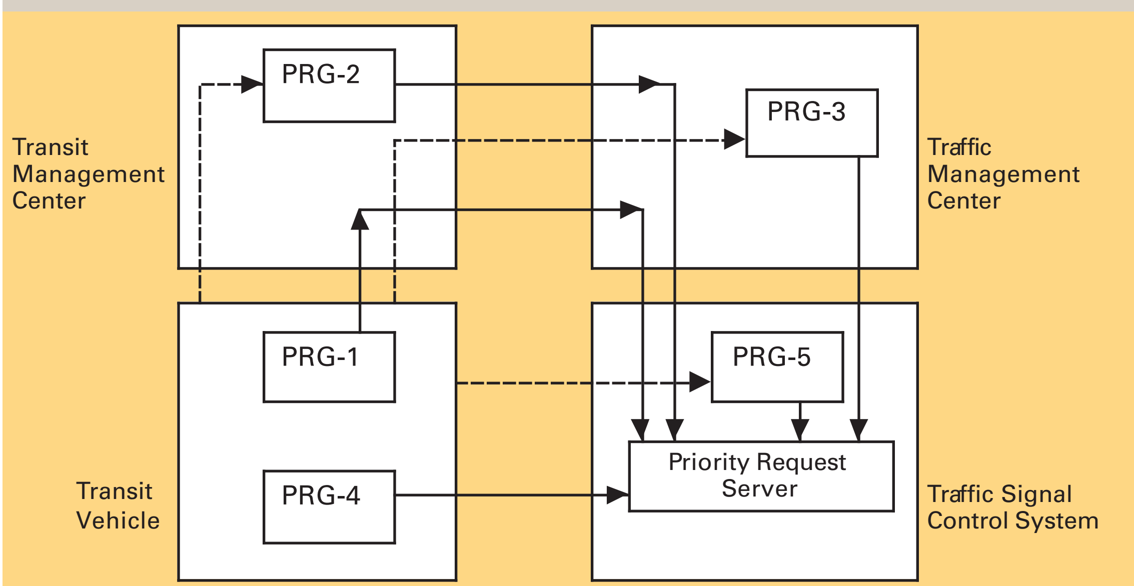
Technology has evolved tremendously, enabling the possibility for a variety of technologies to detect the vehicle, as well as more sophisticated two-way communications between the vehicle and the controller, either directly, or via the central transit and/or traffic centers. This allows for more sophisticated messages and the feasibility of incorporating various criteria to refine the granting of priority based on whether the vehicle meets pre-defined conditions. As a result, ITS standard development efforts for signal priority and TSP have been undertaken as part of initiatives under the National Transportation Communications for ITS Protocol (NTCIP 1211) and Transit Communications Interface Profiles (APTA TCIP TWG 10). These have led to the development of a TSP System Architecture concept. Figure 5 illustrates the main building blocks of the architecture.

Figure 6 illustrates the main elements of a TSP system and the alternative communications scenarios. There are three main systems involved:

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

FIGURE 6 TSP Main System and Components

Note: Solid lines in the figure represent the TSP system links between potntial alternative PRG locations and the PRS. Dashed lines represent information flows required by the PRG to detect a specific bus and/or to assess whether he transit vehicle meets any defined for requesting priority.



13.1.1 Priority Request Generator

Once a vehicle has been detected or has communicated to the PRG, the PRG is responsible for initiating requests for priority based on predefined criteria, which may be unconditional (e.g., priority automatically requested for all transit vehicles on certain routes) or conditional (e.g., priority requested for transit vehicles that are behind schedule by more than 5 minutes).

Depending on the approach selected, the priority request system may be based at the local intersection level or at the management center level. A transit vehicle may be detected at the local intersection level through a combination of an on-board transmitter and a receiver on the intersection approach. For detection at the network level, a transit vehicle may communicate with a transit or traffic management center, providing its location directly. When a priority request is generated, either at the intersection or network level, it may be forwarded directly to the local intersection controller or first pass through a central management center for approval and/or processing.

13.1.2 Communications System

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

Key Question:

WHAT IS CONDITIONAL AND UNCONDITIONAL TSP AND HOW DO WE DECIDE WHAT WE NEED?

The words “conditional” and “unconditional” mean different things to different people. No system is strictly unconditional. All systems have some criteria for granting TSP. For example, if three transit vehicles approach the intersection in three consecutive signal cycles, it is unlikely that the second and third transit vehicles will be granted TSP in any system. For the purpose of this handbook, the term “conditional” means that TSP is granted for transit vehicles that are meeting specific criteria such as (transit vehicles running behind schedule, on route, etc.). In some systems, conditional priority can be granted only if the system “knows” that the transit vehicle is running late. That means that there must be a way of comparing the transit vehicle location to its schedule.

The decision as to whether to have conditional or unconditional priority would be based on several criteria. If you have some kind of vehicle location technology and your goal is to increase reliability, it makes sense to grant conditional priority. Granting priority to a bus running ahead of schedule would decrease reliability. If the goal is to speed up bus service (perhaps because service is very frequent or the route is an express route), then it makes sense to grant priority to all buses. Passengers on an express bus are happy to move quickly once local service is ended; no one will miss the bus because it was early (local service has ended and no more passengers are boarding) and everyone is happy to arrive at a destination quickly. Therefore, the decision of whether to have conditional or unconditional TSP depends on your goals for TSP, and on the technology you have available or planned.

13.1.3 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 pre-emption) override other requests in order of priority.

By establishing standards for interactions between the system components, the NTCIP and TCIP efforts may help to make TSP implementation easier and/or less expensive. NTCIP Standard 1211, "Object Definitions for Signal Control and Prioritization," describes the interfaces with the signal control system. NTCIP 1211 defines four scenarios for TSP operations based on the location of the transit Priority Request Generator (PRG) and the path used to get to the traffic signal system's Priority Request Server (PRS). The PRG can be located in the transit vehicle and communicate directly to the PRS in the controller as is common to date, or be located in either the vehicle, the transit management center, or the traffic management center, and communicate through the transit and traffic centers, as in more sophisticated centralized approaches. (All four scenarios are variously represented in Figure 6). An effort is currently being undertaken by the American Public Transportation Association (APTA) to develop the corresponding TCIP standards from the transit perspective. The results of both efforts are expected to be available in the near future.

13.2 Traffic Control System Components and TSP

The interface between transit vehicles and traffic signal control systems is central to the operation of a TSP system. This section describes the various components of a traffic signal control system from the perspective of how they interface with transit vehicles and other TSP system components.

Although the development of ITS standards is aimed at providing more standardized and open solutions, many of the components of TSP systems are currently proprietary products that are constantly changing and evolving. As such, it is important to note that due to dynamic market forces, some of the proprietary names, manufacturers, model numbers and functionalities of the TSP hardware and software discussed in this section may have changed since publication. Further, all information has been presented in the most objective manner possible and this document does not intentionally favor one vendor/manufacturer over another.

TSP systems consist of the following four main components of the traffic control system:

1. Traffic signal controller hardware
2. Traffic signal controller software (with TSP functionality)
3. Transit vehicle detection systems
4. Communications systems

13.2.1 Traffic Signal Controller Hardware

Traffic signal controllers provide operational control of a signalized intersection. Typically, there is a traffic signal controller located at every signalized intersection. At a given intersection, every traffic signal indication (both pedestrian and traffic signal head) is connected to the signal controller. Most actuated signalized intersections feature in-pavement loops or other vehicle detection methods, and the detector feeds are connected to the controller. Control can be of a single intersection, a corridor or a centralized system where several (or all) intersections are connected together via an interconnect cable or wireless communications system. There are two main components of the traffic signal controller: hardware and software. This section will discuss the traffic signal controller hardware component.

In addition to the type of traffic signal controller, other important considerations include cabinet size and available space; cabinet location; communications connections; and available ports for additional detection. All of these considerations are important in the planning and design of a TSP system and should be considered equally important as the type of traffic signal controller. Further, maintenance of the equipment is important especially when components related to traffic signal operation are maintained by one agency and components related to TSP are maintained by another. Both agencies will need to coordinate and cooperate closely in the development and execution of a maintenance plan for the signal controller and TSP equipment.

There are four main types of traffic signal controllers in operation in the U.S. and Canada:

13.2.1.1 Electromechanical Controllers

These controllers are the oldest, most basic type of controller in operation today in the U.S. These types of controllers have been used for more than 60 years and many are still in operation today. Electromechanical controllers use an electrical magnetic coil to energize and de-energize a solenoid, which physically turns cams and contacts to mechanically change the signals. These types of controllers do not typically have any "active" TSP capabilities; however, these controllers may be interconnected with other controllers at adjacent intersections for coordinated timing or "passive" TSP strategies.

13.2.1.2 NEMA Controllers

There are two types of controllers that follow the National Electrical Manufacturers Association (NEMA) standards — TS-1 and TS-2. These NEMA standards allow multiple manufacturers to produce the controllers, while allowing for equipment interchangeability between manufacturers. NEMA controllers are provided with a manufacturer-supplied software package as part of the controller. A full discussion of the NEMA software TSP capabilities is contained in the next section on TSP software.

The standard for the NEMA TS-1 controller was adopted in 1976 and represented the first industry standard for traffic control equipment. The standard has been revised on several occasions since its original version in 1976, with the most recent version being adopted in 1989.

The standard for the NEMA TS-2 controller was adopted in 1992 in order to provide operational features not covered by the TS-1 standard. For example, the NEMA TS-1 standard did not address traffic signal system communications, pre-emption and priority control. In addition, the 1992 NEMA TS-2 standard enforced plug-compatibility for the equipment provided by different manufacturers. Two types of NEMA TS-2 controllers were developed in an effort to expand the traffic features of NEMA TS-2 controllers: Type 1 and Type 2. Type 1 represents an entirely new performance oriented standard that uses serial communications via a bus interface and Type 2 utilizes several of the same connectors in common use with NEMA TS-1 equipment to maintain backwards compatibility with the TS-1 controllers.

The following are several manufacturers that currently provide NEMA controllers in the U.S.: Eagle (Siemens), Econolite, Naztec, Peek, U.S. Traffic, and Vector. Several other vendors have offered controllers in the past including Traconex, LMD, and Multisonics.

13.2.1.3 Type 170 Controllers

The Type 170 standard was developed by the California Department of Transportation (Caltrans) and the New York Department of Transportation to serve as an alternative to NEMA controllers. While NEMA standards specify that the software be supplied with the controller as firmware, Type 170 controllers include hardware only, and software can be purchased from an independent software developer. If desired, an agency can write its own software. One advantage of the Type 170 standard is that modifications to the software do not affect its hardware compatibility, which is ensured by the controller's open architecture design.

The following are several manufacturers that currently provide Type 170 controllers in the U.S.: Safetran, McCain, U.S. Traffic, and Vector.

13.2.1.4 Advanced Transportation Controllers

Although there are proprietary advanced transportation controllers (ATCs) on the market, the most common and standard type of ATC is the Caltrans Type 2070 controller. The standard for Type 2070 was initially developed by Caltrans but the Joint Committee on ATC is responsible for maintaining this standard for other users. In addition to a more powerful processor, the Type 2070 controller has the capability to upgrade controller software by serial downloads, similar to a personal computer. Due to its better processing power, this type of controller offers more advanced signal control and signal priority capabilities than the NEMA and Type 170 controllers. As with Type 170 controllers, it is necessary to purchase and install separate software packages for the Type 2070 controllers (and the software is interchangeable within the Type 2070 hardware platform). There are currently several versions of the Type 2070 controller available, including the Type 2070 (standard), Type 2070L ("Lite" version) and Type 2070N (compatible with NEMA controller cabinets). All major TSP software packages will run on any of the Type 2070 controllers.

The following are several manufacturers that currently provide Type 2070 controllers in the United States: Eagle, Econolite, Naztec, Safetran, U.S. Traffic, and Vector.

13.2.2 Traffic Signal Controller Software (with TSP Functionality)

With the exception of older electromechanical controllers, all modern traffic signal controllers utilize some type of software to execute all traffic signal control and, where applicable, TSP functionality. TSP-enabled software used for NEMA controllers is typically provided by the controller manufacturer as an integral part of the controller. Manufacturers of Type 170 and 2070 controllers may not provide software as part of the controller assembly. For 170 and 2070 controllers, it is typically necessary to utilize one of several third-party software packages available on the market. The following software packages are currently being used (or are available for use) in the U.S. and Canada:

13.2.2.1 Software for NEMA Controllers

NEMA controllers are provided with a software package by the manufacturer of the controller. Although not required by the NEMA TS-1 1989 standard, all present NEMA controllers have emergency vehicle pre-emption (high priority) routines included in their software. The major manufacturers of NEMA controllers (Eagle, Econolite, Naztec, Peek, U.S. Traffic, and Vector) typically provide in their controllers basic TSP functionalities (low priority) such as green extension and early green (red truncation). However, some of the NEMA manufacturers provide TSP functionality only as an upgrade or enhanced version of the control software. In addition, several manufacturers report that their latest NEMA controller can also run third-party software to achieve TSP with additional and more complex functionality.

13.2.2.2 Software for Type 170 and 2070 Controllers

There are several third-party software packages available for use with Type 170 and 2070 controllers. The following is a discussion of the software capabilities for TSP (low priority) and emergency vehicle pre-emption (high priority) from several leading software vendors:

Bi-Tran – Bi-Tran signal control software is owned by McCain Traffic and is available for use on Type 170 and 2070 controllers. Bi-Tran control software is customized to meet the needs of each individual application and allows for emergency vehicle and railroad pre-emption, as well as transit signal priority applications. Bi-Tran control software runs at the individual intersection level at each controller. System wide control strategies can be achieved by having each individual intersection controller/software send information back to the central end (traffic control center) and then redistribute it out to the individual intersection controllers. While the emergency vehicle and railroad pre-emption is basically the same as the pre-emption offered by NEMA control software, the transit signal priority is slightly more complex and powerful. Bi-Tran transit signal priority allows for functionalities such as: green extension, early green (red truncation), left turn transit phase and queue jump scenarios. These functionalities are designed and implemented to meet the needs of each application and do not depend on the type of controller (170 or 2070). Bi-Tran reports that any type of vehicle detection sys-

PART III

tem can be used to provide the detection input into the controller/software. As of mid-2004, Bi-Tran reported that their software was being used by transit agencies for both bus and LRT signal priority applications in the United States.

Caltrans C8 – This signal control software has been developed and is owned by California DOT for Type 170 controllers. It is Caltrans' standard signal control software used on California state highways. Standard Caltrans C8 offers pre-emption treatments with added TSP functionality for TSP treatments. Based on Caltrans Bus Signal Priority Guidelines, the C8 TSP provides green extension and early green only for coordinated intersection phases. Caltrans' TSP guidelines require that TSP treatment only be given when a transit vehicle is behind schedule and for intersections that are operating at level of service A, B, or C, as defined by the Highway Capacity Manual. The software can work with various vehicle detection systems (point, zone and continuous detection). Caltrans reported that this software is being used for bus signal priority in Alameda County, Santa Clara County, and in San Mateo County.

City of Los Angeles – The City of Los Angeles has developed a suite of traffic control software packages for real time traffic management which include Adaptive Traffic Control System (ATCS)®, Traffic Signal Control Program (TSCP)®, Smart Transit Priority Manager (STPM)®, and Transit Priority System (TPS)®. The TPS program is designed for Type 2070 controllers and includes both transit signal priority and emergency vehicle pre-emption functionalities. The transit signal priority functionalities include green extension, early green (red truncation) and the use of special phases. STPM is a personal computer-based software which operates in conjunction with TSP software. The STPM software function is to monitor and track buses, to request priority at signalized intersections, and to record all bus travel times through the system. When this software is connected to variable message signs it can provide passengers with bus arrival time information. All of the above-mentioned software packages are expected to be available for sale through McTrans.

Econolite ASC/2070 – Econolite's ASC/2070 software supports both pre-emption and a number of TSP functionalities. It is available for use on Type 2070 controllers and operates at the local intersection level only. The pre-emption functionality is basically the same as with the NEMA controllers and other 170/2070 control software packages, and the TSP control allows for advanced TSP functionalities such as: green extension, early green (red truncation), actuated transit phase, phase rotation, etc. According to the manufacturer, there is great flexibility and the TSP functionalities can be set up according to the needs of the individual project. Econolite reports that any type of vehicle detection system can be used to provide the detection input into the controller/software. As of mid-2004, Econolite reported that their software was being used for bus signal priority in King County, Washington. No other applications are currently running.

NextPhase – NextPhase is owned by Siemens and is available for use on 2070 controllers and the Eagle (Siemens) M50 NEMA controller. NextPhase can support emergency vehicle and railroad pre-emption as well as a number of advanced transit signal priority functionalities. NextPhase control software runs at the local intersection level and utilizes a communication connection with adjacent intersections to provide "predictive priority," which allows for continuous, advance adjustment of downstream signalized intersections to accommodate the exact arrival time of the transit vehicle. While the emergency vehicle and railroad pre-emption is basically the same as the pre-emption offered by NEMA control software, the transit signal priority is more complex and powerful than NEMA and some of 170/2070 software packages. NextPhase transit signal priority allows for advanced TSP functionalities such as: green extension, early green (red truncation), left turn transit phase, queue jump, phase rotation, phase insertion and conditional priority requests. NextPhase reports that any type of vehicle detection system can be used to provide the detection input into the controller/software. As of mid-2004, NextPhase reported that their software was being used for LRT signal priority by two cities in the United States: Salt Lake City and Houston. They have indicated that Phoenix, Minneapolis, Las Vegas and Seattle are all planning for, or currently deploying, NextPhase software for TSP.

VS-Plus – VS-Plus signal control software is available for use on Type 2070 controllers. Much like the other 170 and 2070 control software packages, VS-Plus can support emergency vehicle and railroad pre-emption as well as a number of advanced transit signal priority functionalities. VS-Plus control software runs at the local intersection level and has the ability to communicate with adjacent intersections and the central end (control center). In addition to providing standard pre-emption routines, the VS-Plus TSP functionality is more complex and powerful and allows for advanced TSP functionalities such as: green extension, early green (red truncation), left turn transit phase, queue jump, phase rotation phase insertion and conditional priority requests. According to PTV America (the vender of VS-Plus at the time this research was conducted) VS-Plus' TSP functionalities have "virtually no limitations." PTV America reported that any type of vehicle detection system can be used to provide the detection input into the VS-Plus software. VS-Plus software has been used for more than twenty years and is currently being used for bus and LRT signal priority by numerous cities in Europe and China. The company has indicated that while the VS-Plus software is currently used for basic intersection control in the United States, there are no TSP applications currently running in the U.S. or Canada.

Wapiti – Wapiti's product [called Actuated Local Intersection Firmware (W4iks)] is designed with both emergency pre-emption and transit signal priority functionalities. The main TSP capabilities are green extension and red truncation. Although phase insertion is not specifically designed for the TSP application, utilization of other exiting features may enable this software to implement phase insertion. Wapiti's W4iks software is being used in numerous locations with capabilities to run TSP. One of the main TSP applications is with the City of Portland. W4iks software can run on Type 170 controllers. Most of the 2070 controllers are using a newer Motorola processor, which is not compatible with W4iks software.

13.2.3 Transit Vehicle Detection Systems

In order for TSP systems to assign priority treatment to transit vehicles, it is necessary for the system to be able to distinguish transit vehicles from the rest of the traffic. Therefore, one of the keys to a successful TSP system is accurate detection of transit vehicles. Selection of the detection system is a rather involved process that requires detailed planning and design to determine which type of detection system can best meet a project's objectives. Inappropriate application of a detection system can be a fatal flaw in the TSP system's design. The accuracy of detectors can be impacted by a number of factors, including environmental conditions, surrounding objects and detector placement. Detector placement requirements can be the main factor in the detector selection process. The most common detector placements are (1) in the pavement (2) facing the oncoming traffic flow and (3) on the side of roadway (side-fire). One of the often missed limiting factors of some Radio Frequency (RF) detection systems is the requirement for an FCC license. The FCC license application procedure is rather lengthy and approval is not guaranteed. In general, the FCC license ensures that the system will not interfere with other existing systems, and the approval process is based on FCC-defined priorities. It is good practice to determine if the detection system requires an FCC license and if not, if there is possibility of interference from other systems that will impact the detection system's accuracy.

Detector selection has to be made in parallel with selection of transit signal priority software. Transit signal priority logic requirements must be carefully coordinated with the detection system. For example, it is important to determine when the transit vehicle has cleared the intersection during the green extension phase so that the green extension phase can be terminated and signal timing can be returned to the original operational mode as soon as possible. Some transit signal priority detection systems have limited capabilities to accommodate this type of "check out" detection. Most of the time a different detector configuration and/or additional detectors may resolve this issue but sometimes more radical changes may be required, such as utilization of a different detection system. All detection technologies have limitations and it is important to complete a thorough evaluation and system design to ensure the desired functionalities are possible.

Many times the selection of a detection system is driven by the detection system being used by the traffic agency. Coordination with traffic agencies is a must, since in many instances traffic agencies end up responsible for system maintenance. But, if a detection system cannot provide the required functionalities for efficient TSP system operation, alternative solutions should be evaluated.

13.2.3.1 Hard-Wired Loop Detection

This type of detection system consists of a transponder attached to the underside of the emergency or transit vehicle and a vehicle detection receiver that integrates with the signal controller. The transponder is detected by a standard traffic loop embedded in the pavement. The transponders are coded with unique identification numbers for automatic vehicle identification (AVI) functionality.

The advantages of loop detection systems are that the system is compatible with commonly used loop detectors, does not require line-of-sight or visibility, and transponders may be mounted on emergency vehicles for pre-emption and transit vehicles for signal priority functionality. It is also relatively easy to accommodate "TSP check-out" by merely inserting another loop after the intersection.

The limitations of this type of system are that it requires in-pavement loop detectors that need to be appropriately placed; loop detectors are prone to failure due to pavement flexing; and they are often cut during roadway resurfacing activities. In spite of these drawbacks, loop detectors are considered by some agencies to be one of the most reliable types of vehicle detectors available, and there are many professionals in the traffic engineering community that are familiar with the operation and maintenance of loop detectors.

13.2.3.2 Light-Based (infrared) Detection

This type of vehicle detection system is one of the most widely used for emergency vehicle and transit vehicle detection in the U.S. The system typically consists of three main components: (1) infrared strobe emitter located on the transit vehicle (2) infrared detectors located at each intersection and (3) a "phase selector" interface within the traffic signal controller cabinet that relays the message to the traffic signal controller. The emitter on the transit vehicle is typically located on the top front part of the vehicle and can be activated manually by the driver or by some type of automatic means. When activated, the emitter sends an infrared signal to the detector (most commonly located on the signal mast arm or span wire) at the signalized intersection. The signal sent by the transit vehicle may contain an identification number that may be configured as unique to each vehicle (or class of vehicles) so that the transit/traffic management agency can track the location/progression of every transit vehicle. The infrared detector at each intersection receives the signal from the transit vehicle and routes it to the "phase selector," where the priority request is validated and forwarded to the signal controller. Check out detection is achieved by noting when the vehicle's infrared strobe is no longer detected at the intersection.

This detection system has two main advantages: First, it is widely used in the U.S. for emergency vehicle pre-emption systems. This allows a city/region to utilize the same system for both its emergency vehicle pre-emption system and its transit signal priority system. The detection and controller interface equipment that is located at the individual intersections will serve both needs. Second, the technology has been well tested since it has been in use for many years.

The main disadvantage to this type of vehicle detection system is the use of a light-based technology, which requires line-of-sight between the transit or emergency vehicle and the detector at the intersection. Effective operation of the system can be hindered by roadway geometry, weather problems and obstructions such as tree foliage. Additionally, the profile of the strobe light allows for the potential for interference with nearby or adjacent intersections since light reflections can provide false detection at other detectors.

13.2.3.3 Sound-Based Detection

Emergency Vehicle Siren Detectors - This type of vehicle detection consists of a directional microphone located at the intersection, a controller card in the controller and an optional visual confirmation light fixture. The microphone detects emergency vehicle sirens in yelp, wail, or hi-lo with adjustable frequency, period and range. Although a siren device can be mounted on transit vehicles for transit signal priority, this type of application would be less desirable since an audible siren would be required on all transit vehicles.

An advantage of this system is that emergency vehicles do not need any equipment installation for this system to function since it utilizes their existing sirens. Additionally, this system facilitates interjurisdictional emergency response since the microphones detect and respond to all emergency vehicle sirens. A third advantage is that line-of-sight and visibility concerns are not factors that affect the system's performance.

The main disadvantage of this system is that it is not practical for transit signal priority use due to the requirement of each vehicle using an audible siren. This would create situations where the motoring public would hear emergency vehicle-like sirens and possibly take evasive actions that could be risky and lead to increased accidents. Another disadvantage is the potential for false activations from building alarms and car alarms. Further, there is no capability for vehicle identification or logging without the use of additional equipment on all of the emergency and transit vehicles.

Digital Sound Wave Recognition System - This type of system consists of a digital sound wave recognition system located at the intersection and a phase selector unit that is connected to the controller. Its functionality is similar to that of the siren detection system with one major difference: transit vehicles can be equipped with non-audible sound generators to function with this system.

As with the siren detection system, one advantage of this system is that emergency vehicles do not need to be outfitted with any additional equipment to function with this system. Additionally, transit vehicles can utilize this system for TSP functionality by installing a non-audible sound generator on each transit vehicle. Line-of-sight and visibility issues are not a concern with this system.

The disadvantages of this system are similar to the siren detection system: the possibility of false alarms from building and car alarms, and the lack of vehicle identification and logging capabilities.

13.2.3.4 Radio-Based Detection

This type of detection system consists of Radio Frequency (RF) transponders mounted on the emergency or transit vehicles and RF tag readers installed upstream of the signalized intersections for detection. The tag reader system is connected to the signal controller by means of an RS-232 connector.

One of the advantages of this technology is that it does not depend on line-of-sight or visibility. Limitations of this system are that it requires suitable curbside locations for the tag readers upstream of the intersections, including mounting locations, power and communications connections.

Another type of radio-based detection system consists of an antenna and receiver mounted at the intersection to receive radio signals from emergency vehicle or transit vehicle-mounted spread spectrum radio transmitter. All pre-emption and priority activity is logged by vehicle ID number, priority level, direction of travel, time, date and duration. A drawback to this system is that its non-directional nature requires the vehicle to provide information on the direction of travel.

13.2.3.5 Satellite (GPS)-based Detection

There are several GPS-based detection systems available for use with TSP deployments. This section describes two of the GPS-based detection systems that are currently available on the market.

The first GPS-based transit vehicle detection system consists of two units -- the in-vehicle unit and the field unit located at the signal controller. The in-vehicle unit consists of an onboard computer that performs a range of functionalities of which one is the constant updating of vehicle location using a GPS-based AVL system. Based on vehicle schedule deviation, passenger load and other factors, the in-vehicle unit sends data information to the field unit. The field unit is located at the signal controller to evaluate incoming priority messages with regard to vehicle or route number, vehicle approach, priority level, etc. The field unit also receives the data radio message from the vehicle. The decision as to whether to grant or reject signal priority is made by the signal controller or the traffic control center, depending on system design and configuration. Advantages of this type of detection system are that it does not require line of sight and can notify the signal controller when a transit vehicle has cleared the intersection.

There is another type of commercially-available transit vehicle GPS-based detection system that allows for the determination of vehicle location, speed and heading. This system requires the installation of radio transceivers on each emergency or transit vehicle and radio receivers at each intersection. As the vehicle enters the intersection's radio range, the vehicle-mounted transceiver sends the vehicle's location, speed and heading information to the receiver located at the intersection. An interface unit processes this information and connects with the intersection controller.

A limitation of some AVL-based detection systems is that the polling rate of some existing AVL systems may not support adequate sampling of vehicle locations for closely spaced intersections or for check in/out calls if the mid-block bus stop is close to the intersection. Further, urban environments may provide additional challenges for GPS-based systems.

13.2.4 Communications Systems

There are two types of communications associated with emergency vehicle pre-emption and TSP systems, (1) vehicle detection communications and (2) communications between intersections and central end (control center). Some TSP applications require only the first type, and others require only the second type; however many require both types.

The first type of communications involves local communications between the transit or emergency vehicle and the signal controller located at each intersection. Typically, this communications system is an integral part of the vehicle detection system, which will include both the transceiver and receiver as part of the system. The following are the different types of communications used in vehicle detection systems:

- Hard-wired loop-based
- Light-based
- Sound-based
- Radio (RF)-based
- Satellite and Radio-based

The second type involves communications from individual intersections to the central end (control center). There are some advanced TSP software packages that permit communications between the local intersection controllers at each intersection in the field and with the central end (control center). This allows for enhanced TSP operation but requires communications between intersections and the central end. Typically, intersection controllers and/or the central end are interconnected by means of a physical connection consisting of fiber optic or copper cable. If not already implemented, this type of communications requires significant infrastructure costs for the installation of conduit and cabling between intersections. Newer systems utilize wireless technology, which eliminates the need for expensive conduit and cable connections between intersections and the central end (control center).

14 TRAFFIC ENGINEERING TERMINOLOGY

It is important to understand the key traffic engineering, signal timing and TSP fundamentals before beginning the implementation of a TSP deployment. The intent of this section is to provide basic traffic engineering and TSP definitions and concepts that will improve the reader's understanding of signal timing considerations necessary to appropriately implement TSP. The first section, Key Traffic Engineering and TSP Definitions, provides basic definitions of important terminology along with several examples and graphics. The second section, Key Traffic Engineering and TSP Concepts, offers more in-depth discussions of key areas in the traffic engineering and TSP fields and provides several examples to illustrate the concepts. For additional information on this subject, a number of traffic engineering documents are available, including the Highway Capacity Manual; Manual on Uniform Traffic Control Devices (MUTCD); and A Policy on Geometric Design of Highways and Streets (AASHTO "Green Book").

14.1 Key Traffic Engineering and TSP-Related Concepts

This section provides definitions and explanations in four categories: general traffic engineering terminology; traffic signal timing terminology; signal coordination terminology; and basic TSP terminology.

14.1.1 General Traffic Engineering Terminology

Delay: the time lost while traffic is impeded in its movement by some element over which it has no control and is usually expressed in seconds per vehicle. Delay at intersections usually refers to control delay due to a control facility like a traffic signal and includes initial deceleration delay, queue move-up time, stopped time and final acceleration time.

Dilemma zone: refers to the portion of the roadway in advance of the intersection within which a driver, confronted with a yellow signal indication, is indecisive regarding stopping prior to the stop line or proceeding into or through the intersection.

Fully-actuated operation: timing on all of the approaches to an intersection is influenced by vehicle detectors. Each phase is subject to a minimum and a maximum green time, and some phases may be skipped if no demand is detected. The cycle length for fully actuated control will vary from cycle to cycle based on traffic demand.

Initial Interval: designed to allow the space between the detector and the stop line to clear vehicles.

Extension interval: (also called vehicle interval, gap time or unit interval) the time the green is extended for each arrival at the detector, from the instant of arrival of the detector.

Maximum interval: or maximum period is the total time allowed for the phase.

Headway: time between successive vehicles as they pass a point along the lane, measured from some common reference points on the vehicles.

Lane group: consists of one or more lanes that have a common stop line, carry a set of traffic streams and whose capacity is shared by all vehicles in the group.

Level of service: defines the operating conditions that may occur on a given lane or roadway when it is accommodating various traffic volumes. Level of service for intersections is defined in terms of average control delay per vehicle and is categorized as given in the table below.

Level of Service	Control Delay per Vehicle (sec)
A	≤10
B	≥10 and ≤20
C	≥20 and ≤35
D	≥35 and ≤55
E	≥55 and ≤80
F	>80

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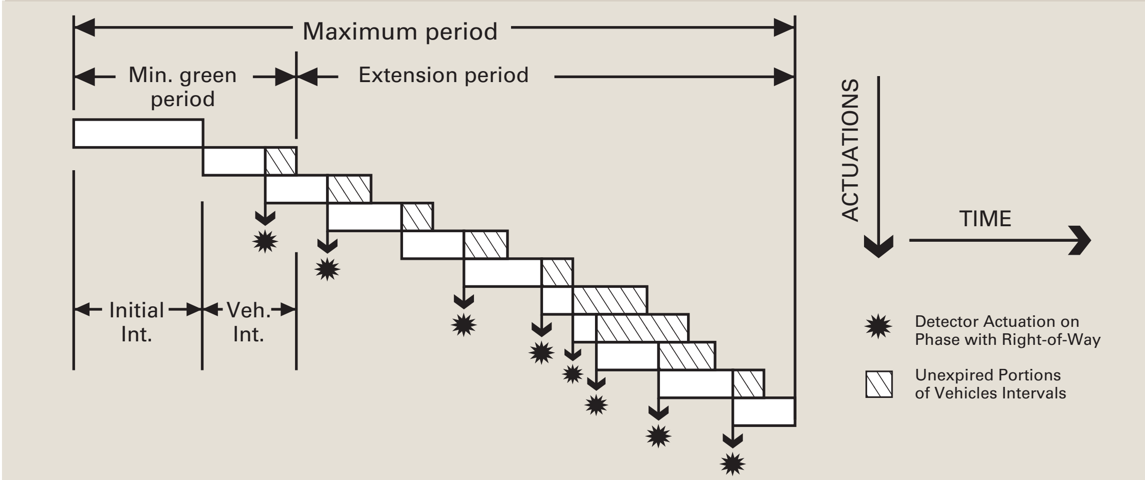
FIGURE 7 Actuated Phase Operation

This table explains the actuated operation of an approach at a signal. The figure shows the Initial Interval being extended by a time period equal to the Vehicle Interval upon the arrival of vehicles (denoted by a '*') on the approach. This extension of the interval is continued until the Maximum Interval period is reached upon which the right of way is given to another movement.



Peak hour factor: is a measure of the variability of demand during the peak hour of traffic. It is the ratio of total hourly volume during the peak hour to the maximum rate of flow during a given time period (usually 15 minutes) within the peak hour. PHF = volume during the peak hour/(4 x volume during peak 15 min within the peak hour)

Example: consider an area where the peak hour is between 7:00 a.m. and 8:00 a.m. If the 15 minute traffic volume counts in the area are

7:00 – 7:15 a.m.	54
7:15 – 7:30 a.m.	75
7:30 – 7:45 a.m.	82
7:45 – 8:00 a.m.	59

Then PHF = (54 + 75 + 82 + 59)/ (4 x 82) = 0.823

Pre-timed operation: method for operating traffic signals where the cycle length, phases, green times, and change intervals are all preset.

Right turn on red: means that vehicles can make a right turn at an intersection even though they face a red indication.

Semi-actuated operation: some approaches (typically on the minor street) have detectors, and some do not. The earliest form of semi-actuated control was designed to confine the green indication to the major street in the absence of minor-street actuation. Once actuated, the minor-street green is displayed for a period just long enough to accommodate the traffic demand.

Signal face: part of the signal head provided for controlling traffic in a single direction. Turning indications may be included in a signal face.

Signal head: assembly containing one or more signal faces which may be designated accordingly as one-way, two-way, etc.

Traffic control signal: type of highway traffic signal manually, electrically or mechanically operated by which traffic is alternately directed to stop and permitted to proceed.

Turn type: defines the type of turns made at an intersection:

> **Permitted turn** is a turn made through a conflicting pedestrian flow or opposing-vehicle flow. Thus a left turn movement that is made at the same time as the opposing through movement is considered to be permitted, as is a right-turn movement made at the same time as pedestrian crossings in a conflicting cross walk.
>
> **Protected turn** is a turn made without any conflicts, such as turns made during an exclusive left turn phase or a right turn phase during which conflicting pedestrian movements are prohibited.

Not opposed turning movements are those that do not receive a dedicated left-turn phase (i.e., a green arrow), but because of the nature of the intersection, they are never in conflict with through traffic. This condition occurs on one-way streets, at T-intersections, and with signal phasing plans that provide complete separation between all movements in opposite directions.

14.1.2 Traffic Signal Timing Terminology

All red interval: an interval during which all signal indications at an intersection display red.

Change and clearance interval: yellow plus all-red intervals that occur between phases to provide for clearance of the intersection before conflicting movements are released.

Cycle: refers to any complete sequence of signal indications.

Cycle length: total time for the signal to complete one cycle, stated in seconds.

Effective green time: time that is effectively available to a movement. It is the green time plus part of the change and clearance interval minus the lost time for the designated movement.

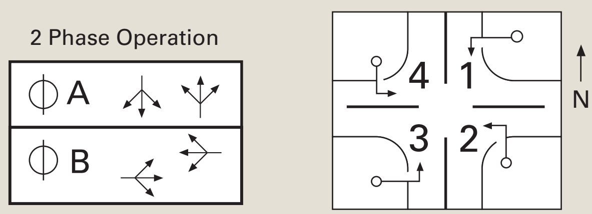
Green interval: time within a given phase during which the green indication is shown.

Interval: period of time during which all signal indications remain unchanged.

Lost time: time during which the intersection is not effectively used by any movement, which occurs during part of the change and clearance

FIGURE 8 Relationship between Interval, Phase and Split

Figure explaining the relationship between an interval, phase and split in a two phase signal operation.



Signal Head	Movement
1 & 3	N.B. & E.B.
2 & 4	S.B.. & W.B.

Signal Indications

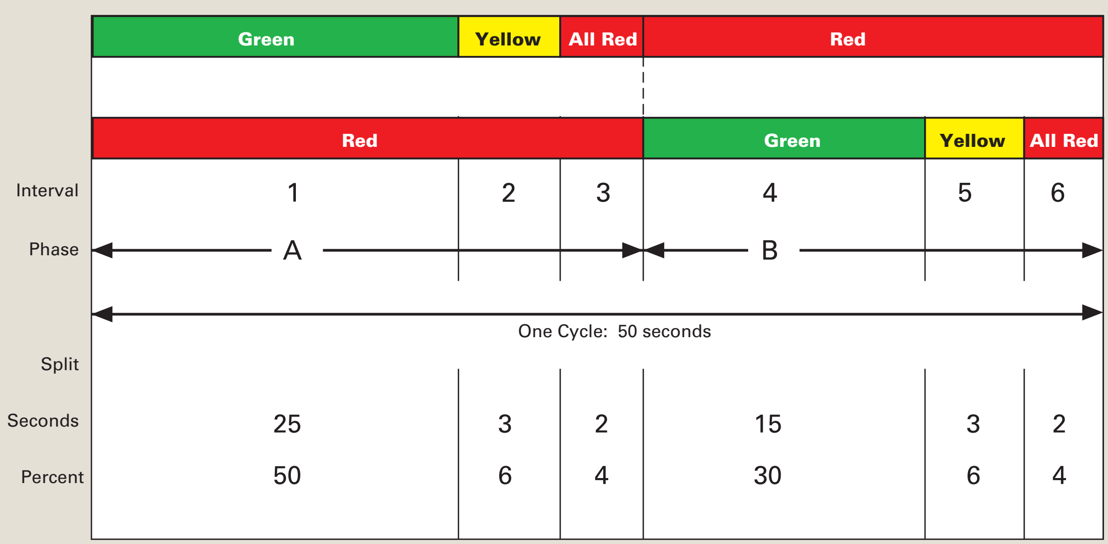
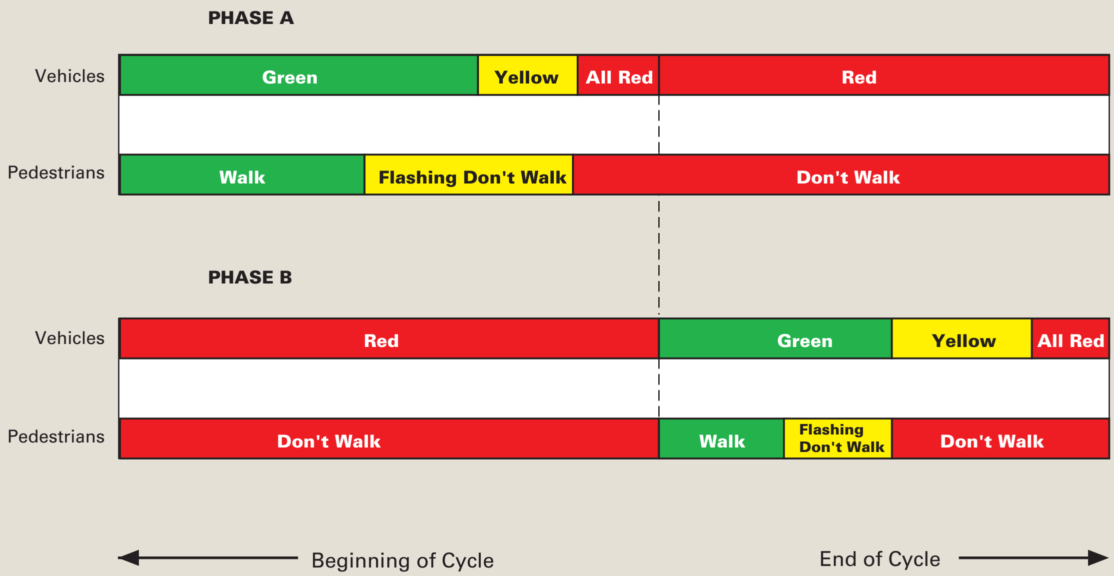


FIGURE 9 Relationship between Pedestrian and Vehicular Signals

Figure explaining the relationship between pedestrian and vehicular signals in a two phase signal operation. (Note: Phase A would be for Street A and Phase B would be for the cross street, Street B)



interval (when the intersection is cleared) and at the beginning of each phase as the first few vehicles in a standing queue experience start up delays.

Maximum green time: maximum green time that can be allowed for a phase

Minimum green time: shortest green time allowed for a phase.

Pedestrian (walk) interval: allows adequate time for pedestrians to leave the curb before the clearance interval is shown. Under normal conditions, the minimum walk interval is typically four to seven seconds.

Pedestrian clearance (Flashing "don't walk") interval: provides time for pedestrians to clear the intersection. It should be equal to or greater than the time required for pedestrians to leave the curb and travel to the center of the farthest traffic lane before opposing vehicles receive a green indication. A pedestrian walking speed of 4ft/sec is usually used in the calculations.

Phase: part of a cycle allocated to any combination of one or more movements receiving the right of way simultaneously during one or more intervals.

Split: portion allocated to each of the various phases in a cycle (usually expressed as a percentage)

Yellow interval: interval following green in which the yellow indication is shown indicating phase termination.

14.1.3 Signal Coordination Terminology

Background cycle length: identifies the cycle length that all controllers operating within a coordinated system must have.

Band speed: slope of green band on a time speed diagram representing the progressive speed of traffic moving along the arterial.

Bandwidth: amount of green time available to a platoon of vehicles through intersections without stopping in a progressive signal system. It is also referred to as through band.

Force off point: point within a cycle at which the

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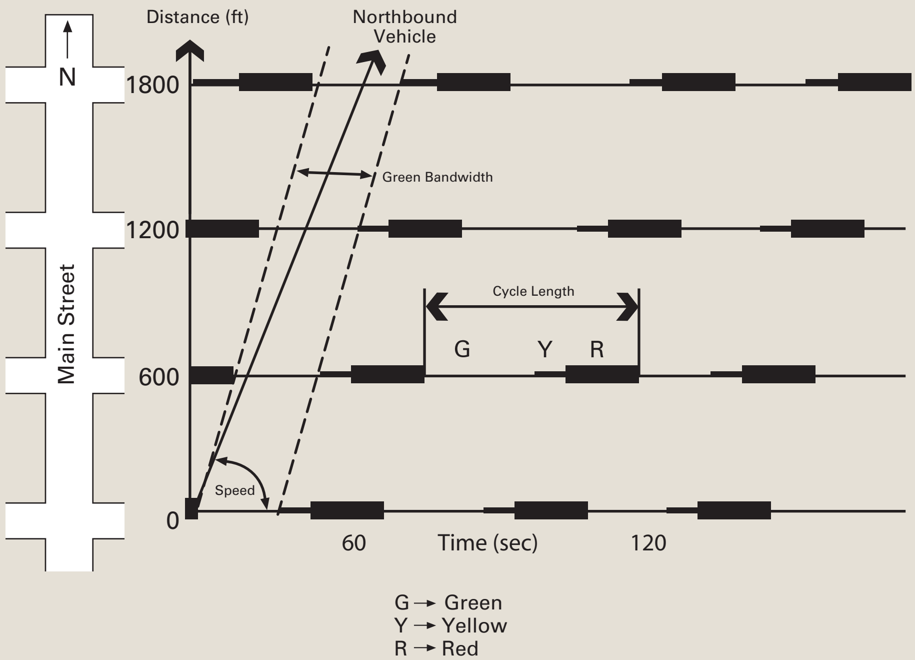
FIGURE 10 Green Bandwidth and Vehicular Progression along a Street



right of way is terminated so that subsequent phases can be serviced at the proper time

Gap out: termination of a green interval due to an excessive time interval between the actuation of vehicles arriving on the green, so as to serve a conflicting movement.

Hold: command that retains the existing right of way.

Offset: of an intersection is the time lapse in seconds (or the percentage of the cycle length) between the beginning of a green phase at the intersection and the beginning of a corresponding green phase at the master intersection.

Passage time: amount of time required for a vehicle to travel at a selected speed from the detector to the nearest point of conflicting traffic.

Permissive period: time period in which the controller unit is allowed to leave a coordinated phase under coordinated control and go to other phases.

Progression: used to describe the progressive movement of traffic through several intersections within a control system without stopping.

Recall: operational mode for an actuated controller unit whereby a phase, either vehicle or pedestrian, is displayed each cycle whether or not demand exists.

Yield point: point at which the controller is allowed to leave the coordinated phases to service other phases. It marks the beginning of a permissive period.

14.2 Basic TSP Terminology

The following are definitions of TSP strategies and terms related to traffic priority.

Compensation/Recovery: non priority phases are given some additional time to make up for the time lost during priority. Some compensation techniques include limiting the number of consecutive cycles in which priority is granted (e.g. locking out the granting of a priority request from the next cycle).

Early Green(red truncation): desired phase green is started earlier. This is helpful if the transit vehicle is detected during the red phase.

Phase/green extension: desired phase green is lengthened up to a maximum permitted time. This proves helpful when the transit vehicle is detected near the end of the green and no near side bus stop is present. By extending the green a few seconds, the transit vehicle avoids stopping at the signal.

Phase suppression/skipping: logic is provided so that fewer critical phases are skipped. This can be used with logic that assesses congestion on the approaches to the skipped phase.

Phase Rotation: strategy where the order of signal phases is "rotated" 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 strategy, the left turn phase could be served as a leading phase (before the through green) in order to expedite the passage of the transit vehicle.

Pre-emption ("High" Priority): as per NTCIP 1202 Version 2, the transfer of the normal control (operation) of traffic signals to a special signal control mode for the purpose of servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage, and other special tasks, the control of which requires terminating normal traffic control to provide the service needs of the special task. The pedestrian "don't walk" movements are completed to clear pedestrians.

Priority ("Low" Priority): modifies the normal signal operation to better accommodate transit vehicles. As per NTCIP 1211, the preferential treatment of one vehicle class (such as a transit vehicle, emergency service vehicle or a commercial fleet vehicle) over another vehicle class at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations. Priority may be accomplished by a number of methods including the beginning and end times of greens on identified phases, the phase sequence, inclusion of special phases, without interrupting the general timing relationship between specific green indications at adjacent intersections.

Queue Jump: a strategy where transit vehicles are provided the means to pull ahead of regular vehicular traffic that is stopped at an intersection, thereby providing the transit vehicle with advanced green (a "jump") in relation to other vehicular traffic.

Red interrupt or special phase: a short special green phase is injected into the cycle. This can be used to create a transit-only phase such as to permit a queue jump, and can be especially helpful with near side stops serviced from a shoulder. Buses get a special advance phase display which allows them to get through the intersection smoothly and get back into a regular lane of travel easily.

Window stretching: non priority phases are given a core time, which must be serviced every cycle, and a variable time which could be taken away for priority purposes. Flexible window stretching differs in that the core time is not fixed in position relative to the cycle.

14.3 Key Traffic Engineering and TSP Concepts

This section provides a more in-depth discussion of several key traffic engineering and TSP concepts to augment the basic definitions provided in the previous section.

14.3.1 Coordinated vs. Free Operations

Signals may be either part of a coordinated system or independent (no coordination). An intersection may operate in either mode, depending mainly on site conditions. The method of signal operation dictates the implementation of TSP for a signal, where signal coordination introduces additional constraints for the TSP implementation compared to independent signal operation. When a signal is operating in coordinated mode, it is constrained by the local cycle and its zero point, which defines the relationship between adjacent intersections. At this point during the cycle, the coordinated phase must be in operation and thus phases can only be adjusted around this constraint. Essentially, the phases are adjusted to provide transit priority while remaining coordinated beyond the current cycle, such that the signal can always return back to its coordination at this point. This adjustment is consequently limited by the coordination, although the limitation often still exceeds the amount of TSP desired at an intersection.

The most common implementation of TSP relies on green extension or red truncation to provide an advantage to the transit vehicle. When the signal is operating in a coordinated system, either the green time for the transit phase is lengthened or the red time for the transit phase is shortened. This is accomplished by changing the green allocation for each phase while maintaining the "zero point" to keep the signal in coordination with the system. This zero point, commonly referred to as the yield point or reference phase, may be shifted for one cycle, but should allow the signal to remain in relative coordination between intersections (fully described in the NTCIP 1211 standard).

14.3.2 Cycle Lengths

The cycle length at an intersection is the time required to serve each phase in a traffic signal. Cycle length is impacted by several factors and more details on these factors and cycle length calculation procedures can be found in numerous traffic-related publications such as the *Highway Capacity Manual*.

The cycle length impacts the extent to which signal priority is provided in two different ways: (1) generally speaking, intersections with higher cycle lengths have a greater flexibility to provide transit priority. On the other hand, longer cycle lengths may also cause longer delays for transit vehicles if they arrive at an intersection during the red phase and (2) short cycle lengths allow efficient operation for transit vehicles (and other users) that arrive randomly within the cycle length but they have lower flexibility to provide transit priority compared to longer cycle lengths.

In coordinated operations, cycle lengths at adjacent intersections are required to be the same in order to maintain coordination between the intersections. Cycle length calculations for both coordinated and non-coordinated operations are generally completed utilizing a traffic signal optimization software package.

14.3.3 Phasing (Two-Phase vs. Multi-Phase Signals)

Two-phase signal timing plans are the simplest form of phasing for traffic control, and, simply stated, separate the main street traffic from that on the cross street. Adding left-turn movements (typically identified by left-turn arrows at an intersection) result in multi-phase signal timing plans that can include eight or more phases.

Since the transit vehicle phase is provided priority by reducing the green time of other phases, having only two phases may limit the amount of time that can be taken from the non-transit vehicle phase and given to the transit vehicle phase. This is especially noticeable when the cycle length is short and both of the phases have pedestrian recall/actuation.

Multi-phase intersections present difficulties in providing priority and specifically in determining how much to reduce non-transit vehicle green times; however, there is typically more flexibility in having additional phases to reassign time from. The priority is often constrained by the elements discussed above, however, providing even minimal priority will still benefit transit travel time. At actuated and semi-actuated intersections, the coordinated phase is designed for the busiest stream of traffic, which in a coordinated system receives the unused time associated with non-coordinated phases. In the cases where transit vehicles operate along the arterial, the coordinated phase typically receives a high percentage of green time already thus, the added benefit of time might be a small percentage of the time beyond what is already provided in the signal cycle.

Conversely, any vehicle (including a transit vehicle) on the non-coordinated phase will typically not receive a high percentage of green time. Due to the amount of time already given to the coordinated phase, there may be more flexibility to provide priority to transit vehicles on the non-coordinated approaches, with resulting impacts to the highest traffic stream.

Planning of future transit signal priority projects should consider the opportunities associated with transit vehicles on non-coordinated phases, which have the greatest potential for improvement of transit operation.

14.3.4 Splits

The split at an intersection is the time allocated to a given phase relative to the cycle length. A phase is a timing unit associated with the control of one or more indications. Each phase at an intersection has a set of timings. Phases typically contain vehicle and/or pedestrian timing. Minimum times for each phase must be met and the excess (flexible) time in the cycle can be allocated to the transit vehicle phase, based on traffic characteristics. When adjusting splits to provide priority, consideration must be taken so that the adjustment does not dramatically impact the vehicular traffic on the non-transit vehicle phases. Consideration of overall person delay rather than only vehicular traffic delay allows a more aggressive approach to the timing settings. If the splits are adjusted too much, the non-transit vehicle approaches may experience noticeably higher delays, resulting in longer queues and complaints from motorists.

14.3.5 Pedestrian Timing

Traffic signals without pedestrian actuation or push buttons must rely on a recall in the traffic controller that ensures a pedestrian WALK indication will be displayed during each cycle. Pedestrian Recall calls up the time necessary for pedestrian timing for specific phases that do not have pedestrian actuation. For example, when pedestrian recall is on the non-transit vehicle phase, the minimum pedestrian cycle timing (Walk and Flash Don't Walk) will occur, potentially delaying the transit vehicle.

The lack of pedestrian push buttons (thus necessitating the use of Pedestrian Recall) at a signalized intersection limits the amount of time available to shorten a phase (provide red truncation to the transit vehicle phase). For example, when side streets have pedestrian recall activated, priority timing for the transit vehicle phase is limited; because the side streets need to serve the Walk and Flash Don't Walk each cycle, regardless of whether a pedestrian is present at the intersection.

In instances with pedestrian push buttons, (without pedestrian recall) the pedestrian timing must be taken into account when providing priority. A signal priority strategy must be developed such that, in the event of a pedestrian call, allows the signal to serve the pedestrian timing without driving another phase to its minimum or negatively impacting the transit vehicle phase. This is done by providing priority for the "worst-case" scenario, assuming pedestrian timing will be called even when Pedestrian Recall is not active.

14.4 Transit Signal Priority Examples

Transit Signal Priority (TSP) is the process of altering the signal timing to give a priority or advantage to transit operations, as illustrated in the figure below. Signal priority <u>modifies</u> the normal signal operation process to better accommodate transit vehicles. This is different from signal "pre-emption," which <u>interrupts</u> the normal signal operation to accommodate special events (e.g. train approaching a railroad grade crossing adjacent to a signal, emergency vehicle responding to an emergency call).

TSP systems can either be manually implemented by the transit vehicle driver or automatically implemented using on-vehicle technology, which is the preferred method because it eliminates the human factor, having the driver remember to activate the emitter. In many cases, the automated TSP will only occur at a signalized intersection if the corresponding transit vehicle is behind schedule, based on the TSP logic programmed into the traffic signal controller.

Early Green (red truncation): The desired phase green is started earlier. This is helpful if the transit vehicle is detected during the desired phase red.

Example: Early Green - Bus traveling on Main Street and arrives during Side Street green and wants an early green light for the Main Street.

Green extension: Desired phase green is lengthened up to a maximum permitted time. This proves helpful when the transit vehicle is detected near the end of the green and no near side bus stop is present. By extending the green a few seconds, the transit vehicle avoids stopping at the signal.

Example: Phase Extension - Bus traveling on Main Street and arrives late during Main Street green and wants phase extension.

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FIGURE 11 Transit Signal Priority Examples [21]

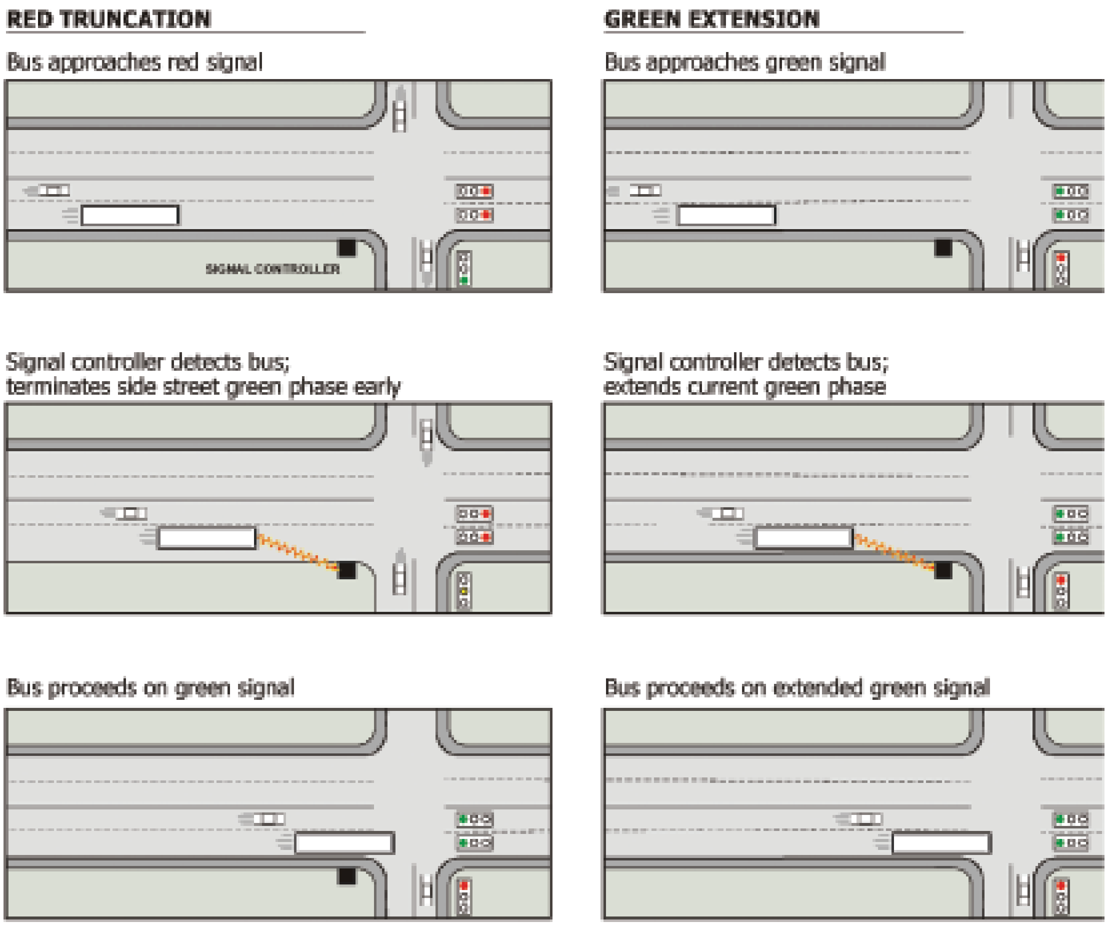
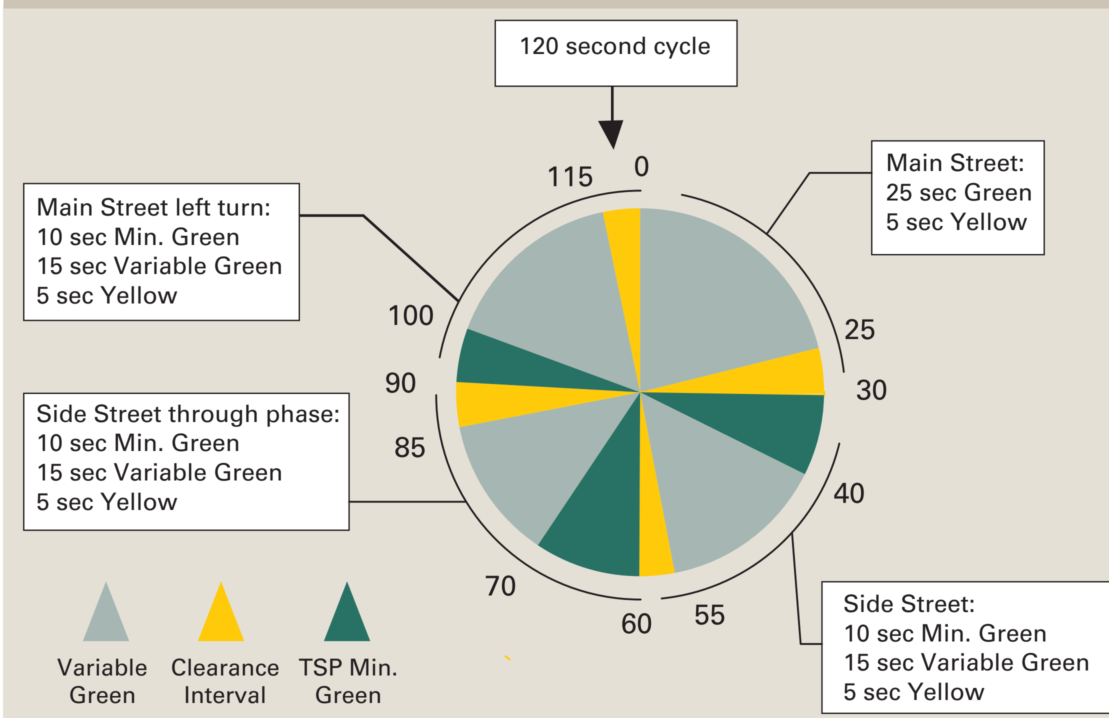
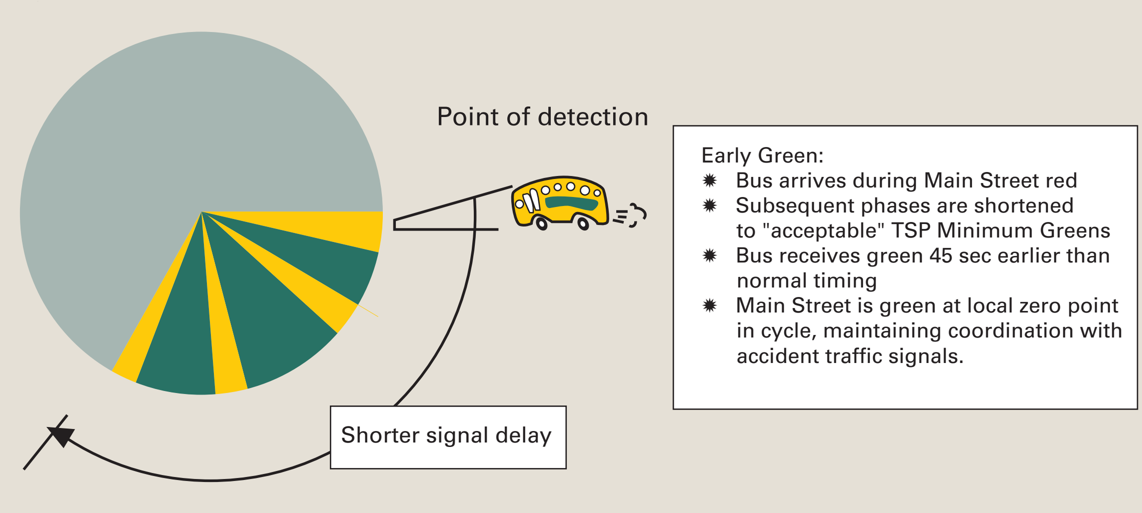


FIGURE 12 Normal signal timing operation



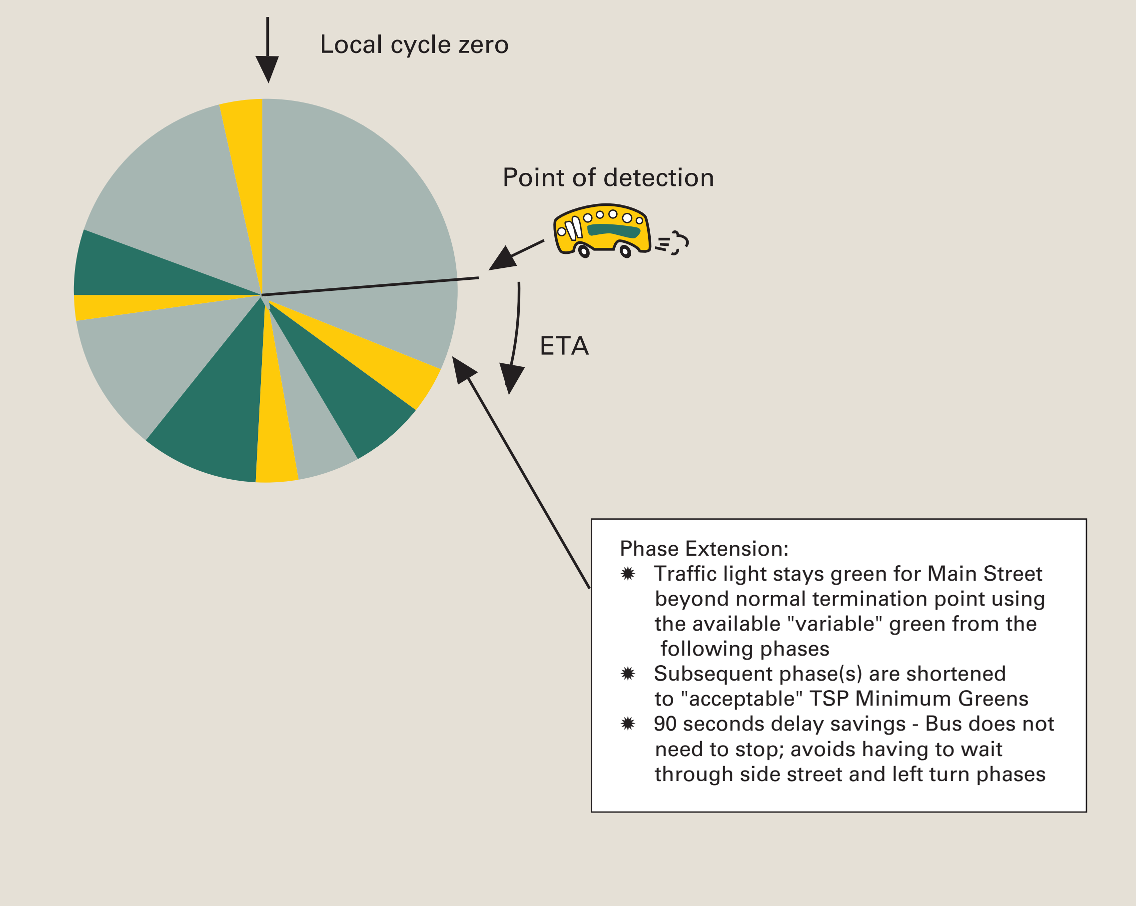
[21] Transit Capacity and Quality of Service Manual, Transit Research Board, 1999.

FIGURE 13 Signal timing operation with early green (red truncation)



Green Extension: desired phase green is lengthened up to a maximum permitted time. This proves helpful when the transit vehicle is detected near the end of the green and no near side bus stop is present. By extending the green a few seconds, the transit vehicle avoids stopping at the signal.

FIGURE 14 Signal timing operation with phase extension



Example: Phase Extension - Bus traveling on Main Street and arrives late during Main Street green and wants phase extension.

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15 SIMULATION AND OPTIMIZATION TOOLS FOR TSP

15.1 Introduction

Traffic signals are provided at intersections to permit safe movement of traffic and/or pedestrians. The purpose of a traffic signal is "to alternate the right of way between traffic streams so that the average delay to all vehicles and pedestrians, the total delay to any single group of vehicles and pedestrians and the possibility of accident-producing conflicts are minimized"[22]. Right-of-way for different movements at a signal is governed by indications that display green, amber or red for vehicles and/or walk, "flashing walk" or "don't walk" for pedestrians. The indications are controlled by traffic signal controllers. There is a traffic signal controller at most intersections and it typically controls a single intersection or, in the case of a coordinated traffic corridor – it might also monitor multiple signals. Settings that govern the display of different signals by a traffic controller are called traffic signal timing plans.

Traffic signal timing plans are designed to accommodate the various users of the street network. Traffic engineers typically use field observations, various data, and computer models prior to implementation of a signal timing plan. Optimization of a signal requires field adjustment to make a signal timing plan effective. One of the primary problems with the existing signal timing models, is that they are designed solely for vehicular traffic rather than transit, pedestrians, or freight. The implementation of transit signal priority is an additional level of complexity that requires additional understanding of the controller's logic and even modification in some cases. Traffic simulation models provide an opportunity to assess the impact of transit signal priority. This chapter gives the reader a brief overview of these tools. The chapter is divided into two sections – simulation and optimization.

15.2 Simulation

15.2.1 What is Simulation?

Simulation is the process of replicating a real world situation in a computer model. The model is used to predict system performance based on interactions between its components. In the case of traffic simulation components include infrastructure and traffic using this infrastructure. Infrastructure might include streets, signals, crosswalks, bus stops, etc. while traffic includes passenger cars, buses, trucks, pedestrians, bikes and trains. Performance of a traffic system is usually evaluated by different measures of effectiveness (MOE) like delay, queue length, travel time, system throughput, etc.

Traffic simulation can be broadly classified into three categories based on the fidelity level of the model being employed – macroscopic, mesoscopic and microscopic. The difference between these types of simulation is the level of detail to which traffic is replicated in the model. A macroscopic model is one in which the level of detail is low and traffic is simulated as a stream. A mesoscopic model has a moderate level of detail with less interaction between the individual vehicles while microscopic models have the highest level of detail and simulate individual vehicles within the network. Vehicles in a microscopic model, as the name suggests, are modeled to the minutest detail usually on a second by second basis. Since the vehicular status is known for each second, microscopic simulation models provide extensive reporting capabilities ? an important requirement for transit signal priority (TSP) evaluation. Microscopic simulation models permit different acceleration/deceleration rates, driver characteristics, gap acceptance characteristics, and similar factors to be assigned for pre-selected vehicular or driver groups, making interactions in the model as realistic as possible. Due to their ability to simulate individual vehicles in the network, only microscopic models are able to simulate transit signal priority applications at the individual intersection level. Therefore, this document will address only microscopic simulation.

15.2.2 The Need for Simulation

Simulation allows the user to test a new system or redesign an old system on the computer before deploying it in the field. It also allows the user to test different alternatives or "what if" scenarios that cannot be tested in real life. Some of the advantages of simulation include:

[22] Parsonson, Peter, NCHRP Synthesis 172 – Signal Timing Improvement Practices, Transportation Research Board, February 1992

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- Provides a cost effective way of testing and evaluating different scenarios
- Allows the user to test scenarios faster than in real life
- Offers an insight into the characteristics of traffic system operations that are important, allowing the user to make a more informed decision
- Provides outputs/animation that the public can understand

At the same time simulation has some disadvantages:

- Requires collection of detailed data on field conditions
- Needs calibration and validation of the model prior to testing scenarios
- Requires an understanding of how the model works before assessing the outputs

The processes of conducting a simulation study are described in the following section.

15.2.3 How to Conduct a Simulation

This section gives a brief outline for identifying the best simulation model suited to a particular job, conducting a simulation and analyzing outputs of simulation runs.

15.2.3.1 Selecting a model

There are a number of simulation models available on the market, including but not limited to, AIMSUN, CORSIM, HUTSIM, INTEGRATION, MITSIM, PARAMICS, SIMTRAFFIC, TEXAS, TRANSIMS, VISSIM and WATSIM. This section helps users in selecting a simulation model that best suits their purpose. Simulation users need to understand that every simulation model has its own strengths and weaknesses. Selection of a simulation model should be primarily based on model capabilities and project objectives. Simulation models have different capabilities related to the size of the network they can simulate (number of links and nodes they support), amount of data and hardware they require for input, amount of flexibility they provide users in simulating real world situations and outputs they generate. Their capabilities have to be assessed before selection of a model. Given below is a list of things to consider in the selection of a simulation model.

Size of network: Although most simulation models do not have predefined limits (most of them are limited by the computational power), some of them are limited in terms of number of nodes, links, detectors, and other features. If a large network needs to be simulated it is necessary to choose a model with that capability.

Elements supported: Simulation models differ in their ability to model individual traffic elements like cars, trucks, buses, rail, bicyclists, motorists and pedestrians. For TSP, it is important to be able to model and track individual transit vehicles. If a model supports any or all of these elements, it is also useful to know the extent to which these elements are supported in the model. Some of the models allow the user to define the features like acceleration/deceleration rates and driver aggressiveness.

Many simulation models have limited or no ability to simulate transit vehicles and it would make little sense in choosing them to simulate transit signal priority.

Simulation models also differ in their ability to model different scenarios. Some models are not capable of modeling roundabouts, high occupancy vehicle (HOV) lanes, railroad crossings, unsignalized intersections, work zones and toll plazas. The user should be aware of model limitations in simulating scenarios that need to be evaluated.

Vehicular movement control: The movement of vehicles in a microscopic simulation program is controlled by different logic. There might be logics for car-following, lane changing, merging, behavior on freeways and urban routes. It is necessary to have a basic understanding of the logic being applied in the simulation model before selecting it. It is also helpful to know if the user is given control in modifying or changing the logic in the model.

Ease of use: Each simulation model is different in terms of its ease of use. Some simulation models provide an easy to use graphic user interface (GUI) and have a simple process for data input. Some models allow the user to use an aerial photograph or map as a background

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while coding the network, which makes geometry coding much easier. And some models are easy to calibrate/validate by providing different measures of effectiveness in a readable format.

Flexibility: Some simulation models provide more flexibility to simulate different scenarios and also provide a selection of parameters that the user can manipulate. For example, in some models vehicle acceleration and deceleration rates can be modified for each type of vehicle. Also models that have the capability to modify dwell times for each transit stop and for each transit line allow users to match the model to field conditions. Other features that the user might be interested in are:

- Data transfer – to and from other models
- Application Program Interface (API) – Some simulation models support APIs allowing users to customize the signal timing plans or to simulate traffic controllers/hardware that are used in the field.

Flexible models enable users to simulate more complex scenarios and usually require additional field data and time in coding the model, but, they also provide more reliable and accurate results. For projects that require the evaluation of a large number of scenarios, models with less flexibility and capabilities may be used to reduce the effort and cost of evaluation. But, for projects in which a few pre-selected scenarios are to be evaluated, models with better flexibility and more capabilities are preferred.

It should be noted that use of a flexible model requires that the user has a thorough understanding on how the model works. The user also would have more to input during the network building process, which might make the simulation model less easy to use.

Signal control logic and detection: Signal control logic and detection are important simulation features necessary for simulating transit signal priority operations. Simulation of TSP requires that simulation models can detect and distinguish between various types of vehicles and their routes, in particular transit vehicles. Modeling transit signal priority requires making changes to the traffic signal control logic of the controller. Many simulation models offer basic TSP features like green extension and red truncation. Users should understand the capabilities and limitations of the model in simulating green extension and red truncation given that traffic signal controllers accomplish these treatments in different ways, including which phases are shortened and whether the time is taken from the current cycle or the next cycle. Users should also understand the capabilities and limitations of the model in simulating advanced features like phase rotation, phase insertion and phase skipping. In addition, the user should know if changes to signal control logic can be done by the user or have to be done by the software vendor, since the latter might be expensive and time consuming.

Animation and output: Simulation models provide users with animation of the network. Some models have the capability to provide 3-dimensional animations with other details (like buildings, traffic signals, etc.) and also to allow the user to zoom or pan across networks. Most of these animations can be made into movie clips and are great tools for presentations, providing a vivid presentation of the benefits of TSP to policy boards and public.

Most simulation models have a provision that allows for customizing output format. It helps the user to have the results in a compiled form rather than a vehicle-by-vehicle or a link-by-link basis. Sometimes the models also support tracking individual vehicles and this might be useful in the case of transit signal priority. Travel time, delay, queue length, number of stops, fuel consumptions, emissions, bus/tram wait time are some of the most used outputs.

Cost of Simulation: Users have to be careful in the selection of a simulation model. Prices of simulation models vary considerably and depending on the model, the amount of time and effort needed to collect data, build the model, calibrate/validate it, and analyze different scenarios varies considerably, leading to considerable differences in project cost.

It should be noted that initial coding of the network in a simulation model takes a considerable amount of effort and is usually expensive. Once the network is coded-calibrated-validated for a particular time period (a.m. peak or p.m. peak), or a particular scenario, subsequent testing for other time periods or other scenarios is relatively easy and inexpensive.

15.2.3.2 Collecting Data

Field data is required to conduct a simulation study. The data usually required to conduct a simulation is as follows:

- Geometric – length of lanes, lane widths, number of lanes, lane assignment, length and location of crosswalks
- Signal timing plans – cycle lengths, number of phases, duration of phases, etc. for different times of the day
- Speed – speed limits and average vehicular speed
- Transit vehicle – travel times, dwell times and distribution of dwell times

The actual amount of data collected depends on available budget, time and project requirements. At a minimum a.m. and p.m. peak data should be collected. If there is a significant variation in traffic volumes, additional data may need to be collected such as midday, Saturday and Sunday. Attention should be given to the time period of data collection. For example, data collection of regular weekday traffic should be conducted between Tuesday and Thursday to avoid traffic fluctuations due to weekend trips and preferably, should not be during a holiday season. Weekend data should be collected during times that are most relevant to meet project objectives, such as weekend traffic peak period and/or weekend peak transit operational headways.

15.2.3.3 Developing the Network for Simulation

Developing the network for simulation involves the processes of coding, calibration and validation. Calibration and validation are extremely important, but often do not get the attention they deserve in the simulation process.

Coding: Coding is the process of building the network in the simulation model. It involves input of the study area geometry in the simulation model with other information like the timing plans and volumes. Given below are the different ways to code a network in a simulation model:

- The network can be coded in the simulation model itself.
- The network can be coded in a Network Editor that is bundled with the simulation model and can then be transferred to the simulation model. The Network Editor is designed to simplify network coding.
- In some cases the network can be coded in simulation or optimization models and can be transferred/exported to other simulation models. This procedure is mainly used when multiple softwares are required for the analysis and optimization of the network. Sometimes, due to the simplicity of the Network Editor, the study network is coded in one model and then transferred to another model. If this method of coding the network is used, the user should be aware of the features/elements that may be altered or missed during the transfer process.

Calibration: Simulation models need to be calibrated before they are used for testing future scenarios since an un-calibrated model might lead to skewed results. Calibration involves changing some of the default parameters used in the simulation model so that it reflects the conditions observed in the study area. As previously mentioned, the movement of traffic in a simulation model is governed by different logics. Simulation models provide the user with different parameters to fine tune the logic and other aspects of the model. Examples of these parameters include minimum headway, minimum acceleration rate, minimum deceleration rate, maximum acceleration rate, etc. These parameters are given some default values based on studies conducted by the model developer and are usually meant to reflect generic situations. It should be noted that simulation model parameters might not be independent of each other and simulation model calibration should be conducted by studying the effect of change of one parameter on another and performing modifications to parameter values accordingly.

Validation: Validation can be understood as a check on the calibration of the simulation model. It is done by simulating the calibrated model using a set of real world data different from the one used for calibration. The output from simulating this real world data is compared to field observations. If the output matches field observations, the user can be sure that simulation model calibration is accurate and be confident in using the calibrated model to simulate future scenarios or other scenarios that cannot be tested in the field. If there is a mismatch, then the user should reconsider calibration adjustments before using the calibrated model to test or compare different scenarios.

The user should also be aware of limitations of any simulation model in representing real world situations. It is important to view the animations during the validation process to check for discrepancies. Results of a simulation might vary considerably due to some of the assumptions made in simulation modeling. For example, a vehicle that is supposed to make a left turn at a signal might have been unable to change to the turning lanes until it is too close to the intersection and might therefore be blocking the through movement of traffic. In real life conditions, if such a situation occurs, a driver would simply move through the signal and make a U-turn at the next intersection. Unfortunately, simulation models do not permit this kind of movement and thus might lead to unexpected results. These types of anomalies should be addressed before using/comparing the outputs of the simulation.

Example: Given below is an example of developing a network for simulating future TSP scenarios.

For example, consider the case of simulating a bus route for a network during the a.m. peak hour. The measure of effectiveness in this case is bus travel time from its origin to its destination. Factors affecting bus travel time are observed to be volume of traffic along its route and number of passengers waiting at the bus stops. Data has been collected (for the purpose of calibration and validation) in the field for a period of two hours during the morning peak period. Within these two hours, the bus has made a total of 12 trips from its origin to destination and the user has all the required information – number of passengers at the bus stops, volume of vehicles in traffic along the route and bus travel time for all trips.

The coding of the network in the simulation model would involve the input of geometry of the roads and intersections along the bus routes, locating the bus stops and the input of traffic signal timing plans at intersections for the morning peak period along the bus route. Once this information is coded in the simulation model, the model can be calibrated using data collected during the first hour in the field. Traffic volume and number of passengers waiting at bus stops for the trip representing the median of the travel times, among the six trips during the first hour, can be used for calibration. Using this traffic volume and passenger number in the network, values of parameters in the simulation model can be modified until travel time output of the simulation matches what was observed in the field.

The calibrated model (with modified parameters) then has to be validated using data collected during the second hour. This might involve simulating the calibrated model using traffic volume and number of passengers observed in the median trip for the second hour. If the travel time output from the simulation matches field observation for that trip, you can be confident in using the calibrated model to simulate the bus route with different traffic volumes or different numbers of passengers at bus stops. Then you can rely on the bus travel times that the simulation predicts. If output of the calibrated model does not match travel time observed during the validation process, you should reconsider the values that are calibrated.

In the above example, data for a single trip has been used to illustrate the calibration and validation process. If resources permit, it is good practice to use multiple data sets and multiple simulation runs (for more information see section 4.2.3.5). Statistical methods are to be used for comparison of simulation results.

15.2.3.4 Warm Up Time

When a scenario is simulated, the simulation starts with zero vehicles in the network. Vehicles are gradually seeded (input) into the network and the user should gather Measures of Effectiveness MOEs after the network in the simulation model has vehicles interacting as they would do in real world conditions. The transition time, from the start of the simulation to the time when vehicles begin to interact, is called the warm up time. Outputs from the simulation run are to be taken from a period starting after the warm up time. Most simulation models allow users to define a warm up period. The amount of time given for the network to warm up varies but as a rule of thumb it can be used as the time taken for a vehicle to travel the longest link/route of the network from one end to the other.

15.2.3.5 Number of Simulation Runs

Most of the micro-simulations are stochastic in nature. Some of the features like driver characteristics, acceleration, arrival of vehicles, etc. within these models follow different probabilistic distributions. This is done to simulate the variability of real world conditions. To incorporate variability in the results, simulation models provide random number sequences (also called random seeds). Multiple runs can be conducted on a particular scenario with different random numbers to check the result of variability.

Results of a simulation analysis, drawn from a single run (for the case of a microscopic stochastic simulation model), are almost always misleading (unless the run happens to represent the median). The inherent variability of a stochastic process requires that we simulate multiple runs. Multiple runs allow the replication of variation of real world situations in simulation modeling. A probabilistic approach should be used in identifying the number of simulation runs to be conducted. The number of simulation runs should be based on variability, in the results of the simulation.

The following steps can be followed in identifying the number of simulation runs to be conducted:

- Make an initial sample run
- Estimate the sample variance (in terms of results for the measure of effectiveness)
- Determine or select the confidence interval
- Estimate the number of runs to be conducted based on the confidence interval

15.2.3.6 Analyzing the Outputs

Simulation models can enable a detailed analysis of a complex intersection or corridor and measure the outcomes of introducing TSP. Most simulation models have the capability to format the output for a quick view of the MOEs. Some simulation models also provide tools to conduct multiple simulation runs without the user having to change the random seed numbers and also provide the results of all the multiple simulation runs.

MOEs – Different measures of effectiveness can be used for evaluating the output of simulations, including but not limited to queue length, delay, travel time, traffic volume, speed variation, etc. In the case of multiple runs, results on these measures should be presented in such a way as to provide the ultimate user information on the mean and the variability of the results of the measure.

Simulation models also permit the testing of different scenarios with respect to intersection geometry and the design of traffic signal strategies, such as transit-only phases for bus turn movements or queue-jumps, phase rotations, different recovery strategies, etc. This may prove useful for determining a TSP design that increases transit benefits while minimizes impacts on traffic in complex situations.

15.3 Optimization

15.3.1 What Is Optimization?

Optimization is the process of designing or modifying a system to make it as effective as possible for a given criteria within a given set of constraints. In the context of traffic signals, optimization can be conducted on isolated signals, traffic signal corridors or traffic signal networks. Signal timing optimization involves the selection and modification of several design elements including cycle length, number of phases, phase sequence, phase duration and offsets to achieve one or more objectives such as:

- Minimize the number of stops.
- Minimize the queue length.
- Minimize the delay of vehicles.
- Maximize throughput.

In addition, other factors like reduction of fuel emissions and noise might also be considered.

The process of traffic signal optimization is carried out by modifying traffic signal timing plans that reside in, or are communicated by a central system to, the intersection controllers. Different software optimization tools are available in the market that optimize timing plans, but none of the popular tools are capable of optimizing all traffic signal design elements. Moreover, there is no software that can optimize traffic signals to minimize transit vehicular delay or to optimize transit signal priority operations. Since only traffic optimization tools are available, the following sections will concentrate on the optimization of regular signalized intersections and traffic signal corridors.

It should be noted that in the case of adaptive traffic control systems, a quasi-optimization process is carried out dynamically in real-time based on continuous monitoring of traffic flows, delays and queues. However, adaptive control is still relatively rare in the North American context.

15.3.2 The Need for Optimization

The primary reason for the implementation of TSP is to reduce travel time and the variability in travel time of transit vehicles. Transit vehicles such as buses share roadways with other vehicles like passenger cars and trucks. The general corridor or network delays impact both transit and other vehicles and any improvement in the performance of the corridor would benefit both. The optimization of traffic signals is recognized as the cheapest available method of improving traffic movement and hence should be considered first before the implementation of transit signal priority.

15.3.3 How to Conduct an Optimization of Traffic Signals

Optimization of traffic signals can involve optimization of an isolated signalized intersection, optimization of traffic signal corridors or optimization of traffic signal networks with an increase in complexity from an isolated signal to a corridor and to a network.

The primary constraints in the development of an effective signal timing plan for an isolated signalized intersection are vehicular and pedestrian demands and intersection geometry. Signal corridors and networks have additional constraints like block lengths and speed limits on the blocks. Pedestrian movement is an important element in the signal timing optimization process. Pedestrian movements require a significant amount of time, especially for wide intersections with multiple lanes at different approaches and limit the extent to which traffic signals can be optimized. During the process of optimization traffic engineers/designers often work with one or more of these constraints and use their expertise to balance them to achieve optimum traffic signal timing plans.

Based on intersection geometry and types of vehicular and pedestrian movements, the minimum initial green time is determined for each phase. Minimum phase length duration is governed by the durations of minimum initial green, yellow and all red intervals. The minimum green phase duration is always the greater value of the minimum pedestrian time or the minimum vehicle phase duration. Standards for minimum pedestrian crossing times and vehicle phase durations are provided by the Manuel for Uniform Traffic Control Devices (MUTCD). It is important to understand that minimum phase duration should not be violated by any type of signal priority procedures. The upper limit of phase duration is governed mainly by the cycle length, number of phases and the number of vehicles using the phase. Cycle lengths are typically shorter in urban environments, compared to the intersections in suburban environments. It is good practice to keep cycle lengths as short as possible to avoid unnecessary delays to pedestrians. The upper limit of cycle lengths is usually governed by the agency operating the signals.

In coordinated traffic signal systems, the cycle length of all signals has to be the same. If the cycle length of signals differs, offsets between intersections will not be constant and the signal progression cannot be maintained. There are some special instances where a signal in a coordinated system can operate at half the cycle length of other signals in the system, due to limited side street demand. It is desirable practice that signal priority does not change the cycle length of a coordinated signal system. Every time the cycle length is changed, signal coordination is interrupted. Interruption of signal coordination may result in vehicular delay increase, which may in turn increase the delay of transit vehicles.

As mentioned above, signal timing optimization tools are limited in their capabilities. Most of the tools currently available only optimize some of the elements such as the phase durations, cycle lengths and offsets. Knowing that each of the optimization tools has different capabilities, the selection of the model with capabilities that suit the project objectives is an important step. It should be noted that to maintain uniformity of analysis among design firms, many governing agencies impose restrictions on which software to use for traffic signal optimization.

The selection of an optimization model is the first step in conducting a traffic signal optimization. Different software programs are available in the market including, but not limited to, SYNCHRO, TRANSYT 7F, PASSER, and MAXBAND. Some of these specialize in minimizing the delay of vehicles while others specialize in maximizing the green bandwidth of signals along a corridor.

The selection of an optimization model is similar to that of selecting a simulation model. Features such as size of the network, elements supported, traffic control, ease of use and flexibility are to be considered in the selection process. Most optimization models are deterministic in nature, therefore multiple runs are not required, contrary to the situation with stochastic simulation models.

The selection of a model has to be followed by collecting field data and coding the network in the model. Data required by optimization models is less detailed than that required by simulation models since optimization models are representing average flows as opposed to individual vehicles. The next step after coding involves optimization of the signal or the corridor. This step usually involves the selection of an intersection or a network and asking the model to optimize features like splits, cycle times, network offsets, etc. Due to optimization model limitations it is wise to check optimization results and determine if manual changes in the phase order, and/or type and number of phases, could improve optimization results and if the modified phasing would require an optimization rerun.

Optimization results in revised traffic signal timing plans – cycle lengths, phase duration, phase order, offsets, etc. It is strongly recommended that the user note the change in the timings of the phases, the splits and the cycle lengths of the resulting optimized timing plan. Budget permitting, it is wise to simulate the new timing plan to check the overall effects of optimization.

15.4 Summary

Transit signal priority studies require two types of software. Simulation software is used to evaluate different transit signal priority scenarios, while optimization software is used to optimize traffic signal operations.

Simulation is a very cost efficient approach to evaluate the effectiveness of different signal priority scenarios. A range of simulation software is available on the market and selection of appropriate software is an important step in cost effective project completion. Simulation software programs require varying amounts of field data in order to provide usable results. The volume of data needed is dependent on project objectives. Calibration and validation are very important steps in the simulation process and should not be taken lightly. Since simulations are stochastic in nature, it is important to complete multiple runs so that variations in network operations will not skew results. Simulation models provide a wealth of different measures of effectiveness but engineering judgment must be used to validate each set of output data, before accepting the results of simulation.

Signal timing optimization for general traffic is one of the first steps to be taken in the signal priority optimization process, since transit vehicle delay is generally impacted by vehicular delay. Many optimization models are available and selection of the right model depends on the project goals, as well as on the preference of a specific traffic agency. It should be noted that there is no optimization software available that will optimize timing plans for transit operational needs and that optimization will be focused on overall vehicular operations. Signal timing plans have safety operations requirements (e.g. minimum pedestrian crossing times) that should not be violated by transit signal priority.

16 TRANSIT TERMINOLOGY

Note: Much of the following transit terminology is derived or modified from entries in the document *Urban Public Transportation Glossary*, published in 1989 by the Transportation Research Board.

Advanced (or Electronic) Fare Collection (AFC): means of collecting transit fares using an electronic medium such as a magnetic stripe or smart card (containing an embedded computer chip) which stores various data on validity, transaction s, security protection, and in some cases user-related data type of user (e.g. senior, student or person with disabilities), loyalty programs, etc.

Automatic Passenger Counting (APC) system: computerized system to collect passenger activity, schedule, and vehicle utilization data. Modern APC systems collect data on boardings, alightings (passengers getting off the vehicle), passenger loads, vehicle location, schedule adherence, vehicle speed, and vehicle movement (e.g. idling, stop dwell time, traffic stop and go movement, etc.). Data is collected continuously during the day and downloaded automatically in the garage for subsequent analysis.

Automatic Vehicle Location (AVL) system: senses or calculates, at intervals, the location of transit vehicles. Vehicle location can be used in various applications, including schedule adherence monitoring, operational control and incident management through computer-assisted dispatching, real-time customer information, transit signal priority, etc. Although in the past some transit AVL systems used sign posts or other technology, most now use the global positioning system (GPS) to determine vehicle location.

Base period (off-peak period): in transit, the time of day during which vehicle requirements and schedules are not influenced by peak-period passenger volume demands (e.g. between morning and afternoon peak periods). At this time, transit riding is fairly constant and usually low to moderate in volume when compared to peak-period travel. See also *off-peak*.

Base-period fleet: in transit, the number of transit units (vehicles or trains) required to maintain base-period schedules.

Block (schedule): daily operating schedule of a transit unit (vehicle or train) between pull-out and pull-in, including scheduled and deadhead service. A block may consist of a number of runs. See below for definitions of "pull-out," "pull-in," "deadhead," and "run."

Bunching: with transit units, a situation that occurs when passenger demand is high and dwell times at stops are longer than scheduled. Headways become shorter than scheduled, and platoons of transit units (vehicles or trains) develop, with longer intervals between platoons. The same effect (one transit unit caught by the following) can also be caused by lack of protection from general road traffic congestion or by traffic signal timing. Bunching can become cumulative and can result in delay to passengers and unused capacity. See below for definition of "headway."

Bus Bay: area in which a bus can pull out of the traffic and dwell at a stop for passengers to board and alight without holding up traffic. Sometimes buses have difficulty moving back into the flow of traffic from a bus bay and may need assistance from traffic signals allowing them to "queue jump."

Bus Rapid Transit (BRT): flexible, high performance rapid transit mode that uses buses or specialized rubber tired-based vehicles operating on pavement, and that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity. One of the many elements that might improve the quality of BRT is TSP.

Busway: special roadway designed for exclusive use by buses. It may be constructed at, above, or below grade and may be located in separate rights-of-way or within highway corridors.

Capacity

> **Crush (crush load):** maximum feasible passenger capacity of a transit vehicle, that is, the capacity at which one more passenger cannot enter without causing serious discomfort to the others.
>
> **Vehicle (normal vehicle capacity, total vehicle capacity):** maximum number of passengers that the vehicle is designed to accommodate comfortably, seated and standing; may sometimes refer to number of seats only.

Check: in transit operations, a record of the passenger volume on all transit units that pass a specific location or time point (also known as a ***passenger riding counter check***), the actual time the unit passes it (also known as a ***schedule check***), the number of passengers who board and alight at each stop on a route or line (also known as and ***on-and-off count or check***), or any combination of these items. The checker may ride the transit unit (an ***on-board check***), follow it in another vehicle, or check the transit units from a particular location (a ***point or corner check***).

Computer-Assisted Dispatching (CAD): computerized tool to assist supervisors/dispatchers to monitor the status of the system, perform operational control tasks, and manage incidents. CAD systems are often combined with AVL (CAD-AVL) to provide more accurate knowledge of the real-time location of transit vehicles and their adherence to schedules.

Deadhead (or deadheading): to move a revenue vehicle in other than revenue service, for example, from one garage to another or from the end of a line to a garage.

Dispatcher: in bus operations, the individual who assigns buses to runs, makes up work assignments to fill runs, directs the operators at the start of their assignments, and in some cases, maintains a constant awareness of the status of the operation, via radio, computer-assisted dispatch -AVL or other means.

Exclusive transit facilities: transportation system infrastructure elements that are set aside for the use of transit vehicles only. Examples include bus lanes, off-street bus loading or unloading areas or stations, bus freeway ramps, and separated and fully controlled transit rights-of-way.

Extra board (spare board): roster of open (extra) runs and assignments, or a pool of employees available to cover unfilled runs or extra work.

Headway: time interval between the passing of the front ends of successive units (vehicles or trains) moving along the same lane or track in the same direction, usually expressed in minutes; see also *service frequency*.

> **Base:** scheduled headway between transit unit (vehicle or train) trips during an off-peak (usually mid-day) period.
>
> **Policy:** headway prescribed by reasons other than matching capacity to demand. The maximum permissible headway may be established by the transit agency policy board, usually for off-peak, low demand periods.

Headway management: technique for managing the operation of transit units (vehicles or trains) that focuses on maintaining a certain spacing between units on the same line, instead of adhering to a timetable. For example, if units become bunched, corrective measures might include delaying the units at the rear of the bunch to provide regular headways and hence load distribution, even at the expense of reducing timetable adherence.

In-service trip: time within a transit work run in which the operator picks up and discharges passengers.

Inspector (road supervisor, route supervisor, street supervisor): transit employee who evaluates performance, enforces safety and work rules, and attempts to solve problems. An inspector may be mobile (covering several districts in a radio-equipped vehicle) or fixed (assigned to a post at a designated intersection).

Lane

Bus (bus priority lane, preferential bus lane): highway or street lane reserved primarily for buses, either all day or during specified periods. It may be used by other traffic under certain circumstances, such as making a right turn, or by taxis or carpools that meet specific requirements described in the traffic laws.

Contraflow: highway or street lane on which vehicles operate in a direction opposite to what would be the normal flow of traffic in that lane. Such lanes may be permanently designated contraflow lanes, or, more usually, they may be used as contraflow lanes during certain hours of the day. Sometimes the use of contraflow lanes is restricted to public transit.

Level of Service (LOS): set of characteristics that indicate the quality and quantity of transportation service provided, including characteristics that are easy to quantify (***system performance***, e.g. frequency, reliability, travel time, travel costs, number of transfers) and those that are difficult to quantify (***service quality***, e.g. availability, comfort, convenience, image).

Maximum load point (MLP): point on a transit line or route at which the passenger volume is greatest. There is one maximum load point in each direction.

On-time performance: proportion of time that a transit system adheres to its published schedule times within stated tolerances; for example, a transit unit (vehicle or train) arriving, passing, or leaving a predetermined point (time point) along its route or line within a time period that is no more than "x" minutes earlier and no more than "y" minutes later than a published schedule time. (Values of 0 minutes for x and three (or five) minutes for y are very common.)

Operator: employee of a transit system whose workday is spent in the operation of a transit unit (vehicle or train). [*Operator* is also used to indicate the organization that runs a transportation system.]

Paddle board (paddle, run card, run guide): headway sheets (time schedule) made up for each run (operator's piece of work) that lists all the pieces of work on that run (including any special notations) for the operator.

Passenger load: number of passengers on a transit unit (vehicle or train) at a specified point.

Passenger volume (line volume): total number of passengers carried on a transit line during a given period.

Peak (peak period, rush hours): period during which the maximum amount of travel occurs. It may be specified as the morning (a.m.) or afternoon (p.m.) or other peak.

Peak/base ratio (peak/off-peak) ratio: ratio between the number of vehicles operating in passenger service during the peak hours and that during the base period.

Pull-in: deadhead trip from the point at which the transit unit (vehicle or train) ends an in-service trip to the garage or yard.

Pull-out: deadhead trip from the garage or yard to the point at which the transit unit (vehicle or train) begins an in-service trip.

Queue jumper (queue bypass): short section of exclusive or preferential lane that enables specified vehicles to bypass a queue of traffic or a congested section of traffic.

Relief point: designated time point at which operators may take a lunch period or rest break, or a point at which an operator is relieved by another operator, that is, where one run is completed, and another starts.

Restoration of service: resumption of service according to schedule after it has been interrupted or operating off schedule.

Rider

Captive: rider who has no means of transportation other than public transit.
Choice: rider who has other means of transportation available and chooses public transit. Experience has shown that service improvements that improve transit travel times (such as TSP) can bring more choice riders to public transit.

Road call: mechanical failure of a bus in revenue service that necessitates removing the bus from service until repairs are made.

Run: 1. movement of a transit unit (vehicle or train) in one direction from the beginning of a route to the end of it; also known as a ***trip***. 2. an operator's assignment of trips for a day of operation; also known as a ***work run***.

Split (swing run): two operating assignments separated by a period of time during which the operator is unassigned and not paid.

Straight: run that has no unpaid breaks in it.

Run cutting: process of organizing all scheduled trips operated by the transit system into runs for the assignment of operating personnel and vehicles.

Scheduling: in transit operations, the process of preparing the operating plan (schedule) for a transit line or network on the basis of passenger demand, policy for level of service, and operating elements (travel times, etc.).

Service (types of)

Arterial: generally major (long or heavily patronized) transit routes that operate on principal or major surface arterial streets.
Circulator: bus service confined to a specific locale, such as a downtown area or a suburban neighborhood, with connections to major traffic corridors.
Crosstown: non-radial transit service that does not enter the central business district.
Express bus: bus service with a limited number of stops from a collector area directly to a specific destination.
Feeder: local transit service that provides passengers with connections to main-line arterial service, or to a rail or express bus station.
Limited: transit service that operates only during a certain period of the day, or that only serves specific stops (also known as limited stop service) or in a specified area.
Local bus: bus service that picks up and discharges passengers on city streets. Local bus service involves frequent stops and consequently low average speeds. Its purpose is to pick up and deliver transit passengers close to their origins and destinations.

Service frequency: the number of transit units (vehicles or trains) on a given route or line, moving in the same direction, that pass a given point within a specified interval of time, usually one hour; see also *headway*.

Service standards (service guidelines): rules and measures that are established to guide the policy, planning and management of transit services. Building on corporate goals, service objectives, and system performance targets, service standards encompass route performance criteria, planning guidelines, and evaluation criteria.

Route performance criteria: criteria for managing and evaluating the performance of individual transit routes. These act as warrants for making minor service adjustments or for identifying poorly performing routes. These might include: effectiveness criteria (e.g. loading standards, on-time standard, safety standard); efficiency criteria (e.g. service utilization standard, operator utilization standard), and financial criteria (e.g. cost recovery standard).
Planning guidelines: warrants and design guidelines to establish the need, and guide the planning of new routes or changes to existing routes. These might include: service area war-

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rants (e.g. area location — distance from existing routes; area density — residential or industrial) and design guidelines (e.g. route design, stop spacing, schedule design, service hours).

Evaluation criteria: criteria for selecting, from many new service proposals, the priorities for further consideration. These might include: market performance (e.g. markets served, demand for transit services) and cost performance (e.g. subsidy level).

Short turn (turn back): in transit operations, to cut short a transit trip (to turn back before reaching the end of the route or line), usually to get back on schedule or to meet peak passenger demands.

Sign-up (bidding runs, mark-up, operator pick, pick, run pick, shake-up): procedure by which, at regular intervals or when new service or realignments of service are implemented, operators select their regular assignment for an upcoming period (typically several months). The order of selection is usually by operator seniority and is usually specified in union contracts.

Stop: designated location for boarding and alighting of transit vehicles. Typical spacing of stops on streets is 825 ft to 1320 ft (250 m to 400 m).

Far-side: transit stop located beyond an intersection. It requires that transit units (vehicles or trains) cross the intersection before stopping to serve passengers.

Mid-block: transit stop located at a point away from intersections.

Near-side: transit stop located on the approach side of an intersection. The transit units (vehicles or trains) stop to serve passengers before crossing the intersection.

Time:

Allowance (allowed time, bonus time, dead time, hold time): time for which an operator is paid even though the hours have not been worked in operating a transit unit. Forms of allowance time are pad time, report time, turn-in time, and sometimes intervening time.

Dwell: time a transit unit (vehicle or train) spends at a station or stop, measured as the interval between its stopping and starting.

Layover: time provided under the contract to ensure a periodic work break for the operator and to prepare for the return trip, typically at the end of a route.

Recovery: time built into a schedule between arrivals and departures, used for the recovery of delays caused by traffic conditions and service incidents.

Running: actual time required for a transit unit (vehicle or train) to move from one point to another.

Time point: point on a line or route at which transit units (vehicles or trains) are scheduled to pass at a specified time. Usually, the leaving (not arriving) time is used.

Timed transfer: scheduling of intersecting transit routes so that they are due to arrive at a transfer point simultaneously.

Timetable: 1. usually refers to a printed schedule for the public. 2. a listing of the times at which transit units (vehicles or trains) are due at specified time points; also known as a ***schedule***.

Transit center: transit stop or station at the meeting point of several routes or lines. It is located on or off the street and is designed to handle the movement of transit units (vehicles or trains) and the boarding, alighting, and transferring of passengers between routes or lines.

Tripper: 1. in transit operations, a short piece of work that cannot be incorporated into a full day's run, usually scheduled during peak hours. 2. on some transit properties, a short run that is less than eight hours long.

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Appendices

Appendices

A1 RESOURCES

New material is constantly emerging in the rapidly advancing field of ITS. TSP is no exception. To stay current, one might want to check web sites that might have updates and new information to offer.

ITS America maintains a Web site dedicated to Transit Signal Priority:

http://www.itsa.org/tsp.html

TRIS OnLine is a comprehensive literature search engine on transportation-related documents that is maintained by the U.S. Department of Transportation:

http://trisonline.bts.gov/search.cfm

The U.S. Department of Transportation also maintains a searchable Electronic Document Library for many ITS-related reports it has sponsored:

http://www.its.dot.gov/itsweb/welcome.htm

Technical assistance may be found at Federal Transit Administration's Regional Offices:

http://www.fta.dot.gov/4978_ENG_HTML.htm for contact information.

U.S. Department of Transportation's ITS Professional Capacity Building (PCB) Program provides information on systems engineering courses designed for professionals involved in the implementation of advanced technologies for transportation:

http://www.pcb.its.dot.gov/brochures/ITS_SE.htm

The Transportation Research Board Committee AHB25 "Traffic Signal Systems" maintains a searchable Web site that includes several presentations on transit signal priority:

http://signalsystems.tamu.edu/

The Transportation Research Board (TRB) maintains a searchable list of publications:

http://gulliver.trb.org/publications/

The Transit Cooperative Research Program (TCRP) of the Transportation Research Board maintains a searchable list of publications:

http://www.tcrponline.org/bin/publications.pl

The National Center for Transit Research of the Center for Urban Transportation Research at the University of South Florida maintains a searchable Web site:

http://www.nctr.usf.edu/

The Institute of Transportation Studies at UC Berkeley maintains a searchable Web site:

http://www.its.berkeley.edu/

A2 GLOSSARY

APTA – America Public Transportation Association

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

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

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

http://www.nbrti.org

CUTA -- Canadian Urban Transit Association

DSRC -- Dedicated Short Range Communications

FHWA – Federal Highway Administration

FTA – Federal Transit Administration

GPS – global positioning satellites often used for automatic vehicle location (AVL)

IR detectors – Infrared detectors

ISTEA – Intermodal Surface Transportation Efficiency Act (of 1991)

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

LRT – Light Rail Transit

MPO – Metropolitan Planning Organization – A regional transportation planning body required by Federal Law. US CODE, Title 49, Subtitle III, Chapter 53, subsection 5303 states that MPOs are designated under subsection (c), in cooperation with the States and mass transportation operators, for the purpose of developing transportation plans and programs for urbanized areas of the State. The plans provide for the development and integrated management and operation of transportation systems and facilities (including pedestrian walkways and bicycle transportation facilities) that will function as an intermodal transportation system for the metropolitan area and as an integral part of an intermodal transportation system for the State and the United States.

National ITS Architecture – provides a framework for planning, defining, and integrating ITS.

http://itsarch.iteris.com/itsarch

NCHRP – National Cooperative Highway Research Program

NEMA – National Electrical Manufacturers Association

NEMA controllers – a type of traffic signal controller

NTCIP – National Transportation Communications for Intelligent Transportation Systems Protocol

http://www.standards.its.dot.gov/standards.htm

NTCIP Standard 1211, "Object Definitions for Signal Control and Prioritization," describes the interfaces with the signal control system

http://www.standards.its.dot.gov/standards.htm

PRG – Priority Request Generator

PRS – Priority Request Server

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

TCIP – Transit Communications Interface Profile

http://www.standards.its.dot.gov/standards.htm

http://www.ite.org/standards/tcip.asp

TCIP TWG 10 – Technical Working Group, within the TCIP standards effort, concerned with transit signal priority

http://www.standards.its.dot.gov/standards.htm

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

TSP –**Transit Signal Priority** – an operational strategy that facilitates the movement of in-service transit vehicles through traffic-signal controlled intersections.

Transit Signal Pre-emption – differs from Transit Signal Priority, which modifies the normal signal operation process to better accommodate transit vehicles, while pre-emption interrupts the normal process for special events (e.g., train approaching a railroad grade crossing adjacent to a signal, emergency vehicle responding to an emergency call).

Type 2070 – a type of traffic signal controller

Type 170 – a type of traffic signal controller

U.S. DOT – United States Department of Transportation

A3 CASE STUDY DETAILS

A3.1 AC Transit, Oakland, CA

A3.2 King County Metro, Seattle, WA

A3.3 MTA, Los Angeles, CA

A3.4 PACE, Chicago, IL - Cermak Road Corridor

A3.5 Pierce Transit, Tacoma, WA

A3.6 TransLink, Vancouver, BC

A3.7 TriMet, Portland, OR

A3.8 Virginia - Route 1

A3.1 CASE STUDY – AC TRANSIT, OAKLAND, CA

Interviewer:	Respondents:
Hallie Smith	Jon Twichell and Cesar Pujol, AC Transit

BACKGROUND

Number of corridors involved	One - San Pablo Corridor approx 14 miles
Number of intersections equipped	62 intersections on San Pablo Avenue
Number of buses equipped	Twenty one 40-foot Van Hool buses
Do you use conditional or unconditional priority?	Conditional Priority
Is the system centralized or decentralized?	TSP algorithm runs locally at the traffic signal controller, but signal controllers are interconnected through San Pablo SMART Corridors System
What is the PRG/detection technology?	3M/Opticom – infrared technology
What is the communications technology?	Traffic Signal Controllers are interconnected using twisted pair
Is the system integrated with AVL?	No, TSP is not integrated with AVL.
What strategies are used? (Early green, green extension, phase hold, etc.)	10% of signal cycle or 10 seconds max is provided for early green and green extension
Is TSP integrated with EMS pre-emption?	Yes, except Emergency Vehicles have pre-emption

PLANNING

What sparked an interest in TSP implementation?	San Pablo SMART Corridor Project and AC Transit Rapid Bus project coincided. It was mutually beneficial to agencies involved to design /construct/implement TSP along with the signal upgrades/improvements, including signal interconnect, to be constructed by SMART Corridor
Who is the lead agency?	AC Transit is the lead Agency for TSP

A3.1 CASE STUDY – AC TRANSIT, OAKLAND, CA

What were the stated goals?	Overall Rapid bus goal was to decrease bus travel time by 20% and increase ridership by 25% over the current limited bus service. No stated goal for TSP
Who are the players/partners?	AC Transit; SMART Corridor partnership of 25 federal, regional, and local agencies; SMART Corridor design and construction was done by Alameda County Congestion Management Agency (ACCMA)
How did you choose a corridor(s)?	State of readiness because SMART Corridor was imminent
How did you choose intersections?	Decided that all intersections on San Pablo will have TSP capability. Chose not to have TSP on Broadway because of heavy bus usage.
What technology do you use?	3M/Opticom infrared emitter technology
How did you choose the technology?	Ability to partner with emergency services
Did you use any simulation or modeling?	No
What were the technical obstacles?	Lack of feedback loop in software to evaluate TSP.
How did you overcome them?	We are working to revise software to provide feedback & evaluation
What were the institutional barriers?	TSP is of low importance to some jurisdictions.
How did you overcome them?	We are still working on it.
What is/was the training program for bus operators?	Training manuals were developed for both bus operators and road supervisors. Emphasized to bus operators that they cannot expect signals to turn green upon approach.
What is/was the training program for signal technicians?	None

FUNDING

How was the project funded?	STIP
What was the cost of project implementation?	$25,000 cost to AC transit to purchase and install emitters. Approximately $300,000 cost to ACCMA to purchase and install TSP components

A3.1 CASE STUDY – AC TRANSIT, OAKLAND, CA

IMPLEMENTATION

How were tasks assigned for implementation?	AC Transit purchased and installed emitters for buses. CMA did work required at intersections
What kinds of controllers are present or did you upgrade to?	170E
Was there a test phase?	Equipment was calibrated for activation at correct distance
Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)	All Rapid buses are eligible for TSP at all intersections and TSP may be used every ten minutes for each direction (north-bound/southbound)
Are bus turning-movements considered/impacted?	No
What is the policy concerning near side and far side stops?	TSP works best when stops are far-side, so where possible, stops were relocated to far-side. Only 2 of 39 stops at TSP locations could not be relocated to far-side of intersection. Another stop did not need to be relocated because bus made a right turn at that intersection.
To what extent was updating, installing and/or replacing signal equipment required?	Updating and interconnect of signal improvement was included in SMART Corridor. All intersections now have side street detector loops and pedestrian push buttons
Who paid for controller equipment installation and upgrades?	ACCMA paid for traffic signal equipment installation and upgrades. AC Transit paid for signal timing work
How do you ensure that TSP is working on the equipment at the intersection?	AC Transit is working to set up a maintenance program and also a feedback loop in the software for monitoring and data collection
How do you ensure that TSP is working on the vehicles?	AC Transit maintenance has constructed portable testing unit to test all emitter equipped vehicles on a monthly basis. Each emitter is tested to ensure intensity is equal to prior month level
Was the project publicized?	Yes through efforts of AC Transit Marketing Department and ACCMA
If so, how?	Mailers, Spots on cable TV, Door hangers, Incentive Items such as free ride tickets, movie theater advertising
What data do you collect?	No data currently collected. AC Transit is working on software feedback upgrade for data collection and monitoring

A3.1 CASE STUDY – AC TRANSIT, OAKLAND, CA

MAINTENANCE

What are your maintenance agreements?	This question should be addressed by the planned software upgrade and also an annual maintenance agreement with the ACCMA. This agreement is not in place yet and maintenance costs are not known.

EVALUATION

What Measures of Effectiveness do you use?	We are attempting to develop software feedback loop which to get an accurate picture of TSP granted for each bus trip rather than extrapolation
What are the benefits?	Extrapolation of data from 8 Caltrans intersections indicates approximately 9% time savings
What complaints have you received?	Various groups ranging from drivers to AC Transit board members are unsure whether system is working properly.
How have you responded to complaints?	Working on putting together a software feedback and evaluation program
What is the impact to non-priority street traffic?	Infinitesimal
What has been the overall public reaction/response?	None; TSP should be transparent to users.
How have your bus operators (or union) responded?	They have raised questions whether system is working or not.
How do you maintain on-going communication among partners?	This is an area that needs improvement

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?	Adequate software design
Deployment or installation problems?	Lack of information feedback from system
What do you feel were the keys to success?	Standardization of equipment. Simplicity of TSP objectives. Consensus on software objectives

A3.1 CASE STUDY – AC TRANSIT, OAKLAND, CA

How long did the various phases take: planning? procurement? deployment?	18 months for total implementation
If you were starting from scratch, what technology would use you and why?	We would use the same technology which allows us to partner with emergency services and for standardization.
If you were starting from scratch, what would be your planning strategy?	"Just Do It"
What are your future plans for TSP implementation?	International Ave and Telegraph Blvd – approximately 18 miles total and 104 total signals. AC Transit retrofit of TSP on San Pablo Rapid has 3 goals. Bus equipment maintenance program which is completed. Intersection equipment maintenance program continues to suffer from lack of attention. Software upgrade for feedback loop is incomplete due to low level of attention from Caltrans.
What are your expectations with respect to NTCIP/TCIP TSP standards?	Our expectation are standards adopted will not interfere with our TSP implementations

A3.2 CASE STUDY – KING COUNTY METRO, SEATTLE, WA

Interviewers:	Respondents:
Brendon Hemily & Hallie Smith	Ron Atherley and John Toone, King County Metro

BACKGROUND

Number of corridors involved	TSP has been deployed along three corridors: 99/Aurora, Rainier Ave. and 1st Ave. So., and at one interstate exit ramp
Number of intersections equipped	28 intersections have been equipped: 17 coordinated intersections along Aurora/99, five intersections along Rainier Ave., five on First Ave. So. and one at the So. 272nd exit ramp of I-5.
Number of buses equipped	1,400 buses
Do you use conditional or unconditional priority?	The TSP system does not request priority based on schedule adherence conditionality but there are many traffic-related conditions: phase state, emergency preempt, route/trip and call frequency. Future technology will request priority based on conditions such as lateness and/or ridership.
Is the system centralized or decentralized?	The traffic control system is distributed, with the exception of the City of Belleview that has a centralized (Computran) UTCS.
What is the PRG/ detection technology?	Passive RF tags on buses are detected by wayside readers with RF antennas that are located 500 to 1,000 feet upstream, and then communicate to the intersection Transit Priority Request Generator (TPRG) / Interface unit. The TPRG / Interface Unit is located in the controller cabinet, and generates priority requests to the controller for eligible buses (based on eligibility table).
What is the communications technology?	The wayside antenna Reader receives the RF signal from the bus tag, and communicates to the TPRG using one of several available communications protocols: RS232, RS485, LonWorks, AT Modem and serial attached devices such as fiber optics and spread spectrum transcievers.
Is the system integrated with AVL?	The current TSP is not integrated with Metro's AVL system. However, in the future, TSP will be integrated with the On-Board Systems (OBS) currently being procured. It is planned that detection will use WiFi to replace the current passive RF tags and readers.

A3.2 CASE STUDY – KING COUNTY METRO, SEATTLE, WA

What strategies are used? (Early green, green extension, phase hold, etc.)	The system is designed to provide green extension and red truncation, without shortening any minimum clearance intervals, skipping phases, or breaking coordination. Phase insertion also exists at four queue jumps using loop and/or video for detection, and for a left turn into an off-street Transit Center.
Is TSP integrated with EMS pre-emption?	There is EMS pre-emption in some corridors, but there is no integration.

PLANNING

What sparked an interest in TSP implementation?	King County metro (KC Metro) has a "Transit Speed & Reliability Program" that is designed to make capital improvements to improve transit performance. Improvements include: redesign of bus zones, bus bulbs, roadway improvements, parking removal, queue jumps, TSP, etc. An early demonstration was initiated in 1991. This was followed by the creation of a Regional Oversight Committee (ROC) to assist Metro in developing consensus on system specifications and in evaluating proposals.
Who is the lead agency?	KC Metro
What were the stated goals?	The goals for the TSP program are: ✷ Increase amount of "green time" at intersections for selected bus trips ✷ Decrease average travel time ✷ Decrease variation in travel time ✷ Reduce signal-related delay, and ✷ Minimize impact on general traffic.
Who are the players/partners?	The ROC included representatives from KC Metro, KC Dept. of Transportation, Community Transit, Pierce Transit, Washington DOT, Snohomish County, and seven cities. Pierce Transit subsequently decided to pursue an independent approach, and resigned from the ROC.
How did you choose a corridor(s)?	The two corridors were identified by the Transit Speed & Reliability Program.

APPENDICES

A3.2 CASE STUDY – KING COUNTY METRO, SEATTLE, WA

How did you choose intersections?

Given the high cost of the RF tag readers, intersections had to be chosen carefully. Selection of the initial intersections for implementation was based on a forecast of potential average bus time savings. Subsequently, a Transit Signal Priority Interactive Model (TIM) was designed to assist in the planning phase of developing a potential TSP deployment at an intersection or transit corridor. The user inputs cost assumptions, signal phase splits and TSP setting. The primary product of this model is the expected benefit of one trip. Using the expected benefit, the model reports derived information including daily and annual benefit, and a benefit-cost analysis.

What technology do you use?

Buses are equipped with programmable passive Amtech (now TransCore) RF tags that are detected by antennas at wayside readers. The project also involved the development of a custom TPRG based on the ROC's specifications.

How did you choose the technology?

The ROC's specification development and RFP evaluation processes emphasized the importance of open, non-proprietary systems that were reliable (99% reliability) and easy to maintain.

Did you use any simulation or modeling?

VISSIM was explored during pre-analysis phase, but tools were not sufficiently sophisticated in 1992. VISSIM is currently being used to model impacts related to changes in tunnel operations.

What were the technical obstacles?

The cost of the RF Tag readers prevented having a check-out reader.

How did you overcome them?

A check-out module was developed that uses a logic-based approach building on phase monitoring and learning from arrival patterns over time.

What were the institutional barriers?

The TSP project was planned based on the concept of regional cooperation through the ROC, but the number of jurisdictions involved and the complexity of the TPRG development effort caused delay in the project.

How did you overcome them?

Ongoing communications through the ROC was critical.

What is/was the training program for bus operators?

No driver action is required, all on-board equipment in configured during normal driver log-in operation.

What is/was the training program for signal technicians?

When working with a jurisdiction for the first time, Metro funds a test-bench and training by the equipment manufacturer in the jurisdiction's signal shop. Refresher training is available as needed.

A3.2 CASE STUDY – KING COUNTY METRO, SEATTLE, WA

FUNDING

How was the project funded?	The project was funded through normal capital funding.
What was the cost of project implementation?	The first phase cost $2.5 million, and included acquisition of the readers and tags, development and acquisition of the TPRG, 1software, and installation. A second phase of $155,000 was initiated to replace the LONworks communications card with a more robust and less expensive RS485 card, and upgrade or enhance various components and wiring.
What is the breakdown in costs?	Bus RF tags cost $600 per bus (installed) The TPRG costs roughly $3,000. RF tag readers cost $8,000 to 9,000, and $15,000 after installation. A typical intersection installation requires two readers plus TPRG, and costs $35,000 (installed).

IMPLEMENTATION

How were tasks assigned for implementation?	KC Metro was responsible for installation of bus and wayside equipment. In terms of TSP settings, KC Metro recommends TSP settings, but the city traffic engineer decides what settings to implement, and is responsible for their implementation. KC Metro controls the vehicle eligibility table which determines eligible routes, directions, potentially down to the trip level.
What kinds of controllers?	Four traffic controllers were involved: Peek LMD 9200, Econolite ASC-II, Eagle EPAC 300, and 2070 running nextPhase software.
Was there a test phase?	A Rainier HOV study in 1991 included a demonstration of TSP. The contract with the TSP supplier, McCain Traffic Supply, included a Phase 1 test phase to confirm the system's ability to meet the 99% reliability requirement.
Are bus turning movements considered/impacted?	Yes, the approach and trip information are used in processing priority requests. Different outputs can be made to the controller to request priority for a specific phase based on the scheduled movement of the detected bus. There is one location with an inserted left turn phase into a Transit Center that is triggered with a loop.
What is the policy concerning near side and far side stops?	There is no formal policy to have far side stops, but some stops have relocated to make them work better.

APPENDICES

To what extent was updating, installing and/or replacing signal equipment required?

The ROC developed a specification for TSP desirable features for controllers, and staff worked with manufacturers of the four above controllers to develop firmware enhancements to enable TSP features and to smooth transitions.

A fifth type of controller, the Traconex is used in some suburban jurisdictions but does not meet the TSP requirements (e,g, insufficient memory); it will need to be replaced along corridors where TSP is planned.

More generally, the adopted approach focused on developing a flexible TPRG unit that could interface with a wide variety of controllers. Although this required a lengthy development and testing effort, the end result is a highly flexible unit that can be used in all the different jurisdictions.

Who paid for controller equipment installation and upgrades?

KC Metro is responsible for purchasing and installing the TPRG. Individual jurisdictions are responsible for purchasing controllers if they need to be replaced

How do you ensure that TSP is working on the equipment at the intersection?

The TPRG generates data on its performance, but it is hard to correlate this with controller action.

How do you ensure that TSP is working on the vehicles?

RF tags are not tested, but some information can be gathered from periodic logs.

What data do you collect?

The TPRG logs RF tag ID and priority requests made.

How is the data used?

Travel time and variability studies, before/after studies, tag function check, equipment function check, communications function check.

MAINTENANCE

What are your maintenance agreements?

Individual Operations and Maintenance (O&M) Agreements are in place with the City of Seattle and City of Shoreline, and agreements in principles have been developed with the other jurisdictions for future deployments.

King County has adopted the position that once the TPRG equipment is installed, it becomes the property of the city, and the city is responsible for the ongoing O&M. All agreements have very liberal termination for convenience clauses to minimize the perception of long-term risk. In the event that a city chooses to withdraw form the program KC metro has reversionary rights to the TSP equipment.

King County is responsible for maintaining the TSP application and any required development.

Whar was the cost of maintenance?

$1,000 per intersection per year for power, communications, pole attachment fees, FCC licensing, and O&M.

How is the system monitored?

The system does not provide data to correlate actions taken by controllers and their impact on transit. Logs are monitored for expected/appropriate functionality in terms of requests made. After a settling period, a study is done to correlate TSP logs with controller logs to confirm end-to-end functionality.

How do you optimize/adjust the system?

Efforts are underway to link the TPRG logs and the controller actions; this will provide a better understanding and allow TSP settings to be refined over time.

EVALUATION

What Measures of Effectiveness do you use?

Evaluation studies were conducted for both Aurora and Rainier corridors. For the Aurora evaluation, the study conducted a measurement of the travel time savings by "lifting" the time points during the peak period; after informing customers, bus operators were instructed to disregard early arrivals and simply proceed down the corridor.

The before/after evaluation studies considered nine MOE's:

- Average intersection control delay (seconds/vehicle)
- Average minor movement delay (seconds/vehicle)
- Minor movement cycle failures
- Bus corridor travel times (seconds savings)
- Bus schedule reliability
- Average intersection bus delay
- Average person delay
- Vehicle emissions
- Accidents

What are the benefits?

Key benefits identified from the two studies were:

- 25-34% reduction of average intersection delay for eligible buses
- 14-24% reduction of stops at intersections
- 35-40% reduction in trip travel time variability
- 5.5-8% reduction in travel time along the corridors during peak hour

What complaints have you received?

There have been no complaints regarding normal operations.

What is the impact to side street traffic?

Side street delay was minimal.

How have your bus operators (or union) responded?

The system is transparent to bus operators.

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

Developing specifications and operations acceptable to the over 20 different stakeholder jurisdictions in the region.

Deployment or installation problems?

The RF reader technology requires installation upstream on a utility pole with access to power. Finding a suitable location, obtaining approvals, and installing is sometimes difficult and can be a lengthy process.

What do you feel were the keys to success?

Maintaining ongoing communications through the ROC was critical to the project's success.

How long did the various phases take: planning? procurement? deployment?

System development took several years. For an individual corridor planning and design takes the bulk of the project cycle when working with a new jurisdiction due to the need for agreements and these are usually tied to larger projects and grants. Planning, design and procurement typically take up to one year, and deployment takes an additional 2-3 months. Follow-up studies and close out typically takes another 2-3 months.

If you were starting from scratch, what technology would use you and why?

At the time, the RF tag technology was the best available to meet identified requirements, but entails several limitations. The readers are expensive to purchase, and to install, limiting cost-effective locations. The readers require location on a utility pole and power hook-up, entailing agreements and ongoing fees. The RF tags require FCC licenses. For these various reasons, a wi-fi technology solution is being pursued for the future.

A3.2 CASE STUDY – KING COUNTY METRO, SEATTLE, WA

If you were starting from scratch, what would be your planning strategy?

The project focused on the development of the TPRG unit separately from any required upgrading of the controllers. It would probably be preferable to develop an integrated approach addressing both TSP PRG unit and controllers at the same time, and through an integrated procurement process.

What are your future plans for TSP implementation?

Another 40 intersections are being equipped or planned using the current technology.

A project is being undertaken to capture data directly from controllers, but will only work with some controllers.

In the longer term, a new technological concept is being planned that is based on Wi-Fi communications for detection, instead of the current RF tags; this concept is being integrated into the current On-Board Systems procurement.

In addition, efforts are underway to explore ways to improve the interconnect between the TPRGs at each intersection, possibly through the implementation of a high-bandwith communications network.

What are their expectation with respect to NTCIP/TCIP TSP standards?

It is possible to do signal priority without standards but broad standards will be helpful for Seattle to achieve consensus among the over 20 traffic jurisdictions in the Region.

In the longer term, National standards will encourage vendors to develop and provide products with TSP capabilities, thereby providing more flexibility to local jurisdictions purchasing signal control equipment. It should also lead to the development of more standardized data collection and consistent data sets.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

Interviewers:
Brendon Hemily
Hallie Smith

Respondents:
Sean Skehan, Los Angeles Department of Transportation, and Rex Gephart, Los Angeles County Metropolitan Transportation Authority

BACKGROUND	BACKGROUND
Number of corridors involved	9 corridors have been equipped — 19 others are planned
Number of intersections equipped	654
Number of buses equipped	283 are equipped with transponders for TSP use on BRT corridors. Other buses are equipped with transponders for monitoring purposes.
Do you impose a condition stating that only late buses receive signal priority?	Yes, based on headway management. The traffic control system tracks the location of buses (each with unique ID) along the BRT corridors and compares passage times to the defined table of headways for that road segment which resides in traffic servers. Priority is only granted to buses whose headway since the previous bus is equal or greater than the defined headway. MTA sends the headway file every six months to LADOT. The headway management system also drives the announcements and arrival signs for stops: central server communicates by CDPD to next arrival signs. This is being changed now to hard wiring because CDPD is becoming less reliable. Communications will be hard wired to hub and then on a twisted pair wire to sign.
Is the system centralized or distributed?	Centralized. The controller communicates to the central system when bus is approaching. And the central system initiates all phase changes. The local controller can only time phases and can be used for backup.
What is the PRG/detection technology?	New bus detector loops plus transponders on bus (only metro Rapid buses receive priority; local buses in corridor do not). Bus loops have to be very wide to cover all lanes, all the way from curb to curb. All the loops are about 4 inches deep. LADOT has over 1000 bus loops – average 1.5 loops/ intersection: small intersections have one loop, large intersections have two loops, and route turning and stations have two loops. Regular loops are also located on all parts of major intersections to measure traffic on all sides on those intersections.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

What is the communications technology?

Twisted pair wire from local to hub, and then fiber to central. All local connections are on twisted pair.

Is the system integrated with AVL?

The system is not integrated with a system-wide bus AVL system.

What strategies are used? (Early green, green extension, phase hold, etc.)

Early green, green extension and phase hold. Most cycles are 90 seconds but range 60 – 120 seconds. Generally, try to give 10% of cycle for TSP – 6-15 seconds. Do not shorten "don't walk" phase.

Extension is more effective than early green because save entire red time Turning buses are detected from the previous intersection so they have time to check in for the left turn pocket. Queue jumps are not used; most stops are far side so queue jumps not needed and the California code doesn't really allow it. LADOT sets the number of cycles it is locked out; priority locked out for next cycle unless it's a major intersection – at major intersections have lock out for two cycles.

Is TSP integrated with EMS pre-emption?

EMS pre-emption is provided at some locations: some of the loops recognize fire trucks and some fire trucks have transponders. The fire department is experimenting with transponders on 44 trucks to see how it works. At EMS-equipped intersections they receive high priority

PLANNING

What sparked an interest in TSP implementation?

Reducing delay to buses at traffic signals: a study in 1995 found that about 24% of delay was caused by red lights.

Who is the lead agency?

LADOT-MTA joint leadership

What were the stated goals?

To reduce bus travel times (20-25%). Interviewed 2000 riders and found out that number one issue was travel time for all bus service in LA area. This triggered the whole program – In 1998, the Westside Bus Restructuring Program determined that speeds had declined by 12% since the mid-1980's, costing 200-250 buses; 50% of delay was dwell time. The Mayor had been to Curitiba and instructed MTA and LADOT to work together. LADOT then decided to move people not vehicles which was a major policy decision. TSP accounts for about 1/3 of the travel time savings. Based on the time savings and ridership gains, have returned to the board to ask for permission to expand application to a total of 28 corridors.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

Who are the players/partners?	LADOT and MTA
How did you choose a corridor(s)?	Determined by MTA with input from LADOT. Criteria for the selection of TSP corridors includes: transit use, transit potential based on census data, and transit dependence. LADOT decided the order in which the BRT and TSP corridors could be built and how fast they could be deployed. LADOT suggests some things based on traffic volumes, but MTA decides which routes to work on.
How did you choose intersections?	All intersections along corridor.
What technology do you use?	Loops.
How did you choose the technology?	Based on an evaluation of alternatives. From 1995 to 1999 evaluated four strategies – toll tags, RF, loops, optical strobe – toll tag uses a reader located on poles reader rather than loops. GPS was not evaluated because of accuracy and canyon issues. The evaluation found that loops were the cheapest and easiest.
Did you use any simulation or modeling?	No. The control system is based on real-time adaptive control with real-time split adjustment. (The software will be made available through McTrans)
What were the technical obstacles?	Rapid deployment using new controllers and involving writing new software. The UTCS had been modified back in 1990 for light rail (which gets priority regardless of whether late or not), but software had to be modified for ATCS. In addition, the control software upgrade was going to require installing 2070 controllers, but the TSP project may have accelerated deploying the 2070's to replace the 170's which didn't have enough computing power.
How did you overcome them?	Dedicated resources and staff commitments
What were the institutional barriers?	Institutional barriers were minimized because LADOT instigated the project.

There was good cooperation which worked well, but there was a short time-frame so that the opening of first 2 BRT lines (Wilshire and Ventura) would coincide with the red line rail extension. LADOT did all the work in house to speed up the program; by keeping all control internal they were able to move very quickly. The same approach was used for the next 2 corridors (Broadway and Vermont). After that, money became an issue and they have had to outsource construction and installation, and contract construction has been a problem.

How did you overcome them?

When design was done in-house, everything was fine. However, awarding contracts is a long and difficult process. In future, they may be able to figure out how to do a design-build contract – this involves preparing detailed plans for each intersection including loop placement, bus stop location (and foundation changes if required), and signal timing.

What is/was the training program for bus operators?

Driver training was needed for the BRT operation because they have fewer stops and want them in the run lane rather than the curb lane.

What is/was the training program for signal technicians?

Training class to explain the new 2070 controller and detector operation. It is important that they understand new controller card and get wires set up properly. There is always new training when there is new equipment, this is nothing new.

FUNDING

How was the project funded?

First 2 demo lines were paid from the MTA capital budget – BRT costs about $200,000/mile without vehicles. Next 7 lines were funded 50-50 from local funding and CMAC funding. Will use federal funding (e.g. CMAC) for expansion. By comparison:

> Light rail costs – $30-$40 M/mile
> Heavy rail costs — $200 - $300 M/mile
> Orange line (BRT bus-only corridor) costs — $20M/mile
>
> It is cost-neutral from the operating perspective (no new buses and no new people). MTA can actually put more miles on buses because they are moving faster.

What was the cost of project implementation?

Budget for the 9 lines that have been completed was probably over $10 M for design and signal work –software controllers, transponders, design and construction. The budget for the next 17 lines is $ 23.5 M.

What is the breakdown in costs?	Software was largest expense in the beginning, then transponders and cabinets. Controllers are $3,000 each. TSP costs about $30,000/intersection, including everything except transponders. Transponders are about $100/bus and are purchased separately.

IMPLEMENTATION

How were tasks assigned for implementation?	Loop crew install loops, and controller staff upgraded controllers. The software is in-house; five servers run all nine lines. Each crew is assigned their own specialty; most of the issues were because of having to hurry so much. Contractors are now doing construction work because LADOT has lost so much staff in the cut-backs.
What kinds of controllers?	2070 – Eagle was low bid. This could change every 5 years when re-tendered; any vendor will work.
Was there a test phase?	Yes, in 1999-2000
Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)	Priority is granted to all buses that are not early (based on headway comparison) with resolution to nearest minute —— 1/10 of minutes late gets no priority; all the rest get priority. The calculation is made every 6 seconds.
Are bus turning movements considered/impacted?	Yes – they put in a phase if it is needed for left turn. LADOT does not provide priority to buses not in revenue service, although MTA wants it when they deadhead to get back in service.
What is the policy concerning near side and far side stops?	Design is far side, near-side used only when far side is not available (curb-cuts or parking limitations) or at rail transfer stations.
To what extent was updating, installing and/or replacing signal equipment required?	All controllers were upgraded to 2070. LADOT codes transponders and then sends to MTA who install.
Who paid for controller equipment installation and upgrades?	MTA
How do you ensure that TSP is working on the equipment at the intersection?	Continuous monitoring through the central systems at LADOT and MTA; this is a great advantage of a centralized system. Has yellow/red warning indicators if twisted pair or loop is damaged (e.g. result of contractor digging in street). LADOT sees problem immediately and can determine exact time of failure. In case of red indicator, they dispatch someone immediately.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

	MTA Dispatcher is also watching board and should be calling driver to see what's wrong.
How do you ensure that TSP is working on the vehicles?	Periodic reporting of vehicle trips identifies malfunctioning equipment
Was the project publicized?	Yes
Is so, how?	Metro rapid was publicized through media events (print, radio, television), but there was also an article specifically on TSP – "magic transponder". MTA media relations takes care of all of this.
What data do you collect?	Bus detections by loop and bus ID
How is the data used?	Bus detections over specific loops are used in post processing to measure travel times between loops, headways, etc. They have also done tests by turning off bus ID's and calculating time savings. Archived data allows them to evaluate from history. Traffic control system log tracks whether priority was requested and whether it was granted or not – every event is recorded – They know when priority started, how long it was granted, what type of priority, how long the "lockout" lasted, and how long it took to recover. Detector failures are also monitored by the central traffic system.

MAINTENANCE

What are your maintenance agreements?	There aren't any. The city maintains all traffic equipment and MTA maintains all bus equipment. LADOT pays for the loop maintenance. City also maintains and operates all signals on state routes that run through the city. Failures are not common, but damage can happen with power failure or broken box – only the loop, cable to controller, and card in controller are TSP-specific.
How is the system monitored?	Through central system at LADOT and MTA Also do monthly queries of individual buses to see how often it has run and whether it hasn't shown up. There are usually five that have been in accidents – but can check transponder, MTA has had to replace about 10% of transponders.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

How do you optimize/adjust the system?

A periodic review of travel time performance is conducted but system is pretty self-regulating. However, if a bus stop is moved or a new signal is introduced on route, they may have to go into route table and insert new loop – giving 10% if needed. They can't optimize any more than that; they might check basic timing and re-do, but would do that any way.

EVALUATION

What Measures of Effectiveness do you use?

Reduced travel time, and increased delay to motorists

What are the benefits?

19 to 25% reduction in travel times. 1/3 of savings is due to TSP, and 2/3 of time savings is due to headway based service fewer stops, and shorter dwell times. Ridership Metro Rapid lines increased 4% - 40% depending on the line. One third are new riders to transit. Businesses also like the buses moving faster and like the arrival information because that allows the people to see when bus will arrive and go shop until it arrives.

What complaints have you received?

Almost none. Only 10% green advantage is given, and nothing is very visible; motorists don't really notice the difference. When TSP was a bit too aggressive at the east end of the Ventura line, they had a bit of a problem, so they just backed off a bit on the time. All telephone calls go to the district office, but if they relate to signal timing, it goes to 3rd floor. If TSP-related, complaint it goes to Sean Skehan. He may also get a call directly from district office asking if there's a problem, and will then look into it. Reduced parking spots because of the Metro Rapid program has also been a concern.

How have you responded to complaints?

Explain system operation

What is the impact to side street traffic?

Typically 1 sec delay per vehicle per cycle

What has been the overall public reaction/response?

Positive

How have your bus operators (or union) responded?

System is transparent to bus operators.

How do you maintain on-going communication among partners?

Regular meeting between LADOT and MTA, and telephone calls between staff – Rex and Sean work together well and chat several times a week.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

Rapid deployment of new technology and bureaucratic limitations to implementation (contracting requirements). For the entire planned TSP system, 86 cities are involved and will require getting agreements with all these cities to install and implement this equipment. Engineers believe they don't have a second to give away from their signals, so this required demonstrating that it works. It is now easier with the demos that showed that it works and it doesn't degrade their system.

Deployment or installation problems?

No technical problems, only bureaucratic (e.g. contracting process). Within MTA, scheduling for Metro Rapid is now headway-based rather than schedule-based, and schedules are prepared by operations staff, not planning. It has been a challenge to affect this change in approach, but it is improving with increased internal dialogue over time.

What do you feel were the keys to success?

Extensive technology evaluation and selection of a reliable technology and continuous and ongoing monitoring of performance. The system has to be reliable and fault tolerant, so this is very important. For example, the system is designed so that if a loop or section is lost, it has no impact. Someone needs to take the lead with strong political push.

Demonstration was valuable in convincing reluctant partners.

"Dare to be Simple": It is important to keep BRT simple (i.e. no dedicated lanes nor prepaid fares), and politically and environmentally sensitive. The objective was just to improve bus service; BRT doesn't have to have all 13 BRT-defined attributes.

If you were starting from scratch, what technology would use you and why?

Loops, because ease of installation and reliability is high; they have had such good results from the loops.

A3.3 CASE STUDY – MTA, LOS ANGELES, CA

If you were starting from scratch, what would be your planning strategy?

Having a time deadline and going fast was a help, but other jurisdictions may need more help. The expansion network is difficult, with all the phases hard to do; it might have been preferable to put up all the lines in LA first, and then expand to the cities that are harder to convince. 80% should have had TSP on opening day so that you have real speed improvement: do the lines that have highest savings first and then take the harder ones next.

What are your future plans for TSP implementation?

Continue deployment on selected corridors Will have 1,013 signals based on current corridor designs – 27 corridors altogether – by year 2008. Partners for full expansion include MTA, LADOT and 35 cities and 11 counties. Beverly Hills is adopting the LADOT system, but the smaller cities don't have staff, and it has been difficult getting them to agree to TSP. The county-wide Bus Signal Priority (BSP) is being set up for the other cities in the region. MTA offered to provide 2070 controllers but the cities didn't want to maintain them, so a separate system had to be designed. It uses GPS and wireless LAN with a processor on each bus. This priority does not depend on bus schedule adherence or headway, but will allow controller to recover. The wireless LAN communicates with one signal at a time. They have to put both TSP systems on the buses that operate in several jurisdictions. The Crenshaw line is the first to use this new system and was tested for 6 moths starting February 2004.

Training operations to dispatch the buses with both systems is the hardest part; five Metro rapid lines operate outside the city of LA.

Metro Orange Line will have a BRT dedicated lane on old track bed; the buses will be granted priority in a block of time not just because they are eligible. However the system will not do red truncation. The Orange Line still uses loops and transponders.

Does the project comply with a Regional ITS Architecture?

Yes. It was a big deal when ITS architecture first came out. County was supposed to take the lead, but not much has happened. The system predated every concept of architecture and uses a communication protocol that could be used on solid state; it is very efficient but not compliant with standards being developed. There isn't any way to change that – grandfathered in old protocol. They are still using old protocol to include everything in network – Would follow architecture if could but can't change now –

What are their expectation with respect to NTCIP/TCIP TSP standards?

None. They wish they could, but the system is too far along.

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

Interviewers:
Brendon Hemily
Hallie Smith

Respondents:

Bob Huffman, PACE; Taqhi Mohammed, PACE; Kathy Meyerkord, Civiltech; Joe Weesner, H.W. Lochner, Inc.

BACKGROUND

Number of corridors involved

1 – Cermak Road – 2.5 mile corridor

Number of intersections equipped

15 intersections on Cermak Road and 5 on a major N/S arterial (Harlem). The whole system included 20 intersections which were modernized and interconnected, but only 15 were equipped with the TSP software and with the check-out loops. This includes Pace routes 304 & 322 and CTA Route 25

Number of buses equipped

Entire fleet at West garage (approximately 125 buses)

Is priority granted to late buses only?

Priority is requested by all buses.

Is the system centralized or decentralized?

Decentralized.

What is the PRG/detection technology?

Loop detection – loops are placed 250 feet (6 bus lengths) before the intersection with a check-out loop downstream of each intersection – existing loops were compatible – IDOT already had loops and loops were the most reliable technology at the time. There are checkout loops at the 15 intersections on Cermak Road – loops are hardwired to controllers.

The loop location was just based on IDOT standard design. It did not have anything to do with travel time, bus length, or anything else operationally.

What is the communications technology?

LoopComm 600A transmitters on the buses, LoopComm 613A receiver/detector amplifiers in the signal controller cabinets

Is the system integrated with AVL?

No

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

What strategies are used? (Early green, green extension, phase hold, etc.)

Early green and green extensions are both used based on where the signal is in its cycle when the TSP call is placed by the bus. The maximum green extension varies and each intersection was studied individually. On a couple of intersections there are no extensions. Green time is taken from cross street phasing — never from pedestrian crossing time. All of the signals have pedestrian pushbuttons although some of the pedestrian phases may be set on recall, particularly at the east end of the project (closest to the City of Chicago where all pedestrian phases are pre-timed).

Is TSP integrated with EMS pre-emption?

No. Some of the intersections do have EMS pre-emption, but Opticom is used for that system and it is not integrated.

PLANNING

What sparked an interest in TSP implementation?

The need to speed up service in congested corridors.

The Signal Pre-emption Working Group of the Transit/Highways Task Force for the Illinois Operation Green Light Program was charged with the responsibility of evaluating the feasibility of systems for granting priority to transit vehicles through traffic signal priority (early studies for the project referred to pre-emption rather than priority).

Operation Green Light was a state initiative that started in 1989 or 1990 – looking at all forms of congestion mitigation and providing some funding. It had a transit workgroup as one of the task forces. Projects that were eligible were varied (sidewalks, curb cuts, signal timing, access to transit, etc). The idea of TSP came out of the task force, Pace liked the idea, and IDOT took it on. It began with a demo because we needed to prove that signal priority works.

Who is the lead agency?

IDOT, Division of Public Transportation, was the lead for the feasibility study. The Signal Pre-emption Working Group was an integral part of the feasibility study. IDOT, Division of Highways, was the lead for the design and implementation stage. Now the only real support for TSP is from Pace & the Regional Transportation Authority (RTA).

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

What were the stated goals?

The goals of the feasibility study and the demonstration project were to identify feasible pre-emption technologies, analyze alternative hardware systems, and select a preferred system for the Cermak Road corridor. Additional goals were to evaluate the potential benefits to bus service and the impacts on traffic operations that would likely result from the installation of TSP.

We began at the Eastern Terminal, a rapid transit station and intermodal connection point. We needed to prove that traffic would be okay and that there was improved schedule reliability.

Who are the players/partners?

IDOT – Division of Public Transportation and Division of Highways, Pace, and Chicago Transit Authority (CTA)

How did you choose a corridor(s)?

The corridor was selected because of traffic congestion caused by a high volume of vehicles and numerous signalized intersections which contributed to schedule reliability problems on three bus routes operating there.

How did you choose intersections?

They were chosen because they were between the North Riverside Park Mall which is a transfer facility for Pace & CTA buses and the CTA Douglas Terminal for the Blue Line. The three bus routes which use this segment of Cermak Road are Pace Routes 304 and 322 and CTA Route 25. Both Pace routes continue further west into the western suburbs but their east terminus is the Douglas Terminal. The CTA route runs only between North Riverside Park Mall and the Douglas Terminal. The 15 intersections at which TSP was installed are located between these two facilities.

Why did you choose Loop Detection?

There was extensive discussion based on a technology evaluation and feasibility study on which communication technology to use and many technologies were tested during the feasibility study. This system was selected because it was compatible with the goals of the project and with the existing actuated signals along the corridor operated by IDOT, it did not increase the burden on the transit operator or the traffic signal operation, and it did not involve any unproven equipment or technology. Although the technology chosen resulted in a "sole source" supplier, it was an off-the-shelf system. From a cost standpoint, this was beneficial. In addition, the technology, which used loops at a set location, assured a consistent operation in the location at which calls for TSP were placed. Other technologies available at the time would have had variability on when the call was placed.

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

What simulation or modeling did you use?

First we re-timed traffic signals, then studied them, then implemented TSP and studied it again. Simulation was also used in the evaluation of the impact of changes in bus priority parameters on bus and vehicular traffic operations.

We used TRAF-NETSIM to model the corridor since it had the ability to model buses based on schedule/headway. At the time (early 1990's) none of the software which also modeled TSP was available. To model TSP, we observed a TRAF-NETSIM run for 3 eastbound and 3 westbound buses and recorded each bus's operation along the system (when & where it stopped and for how long and whether it skipped any stops). We then manually simulated this on a time-space diagram to replicate how TSP would improve bus operation compared to a bus which did not get TSP.

VISSIM was used for the evaluation.

How did you apply the results?

Several VISSIM simulations were run for each combination of parameters and the averaged MOE's were used in the evaluation.

What were the technical obstacles?

During the feasibility study phase the biggest obstacle was deciding on the technology to place TSP calls. One faction was pushing technology which followed NTCIP protocol and would be fully interchangeable. There were no products on the market at the time of the study; therefore this would have required that the project cover the cost of development of this technology. The other faction was pushing off-the-shelf technology. Of the available proprietary systems, LoopComm was chosen because it allowed the exact location at which the bus placed the TSP call to be identified. Other technology such as optical sensor systems did not have this level of accuracy.

The other obstacle came during the design phase where it was noted that the LoopComm detector amplifier had a limited distance from the intersection where it could be placed and still function properly. There was a limit to the length of the lead-in cable.

How did you overcome the technical obstacles?

The technology decision was finally decided by going with the majority opinion. The LoopComm problem was corrected by the manufacturer during the design phase.

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

What were the institutional barriers?

IDOT Division of Highways was initially reluctant in their support of the demonstration, perhaps due to the potential for significant adverse impact on traffic operations due to transit priority. The CTA was a reluctant participant in the demonstration because they were pursuing other priorities and approaches.

How did you overcome them?

By monitoring the traffic delays at signal priority intersections after the turn on of TSP which indicated there were no undue delays in traffic. Also, we awaited complaints from the monitoring public after the turn-on. No complaints have been received to date.

What is/was the training program for bus operators?

No training program was deemed necessary. Operators were informed by bulletin in advance of the turn-on of this technology and what to expect. Also, before and after surveys were administered to operators.

What is/was the training program for signal technicians?

None other than a demonstration of the TSP technology to IDOT signal engineers in order to get approval for the installation of the software on the street.

FUNDING

How was the project funded?

Operation Green Light (state funding) and CMAQ.

What was the cost of project implementation?

$732,000 included completion of the interconnect conduit system between 20 intersections where it did not exit, removal of existing conduit cable and replacement with fiber optic cable, replacement of all controllers and cabinets and installation of advance detector loops and check-out loops where needed. Also included was the purchase of 75 transmitters for installation on Pace & CTA buses and the installation of testing stations at each garage involved in the demonstration.

What is the breakdown in costs?

- Transmitter – about $200/bus –
- Feasibility Study - $175,000
- Design, Construction inspection, Implementation – $148,000 – signal interconnect – check out loops
- Follow-up studies - $130,000
- Construction - $732,000

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

IMPLEMENTATION

How were tasks assigned for implementation?

IDOT DPT (division of public transportation) was lead on study – and hired Civiltech for feasibility study, design, construction management, implementation, follow-up studies.

Then we did a study (using VISSIM) on what happens when you change parameters (length of extension, location of loops, delay time, bus stop location). There were no big differences in operation except far side bus stops would help remove variability in dwell time with the TSP. They also found that benefits of upstream detection was somewhat mitigated by variability caused by heavy congestion levels. IDOT Division of Highways did implementation. Civiltech's client was IDOT

Pace and CTA installed transponders.

Meetings were held with Pace and the CTA to discuss the routes involved, the priority equipment to be installed on the buses, and the need to consistently run the priority-equipped buses on the routes.

What kinds of controllers did you use?

Existing equipment was old and couldn't be connected for progression – IDOT District 1 (DoH) has standardized on Eagle and Econolite. A functional spec was part of feasibility study and it specified that it needed early green and extension. This wasn't available with existing equipment. We do not interrupt green band on progression.

Later we met with IDOT and Econolite and discussed what could be implemented in controller. Econolite modified existing controller to include TSP functions. They develop the software Econolite ASC2.

IDOT uses NEMA only.

Was there a test phase?

Yes. Econolite developed the new software and tested it in-house. It was then bench tested by Civiltech personnel. That process took several months as bugs in the program's operation were discovered by Civiltech and fixed by Econolite. Once the testing was complete, a demonstration was made to IDOT personnel to gain approval to install on the street. To verify that the equipment was operating properly, a Civiltech engineer would travel through intersection with a transmitter with an engineer watching the signal.

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)

At the present time—for all buses whether early, on-time or late. Ultimately, this system will be changed over to smart bus system when the technology is upgraded to only request priority when buses are behind schedule or are operating on an express route.

Are bus turning movements considered/impacted?

Yes, in the original design, the Douglas Terminal was located north of Cermak Road between 54th Avenue and Central Avenue. Buses had to turn left at 54th Avenue to enter the station. TSP was provided for the EB left turn phase at 54th. They also had to turn left out of the terminal onto Central and proceed south to return to Cermak Road. A check-in loop was provided on this driveway at Central Avenue to call the Central NS green.

What is the policy concerning near side and far side stops?

Where possible, far-side stops were established in the priority corridor. This task was made difficult since most of the priority corridor is in a commercial zone where customer parking is permitted and a far-side bus stop lane can not be established.

To what extent was updating, installing and/or replacing signal equipment required?

New controllers were installed at each of the 15 intersections and the controllers were fully interconnected. The other 5 were just part of the traffic signal interconnect and included locations along Harlem Avenue, one of the major cross streets. Those other 5 locations were not equipped with check-out loops or the TSP version of the Econolite software.

How do you ensure that TSP is working on the equipment at the intersection?

There is no feedback – one has to observe in the field. Also bus operators will tell you if it's not working. If they are having a problem with schedule reliability then they know something is wrong.

How do you ensure that TSP is working on the vehicles?

Test stations were installed in one Pace and one CTA garage. These test stations consisted of a loop and two lights, one which indicates that the bus was detected as a vehicle and one which indicates that it was detected as a bus (i.e. the LoopComm transmitter is installed and active). For example, there are two confirmation beacons mounted near the garage door. The bus needs to drive over a loop to exit the garage. One light will come on if the bus is detected and the second light will come on if the transmitter is operable.

How was the project publicized?

A major television station was on hand during the 1st week of the turn-on to do a feature news story on this TSP project. In addition, Pace prepared a video with a split screen showing before and after route progression and travel time – very effective.

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

What data do you collect?

Data was collected for the before and after studies. This data was collected under 3 conditions: before optimization of the traffic signal system, after optimization but before implementation of TSP, and with optimization and implementation of TSP.

Immediately following construction and implementation, bus delay studies were completed by the transit agencies during the PM peak hour. This data included travel time between six waypoints between North Riverside Mall and the Douglas Terminal. In addition, signal timing data was collected to allow approach delay and level of service to be computed at select intersection. This information (travel times and signal timings) were collected both with TSP on and TSP off.

Additional studies were also completed in the early 2000s which included vehicle delay and queue observations; bus arrival time performance; and vehicle travel times. These were completed both with and without TSP active.

How is the data used?

The data was used to evaluate the effect of the installation of bus priority on bus performance and on vehicular performance at key intersections and through the system.

MAINTENANCE

What are your maintenance agreements?

There were no maintenance agreements. IDOT is responsible for all equipment in the cabinets and the transit agencies are responsible for the transmitters on their buses.

Was in the cost of maintenance?

IDOT does not pay additional costs because they have included TSP loops and equipment as part of their normal maintenance.

How is the system monitored?

Signal system operation can be monitored using Econolite's Zone Monitor IV. The primary goal of monitoring had been to detect equipment malfunctions and unauthorized changes to controller settings. The detectors on the priority loops can only be monitored by observing their operation in the field.

How do you optimize/adjust the system?

There have been no optimizations or adjustments to the signal timings since it was installed.

EVALUATION

What Measures of Effectiveness do you use?

For the feasibility study, average vehicle delay, average vehicle speed, average bus delay and average bus speed, all based on the TRAF-NETSIM output, were used. For the follow-up studies, these same MOE's were used but were based on actual field studies.

What are the benefits?

Upon full optimization of traffic signals in this 2.5 miles corridor and activation of priority, eastbound & westbound buses realized an average of 15% reduction (3 minutes) in running time. Actual running time reductions varied from 7% to 20% depending on the time of day. With the implementation of TSP and through more efficient run cutting, Pace was able to realize a savings of one weekday bus while maintaining the same frequency of service.

What complaints have you received?

Before TSP Pace had 100 bus complaints for missed trips – they went down to 12 after TSP – inadequate green time on one cross street.

How have you responded to complaints?

Field observations verified the problem and the bus priority settings were adjusted so that less time was taken from the cross street green interval when a priority call was received.

What is the impact to non-priority street traffic?

Based on the follow-up studies, there is little impact to non-priority street traffic. We are also not aware of any complaints received by IDOT.

What has been the overall public reaction/response?

On-board surveys revealed that TSP has increased the satisfaction level of passengers.

How have your bus operators (or union) responded?

Bus operators have subsequently asked that more Pace routes be set up with TSP. They don't mind cutting running time.

How do you maintain on-going communication among partners?

Did not have an internal committee and planning was part of bus operations.

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

Obtaining support from all agencies involved in the demonstration. Collecting sufficient data (in both quality and quantity) to perform an evaluation of the demo. Presently Pace has an excellent working relationship with RTA.

A3.4 CASE STUDY – PACE, CHICAGO, IL - CERMAK ROAD CORRIDOR

Deployment or installation problems?	Mostly minor – ensuring that the equipment was properly installed and maintained. The transit agencies had their own procedures to ensure that appropriately equipped buses were (or were not) run on Cermak Road.
What do you feel were the keys to success?	Cooperation with agencies and consultants – all partners and allies. Success requires a good team effort. Enthusiastic support of at least some of the agencies involved. The willingness of Econolite personnel to discuss and implement changes to the controller firmware.
How long did the various phases take: planning? procurement? deployment?	✷ Feasibility Study – 1991-1993 ✷ Design and construction – 1994-1996 ✷ Software testing – Dec. 1996 – May 1997 ✷ Implementation – July 1997 ✷ Follow-up studies – 1998 – 2003
If you were starting from scratch, what technology would use you and why?	Consider optical (e.g., Opticom or Tomar) detection, which could provide detection of transit vehicles before the vehicles are slowed by queues at the intersections. Equip buses so that priority was requested only when the buses were behind schedule, to minimize impact on intersection operation.
What are your future plans for TSP implementation?	Project with 20 signal – near Harvey transportation center – not finalized – demonstration now testing with optical system – 8 routes there – transit dependent customers – Also queue jump studying – in initial stages – Phase I – 9 corridors – seeking funding from RTA But will have phases II and III in future – Waiting for completion of RTA regional study. Also planning to integrate with new AVL system
What are your expectations with respect to NTCIP/TCIP TSP standards?	We would like to implement standards but are not sure how we will accomplish that.
Regional architecture	There is a regional ITS transit plan with RTA. We map all TSP projects to the architecture. The GCM corridor has its own architecture and is being used to test multiple technologies.

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

INITIAL DEMONSTRATION (PIERCE TRANSIT)

Interviewers:	Respondent
Brendon Hemily	Eric Phillips, Pierce Transit
Hallie Smith	Chris Larson, City of Tacoma Public Works

BACKGROUND for Demonstration Only

Number of corridors involved in demonstration

One - South 19th Street Corridor

Number of intersections equipped for the demonstration.

18

Tested a couple of different kinds of equipment – ran the test for about 6 weeks or so – checked to see if there was any travel times savings for transit and any side street impact.

PLANNING

What sparked an interest in TSP implementation?

Traffic Congestion was among the worst in the nation!

What were the stated goals and outcome of the demonstration?

- Evaluate transit travel times utilizing TSP Corridor
- Identify impact of TSP on side street traffic
- Evaluate Equipment being considered for deployment
- Develop a "GO" or "No-Go" recommendation for TSP
- Outcomes of Demonstration:
- Sorted out myth vs. reality
- Selected TSP technology
- Built level of comfort with city traffic engineers
- Obtained support to proceed

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

FUNDING

How was the demonstration funded?	100% funded by a Federal Grant
What was the cost of the demonstration?	Demonstration Project Funding — $86,000 (Federal)

TSP PROJECT (PIERCE TRANSIT)

Interviewers:	Respondent:
Brendon Hemily	Eric Phillips, Pierce Transit
Hallie Smith	Chris Larson, City of Tacoma Public Works

BACKGROUND

Number of corridors involved in the TSP project	6 corridors. The first two intersections completed were South 19th St., (Tacoma) and SR 7/Pacific Ave. (Tacoma and WSDOT)
Number of intersections equipped	110
Number of buses equipped	245 – 168 are Pierce Transit and 77 – Sound Transit
Do you use conditional or unconditional priority?	Unconditional— the emitter is always on when in service along TSP corridors.
Is the system centralized or decentralized?	Decentralized
What is the PRG/detection technology?	3M's Opticom – the signal is received by the detector, interpreted by the discriminator, which sends a request to the controller.
What is the communications technology?	IR for the TSP request (communication of the data at TSP intersections is via CDMA to IP)
Is the system integrated with AVL?	Not yet – Pierce Transit is going out to bid on CAD/AVL next year.

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

What strategies are used? (Early green, green extension, phase hold, etc.)

We develop GP coordination plans for the corridors first and then implement TSP control strategies within parameters, such as always maintaining progression, no skipping phases and no interference with pedestrian phases. TSP strategies include green extension and red truncation/early green. A "detection extension" strategy was developed for controllers lacking low priority function and operating in free mode as a means to extend standard loop detection to the max time once a bus is in range.

We have no queue jumps yet, but will put one on a downtown arterial. There is no transit-only phase insertion.

Is TSP integrated with EMS pre-emption?

Yes – fire only in Tacoma – in University Place it is police and fire. E911 paramedic and private ambulances are required to be coded in City of Tacoma to use the 700 series Opticom for EVP. We started from scratch in City of Tacoma because the city did not have EVP yet.

PLANNING

What sparked an interest in TSP implementation?

In 1995 there was a lot of technology coming out. Pierce Transit tried to validate whether the technology would improve transit. We tested the water with TSP, and the City of Tacoma agreed to try TSP. The City contacted police and fire right away to see if they were interested in emergency pre-emption.

Who is the lead agency?

The lead agencies are Pierce Transit and City of Tacoma. We focused most of the program around City of Tacoma. There are a lot of other small jurisdictions and in those areas there were questions about who would maintain the equipment. Initially we did not really talk about what kind of TSP function would work. We kept looking for a controller package that would work. The City was concerned about what TSP would do to the flow of traffic and Pierce Transit had to pledge that it would meet the City's requirements. The strategy was that the City would receive benefits for the general traffic first through optimization and coordination, and then Pierce Transit would get benefits from TSP. The City was glad to have the support to conduct extensive traffic engineering work that was needed.

What were the stated goals of the TSP project?

- Improve Transit Service Reliability
- Maintain Transit Travel Times along major operating Corridor
- Reduce dwell time at project intersection

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

Who are the players/partners?

A multi-jurisdictional group – City of Tacoma, Pierce County, City of Lakewood, City of University Place, Wash DOT, Pierce Transit. 80% of the project is in Tacoma. Tacoma and County (for smaller communities who contract with Pierce County for signal maintenance) to maintain the controllers.

How did you choose a corridor(s)?

Corridor choice was based on:

- Passengers per hour
- Service Frequency

How did you choose intersections?

We deploy TSP compatible equipment at project intersections that provide the greatest public benefit.

What technology do you use?

3M's Opticom. Existing and new controllers, some CDMA wireless technology also installed at time points along TSP corridors.

How did you choose the technology?

We already had Opticom in the county. The demonstration confirmed feasibility of that technology, and there was a decision for a sole-source procurement for Opticom. Opticom was required by the project partners to enable integration with EVP/EMS.

What simulation or modeling tools did you use?

We used the Synchro model for optimization for general traffic. Also, we used VISSIM for detailed simulation of the ramps on SR 7 project because Synchro did not give fine enough results. VISSIM is more expensive to use because of detailed data and calibration requirements, but the results are very impressive, especially when presenting to our Board or general audience. VISSIM will also be used to simulate complex signal redesign project in downtown required by introduction of new LRT.

What were the technical obstacles of the project?

We had a lot of controllers that did not have a TSP control strategy and therefore could not provide a response beyond high priority.

How did you overcome them?

We replaced them and conducted extensive testing on others to verify controller features.

What were the institutional barriers?

There was not a lot of communications between transit and traffic in the beginning.

How did you overcome them?

We began developing a relationship among the agencies and opened the lines of communication. Simply visiting one another for a brief conversation over donuts can help open communication. Technical issues and concerns were approached and evaluated through a process of discussing actual data versus a reaction to a proposal without facts.

What is/was the training program for bus operators?

A training program was developed because bus operators manually control emitters. We established TSP Working Group with S&T and Operator participation to develop a Training Program. We know it is important to make sure to communicate regularly with your front line! Training for bus operators is incorporated into operator's manual and is now part of all operators' training. The training explains how TSP works and when to turn it on and off – how you use the system and how it is applied.

Also, use instructions for emitters are included in daily shift/run assignment and are route specific.

In addition, there was training for maintenance of the on-board TSP equipment: we have a few electronics specialists who handle radio, fare box, destination signs, and TSP equipment.

What is/was the training program for signal technicians?

Checking for TSP equipment is just part of the routine checks on traffic signal cabinets.

FUNDING

How was the project funded?

Had 3-4 grants and then an earmark – around 1997-1999

What was the cost of project implementation?

- TSP Implementation — $2.5 Million (Federal) — (CMAQ and STP) — $200,000 (State)
- Total Project Funding (including the demonstration and TSP implementation) was $2,786,000
- Cost per intersection with replacement of controller and cabinet (including engineering): $25,763
- Cost per intersection with no controller replacement (but including engineering): $9,263

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

IMPLEMENTATION

How were tasks assigned for implementation?

Field engineering – (1) collect baseline data on intersection, (2) model the project (Synchro & sometimes VISSIM for special problems) and see how much flexibility is in an intersection, (3) create new general traffic plan and then implement, (4) deploy and fine-tune, (5) another study to include corridor, (6) implement TSP plan, (7) evaluation study to measure benefits compared to baseline and to optimized general traffic plan. Detection ranges are set in the field. DKS and Pierce Transit do this together. We look at intersection design for range of detection and bus stop placement. We then look at the type of controller that is available and the intersection volume to determine settings. Higher side street volumes require more restrictive TSP. We don't want to mess up traffic. We do an after-study and compare it to the base line. We describe what the benefits are at that point. Sometimes we reduce the change in the settings.

What kinds of controllers do you have?

The City did not want a separate black box so we use TraConEx 390 and LMD 9200 controllers. Pierce purchased city-wide upgraded software. For the LMD's we keep the same software everywhere and have no hardware issues. We replaced 18 controllers because they were older fixed-time controllers with no external input capability. The combination of Opticom and new controllers allowed us to create a controller standard.

Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)

All buses on certain routes.

What is the policy concerning near side and far side stops?

We try to have far-side stops whenever possible, based on availability of sidewalks and topography, but we can use mid-block stops or nearside stops if necessary.

To what extent was updating, installing and/or replacing signal equipment required?

Some of the jurisdictions have Tomar (for emergency vehicle pre-emption) and some very old Opticom equipment (100 series). Sometimes detection was set up in only one direction and the location didn't work well. Some old equipment didn't distinguish between high and low priority, so they could be pre-empted by mistake, and had to be replaced. Sometimes it was harder to update an intersection than to start from scratch.

Who paid for controller equipment installation and upgrades?

Pierce provided new controllers where needed.

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

How do you ensure that TSP is working on the equipment at the intersection?

The City has a spare ratio and they just replace equipment with spares when the equipment breaks. The City gets reports from the fire department if the equipment is not working. Pierce Transit reports to the City if there is a disruption in the data collection process because that means equipment is not working. Will show problems, but there are very few problems. The discriminators work fine and detectors can go bad but it is not really a problem.

How do you ensure that TSP is working on the vehicles?

Bus operators are required to perform equipment checks daily and will report if the equipment is not working.

How was the project publicized?

There were some news stories but there was no large media effort.

We had a "ride-along" with an environmental reporter. Customers said they were happy with anything that would get them there faster.

We gave our customers a warning during the data collection phase when the buses ran free (i.e. not adhering to schedules at time points). We told the customers that the buses might run early, so please get to stop a little early for the next few days.

What data do you collect?

We had a special task to develop a complementary system to collect Opticom data from discriminator, and transmit it via CD/PD to Pierce Transit, and integrate it into a system that compared real data (arrival times) to schedule data (arrival times). The data does not tell what controller did – we don't communicate with controller. The data we collect includes: time call was requested, vehicle number, high or low priority, range and intensity, when call was dropped, call duration period, etc. We now use CDMA (broader spectrum).

How is the data used?

We compare real data with scheduled data and have been able to reduce schedule times. We usually have enough recovery built in to compensate for traffic volume. With TSP we try to reduce recovery time.

MAINTENANCE

What are your maintenance agreements?

The City maintains their own equipment and Pierce maintains their own equipment.

What is the cost of maintenance?

There is no discernable extra cost because the technicians clean detectors while they are cleaning signal heads

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

EVALUATION

What Measures of Effectiveness do you use?

- Comprehensive before and after studies
- Travel time
- Stop and signal delay
- Fuel savings
- Air quality benefits
- Public schedule changes
- Operating resources required
- Signal delay significantly increases transit travel time.

What are the benefits?

TSP is an effective tool and significantly reduces signal delay and improves transit speed and reliability.

Implementation of TSP provided significant economic benefit to the general public. Signal coordination alone – $14.2 million annually for the six corridors (after TSP strategies implemented).

On S. 19th Signal Coordination reduced average total signal delay for by 18-70% for GP, and by 5-30% for transit. (AM and PM peak)

On Pacific Ave. signal coordination reduced average total signal delay by 30-65% for GP, and by18-21% for transit. (AM and PM Peak)

The combination of TSP and signal optimization reduced transit signal delay about 40% in both corridors.(So. 19th and Pacific Ave. Corridors)

Implementation of TSP had little impact on traffic progression along these two corridors.

Bus stop locations (far-side optimal for TSP) should be considered during TSP implementation.

Some side street delay increased with TSP implementation, but was well within acceptable limits.

Each intersection designed according to unique characteristics (bus stop location, frequency of times stop served, traffic volumes, type of controller).

Range setting requirements vary and proper setting is an essential implementation task.

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

What complaints have you received?

Complaints are related to coordination rather than TSP. Someone may see that there is no traffic and they want to go ahead. They ask the City to adjust the signal. But the City believes coordination is important and will not "fix" one intersection at the expense of all the others.

What is the impact to side street traffic?

Very little impact.

What has been the overall public reaction/response?

Very little response.

How have your bus operators (or union) responded?

The Union was afraid the schedulers might try to cut too much time from the schedules. Time has shown that fear to be unfounded, so they are okay now. Scheduling maintains on-going communication with operations to ensure no problems arise.

How do you maintain on-going communication among partners?

Have team that used to meet monthly. Doesn't need to meet that often.

State; Cities of Tacoma, Lakewood, and University Place; Pierce County; DKS; from Pierce Transit operations assistant manager, TSP project manager, director of development and planning and scheduling.

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

Convincing traffic engineers of the need for TSP and keeping everyone focused on working on same project; and keeping communications open.

There were issues internal to Pierce Transit because we were bringing a new system on-line. We had to make sure it was incorporated as part of operations. We solved these problems with communications and by giving responsibility and allowing people to feel ownership.

From the City's point of view the greatest obstacles were the complaints about side street delays. The side streets used to run free but are now part of coordination. Therefore, the side street delays are a function of coordination and NOT a function of TSP. On the whole the public is unaware of TSP.

A3.5 CASE STUDY – PIERCE TRANSIT, TACOMA, WA CORRIDOR

	The City was at first concerned that transit would get green light and everyone else would be delayed, but that has not been the case. Also, the City didn't see a huge benefit but there has been a real benefit in getting the traffic coordination.
Deployment or installation problems?	No problems worth mentioning. Decided to install emitters within bus body next to destination sign to avoid possible problems from water infiltration (bus washers and rain)
What do you feel were the keys to success?	Develop strong jurisdictional partnerships for project coordination and implementation. Verify operational benefits in accordance with local jurisdictions traffic engineering requirements. Provide measurable and quantifiable project results and outcomes.
How long did the various phases take: planning? procurement? deployment?	We had 3-4 grants and then an earmark all around 1997-1999. In the Fall of 1999 we started an interagency agreement between Pierce Transit and City of Tacoma which was completed Spring 2000. Construction took place in Spring 2000 to 2001.
What are your future plans for TSP implementation?	Have issued Task Orders for Implementing remaining TSP Corridors. Further use of data collection tool to assist with making schedule changes to take full advantage of TSP. Estimating that we can pull at least one bus from Route #1 – Pacific Avenue Corridor. Assessing and re-designing traffic control system downtown around new LRT Schedule changes will occur over next five service changes. Tacoma Express Bus Corridor Project Prioritize Peak Hour Express Bus Service Coordinated Project with Sound Transit
Are you using either a Regional ITS architecture or the National ITS Architecture?	Regional architecture – all consistent - Puget Sound Regional Council

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

Interviewer:	Respondent:
Brendon Hemily	Hansel Wang, P. Eng. Roads & Infrastructure Planning Program Manager, Transportation Engineering, TransLink

BACKGROUND

Number of corridors involved

TSP is a major component of the 98 B-Line 16 km BRT corridor between Vancouver and Richmond.

[In addition TSP has also been deployed as a stand-alone application at 4 intersections along the Willingdon corridor in Burnaby.]

Number of intersections equipped

59 intersections in the 98 B-Line

Number of buses equipped

28 buses

Do you use conditional or unconditional priority?

On the 98 B-Line, priority is granted based on schedule adherence condition. [The Willingdon Ave. corridor provides priority to all buses.]

Do you use conditional or unconditional priority?

Distributed. Signals are coordinated in Vancouver, but not in Richmond.

What is the PRG/detection technology?

Novax infrared emitters are arranged in a sidefire configuration, with emitters mounted on the curb-side of the bus over the middle doors, and the detectors mounted on utility poles, shelters, etc. The check-in detector is typically located 100-150 m upstream, and check-out is located at the near-side of intersection.

[The Willingdon corridor uses a visual recognition technology. Although the visual recognition system cannot distinguish between buses and trucks, this is not a problem in this specific location because the buses are operating in an exclusive bus lane.]

What is the communications technology?

Communications from detectors to master unit is by hard-wire or RF communications depending on layout of equipment.

Is the system integrated with AVL?

The system is integrated with the AVL system deployed for the 28 98 B-Line buses.

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

What strategies are used? (Early green, green extension, phase hold, etc.)	The TSP system provides maximum green extension of up to 15 seconds, red truncation governed by minimum pedestrian times, and phase insertion. Maximum green extension in downtown Vancouver is 12 seconds because of lower cycle lengths and signal coordination.
Is TSP integrated with EMS pre-emption?	No.

PLANNING

What sparked an interest in TSP implementation?	TSP was planned as an integral part of the 98 B-Line from the beginning.
Who is the lead agency?	TransLink is responsible for transit policy and planning, contracting of transit operations, and the management of the region's Major Road Network (MRN), including co-funding of road maintenance on the MRN network. This unusual institutional framework provides TransLink with both control of transit and some influence over the roads as well.
What were the stated goals?	The goals of the B-Line are to reduce travel time and improve reliability in an effort to provide a much more attractive transit product that emulate a rapid transit service. The TSP system was designed primarily to reduce travel time variability. [In the case of the Willingdon corridor, TSP was implemented to improve service on one of the highest demand routes that links the Metrotown SkyTrain station and the BC Institute of Technology, along a bus lane]
Who are the players/partners?	TransLink, the municipalities of Vancouver and Richmond, and the BC Ministry of Transportation (that controls intersections in the airport area.
How did you choose a corridor(s)?	The 98 B-Line (a BRT) corridor is a major corridor slated for higher capacity transit in TransLink's Strategic Plan. The BRT service is designed to build ridership for a future rapid transit system currently under planning. It also serves as a potential model for the deployment of BRT in other corridors.
How did you choose intersections?	59 of the 68 intersections in the corridor are equipped; those not equipped represent major/major intersections where there was a concern about the impact on buses and general traffic in the intersecting corridor.
What technology do you use?	Infra-red emitters

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

How did you choose the technology?

New Novax traffic controllers were being deployed in Vancouver. A demonstration of the Novax TSP system was conducted in 1999-2000 to test its compatibility with multiple controllers in use in other jurisdictions.

Did you use any simulation or modeling?

Yes.

If so, which tools did you use?

VISSIM was used to simulate operations in a few locations

If so, how did you use simulation tools and apply the results?

Simulation was used to determine the best location of check-in detectors. However no systematic assessment of the entire corridor was conducted before implementation. A new project is currently underway to use simulation for evaluation purposes.

What were the technical obstacles?

There was some teething problems with the new controllers especially when configured in coordinated groups, so TSP could only be deployed initially at isolated intersections until this problem was resolved.

There was a problem in finding an appropriate location for the check-in detector. The simulation analysis provided a standard check-in location (15 seconds upstream with location determined by speed of the bus), but this often had to be moved substantially to the next available utility pole downstream, reducing the potential benefit of TSP.

How did you overcome them?

The new simulation project will provide more detailed analysis for some locations. In addition, a new generation of TSP technology is currently being evaluated that will provide a more dynamic approach to detection.

What were the institutional barriers?

Despite the considerable discussion of TSP over the years and the high profile of the 98 B-Line, understanding of TSP among the municipalities remains fragmented.

How did you overcome them?

The unusual institutional framework provides TransLink with much influence on the process, but there remains a need for continuous communication efforts with the Ministry, and other municipalities for future TSP implementation.

What is/was the training program for bus operators?

There was only bus operator with respect to the on-board AVL unit; the TSP was transparent to the operators.

What is/was the training program for signal technicians?

Not for the TSP.

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

FUNDING

How was the project funded?

TSP was part of the 98 B-Line deployment budget.

What was the cost of project implementation?

The overall budget for the 98 B-Line was CD$52 Million (US$34.67 M): 44% for the infrastructure (including construction of a median lane in Richmond); 35% for the new buses; 11% for modifications to the maintenance facility; and 10% for ITS.

The TSP budget was CD$1.3 M ($US 860,000 at the time) for hardware and software.

What is the breakdown in costs?

The cost was approximately CD$28,000 per intersection (US$18,700). Emitters cost roughly CD300 (US$200) plus installation. CD$20,000 (US$13,300) was spent on simulation analysis.

IMPLEMENTATION

How were tasks assigned for implementation?

TransLink has overall responsibility.

The AVL and TSP suppliers are responsible for on-board equipment, and the TSP supplier was responsible for wayside equipment. Municipalities are responsible for signal timings.

What kinds of controllers?

Novax in Vancouver and Econolite in Richmond.

Was there a test phase?

The TSP system was demonstrated in late 1990's for its functionalities and integration with an AVL system, prior to the implementation of the B-Line service.

Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)

On the 98 B-Line, priority is granted to buses that are two or more minutes late.

The TSP Master Unit has the ability to distinguish four levels of 'lateness', and in case of conflict, forwards the request by the most severely late bus to the controller.

Are bus turning movements considered/impacted?

Bus-only turn phases are used at the end of the protected median BRT right-of-way in Richmond to enable the buses to reintegrate the normal lanes. In addition, there is a queue-jump at the Airport Station with a bus-only phase for exiting buses.

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

What is the policy concerning near side and far side stops?

The corporate policy is for far-side location of B-Line stations. In some cases, this was not feasible because of various reasons, including property availability. B-Line stations are mostly separated from local bus stops.

To what extent was updating, installing and/or replacing signal equipment required?

Vancouver was in the process of upgrading their controllers prior to the B-Line project. New controllers were required in Richmond.

Who paid for controller equipment installation and upgrades?

Both Vancouver and Richmond paid for their new controllers in the corridor.

How do you ensure that TSP is working on the equipment at the intersection?

A print-out is generated every two to three months or upon request made by TransLink to the municipalities and indicates time of requests, but this is a crude and unsatisfactory approach for monitoring the operation of the TSP Master and wayside units.

If a problem is detected by the municipality between the Master Unit and the controller, TSP is disabled. A more sophisticated monitoring and diagnostic system will be incorporated in the next technology generation currently under development.

How do you ensure that TSP is working on the vehicles?

No system exists.

Was the project publicized?

The B-Line was massively publicized, but TSP element was not emphasized.

What data do you collect?

None other than those recorded by the controllers. The availability of data is a significant issue.

How is the data used?

Not used unless malfunctioning of equipment is detected.

MAINTENANCE

What are your maintenance agreements?

TransLink is responsible for maintaining detectors and TSP master unit. The TSP is currently maintained by Novax under a direct contract with TransLink.

Was in the cost of maintenance?

CD$24,000 (US$20,000) per year

How is the system monitored?

The printouts generated every three months are the only means, but are insufficient.

How do you optimize/adjust the system?

A VISSIM model is currently being developed to assess the performance of the current system.

EVALUATION

What Measures of Effectiveness do you use?

A comprehensive evaluation study was conducted to assess the overall impacts of the 98 B-Line BRT system. As part of this evaluation study, a before and after evaluation was made of the impact of TSP.

What are the benefits?

The 98 B-Line resulted in reducing travel time in the corridor form 100 to 84 minutes. It resulted in a 23% modal shift from auto to transit in the corridor. The net benefit of the BRT line is CD$2.9 million (US$2.4 M) per year.

The main benefit from the TSP system was a significant reduction (40-50%) in travel time variability.

Have benefits been reflected in transit schedules, and how?

This is an issue. Schedules are prepared by the contract operator, Coast Mountain Bus Company. There is a need to monitor actual savings and review time points in light of running time savings.

What complaints have you received?

There have been no complaints; nobody has noticed.

What is the impact to side street traffic?

There has been no noticeable impact.

What has been the overall public reaction/response?

We have not received any complaints from the public.

How have your bus operators (or union) responded?

We have not received any complaints from the operators.

How do you maintain on-going communication among partners?

TransLink has an in-house Project Administrator, but his primary role is technical and maintenance (e.g. when equipment is damaged).

No formal committee was established during deployment. Communications with municipalities for future deployments is being carried out one by one.

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

The requirement for schedule-based conditional TSP should be re-evaluated. TSP has been conceived as having negative impacts on pedestrians by some municipalities.

Deployment or installation problems?

Finding an appropriate fixed location for the check-in detectors, that does not sacrifice performance is an issue.

What do you feel were the keys to success?

The availability of funding for the B-Line was a key to success.

In addition, the use of simulation, even limited as it was, was useful to demonstrate potential benefits in terms of overall travel delay, and facilitated negotiations with traffic departments.

How long did the various phases take: planning? procurement? deployment?

Planning = 3 years
Procurement = 1/2 year
Installation = 2 years

If you were starting from scratch, what technology would use you and why?

A system that provided more ongoing data collection and diagnostics capability would have been preferable, but was not available at the time.

In addition, the technological solution adopted involves considerable hardware on the street, capital costs, and power requirements.

If you were starting from scratch, what would be your planning strategy?

Adopting an unconditional approach to TSP would greatly simplify the deployment because it does not require integration with AVL, and would reduce overall costs considerably. The potential for an unconditional approach is being explored for future deployments.

More planning to understand the optimal location of check-in point for each intersection would have been useful, but the technology is still constrained by the need of mounting check-in detector at a fixed location.

A3.6 CASE STUDY – TRANSLINK, VANCOUVER, BC

What are your future plans for TSP implementation?

A major study, involving the University of British Columbia, is underway using VISSIM and data from several corridors, to evaluate more accurately various related issues, including: passive coordination, conditional vs unconditional TSP, and other related measures such as parking bans, queue jumps, etc.

In addition, a new generation of TSP technology is currently being assessed that may address some of the identified technical issues.

TransLinks's strategic plan has identified various other corridors for BRT deployment once these initiatives have been completed.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

Interviewers:	Respondents:
Brendon Hemily	Jon Lutterman, TriMet
Hallie Smith	Willie Rotich, City of Portland

BACKGROUND

Number of corridors involved	Phase one is complete and includes 8 corridors. Phase two began March 2004 – TriMet is gradually adding corridors and other intersections.
Number of intersections equipped	There are 250 intersections equipped in Phase 1- There will be 370 at end of phase II.
Number of buses equipped	There are 650 buses equipped. That includes all fixed route buses except 20' circulators.
Do you use conditional or unconditional priority?	Conditional — based on four criteria. (See below.)
Is the system centralized or decentralized?	Decentralized
What is the PRG/detection technology?	3M's Opticom

Phase I – Activation is based on four criteria: 1) Door closed, 2) on-route, 3) 30 seconds or more late, and 4) within city of Portland as defined by a geometric polygon. The initial project was funded based on a request by the city of Portland, and only applies to the city. Parameters have not been set up to date to implement TSP in suburban municipalities.

There is no checkout detection.

Phase II will create "Activation points" and won't request priority from bus until it reaches an exact point as determined by AVL system. There is about a bus length in differential GPS accuracy.

Creation of activation points requires two changes: a change to on-board firmware and to software of data derived from TriMet's scheduling software that will allow definition of activation points. It is like a new scheduling point. In addition, the creation of activation points Phase II will require some development of the business rules to use in

APPENDICES

determining distances from the intersection in special situations. For example, for near side stops, the activation point may be set at stop-bar as opposed to the normal up-stream distance. Once activation points are created, granting of priority may also be linked to other factors such as activation of passenger push buttons, length of time for door openings, and historic likeliness of stopping.

The buses operate in low priority range. Opticom provides 10 classes within "low priority". In theory, if the phase selector receives several requests, it could go to highest class. However, this feature has not been used to date in Portland. Priority is granted on a "first come first serve" basis.

What is the communications technology?

Encoded Infrared Communications

Is the system integrated with AVL?

Yes.

What strategies are used? (Early green, green extension, phase hold, etc.)

Both green extension and red truncation are used. Recovery is not needed because the signals are never out of coordination. The system does not provide priority to a bus request in the cycle following a cycle in which priority was requested.

The system allows 7-10 seconds extension which changes by intersection. If there is a pedestrian push button, the walk time will not be shortened beyond the 4 second minimum as set by the MUTCD. The maximum cycle length is 120 seconds with either phases but in the central business district some cycles are as short as 60 seconds. If signals are too close together, no bus priority is given.

Portland also has some queue jumps which is used when a bus lane is in a right turn only lane. The queue jump gives six seconds of advance to buses to jump the queue. Both loops and Opticom are used to grant the signal in right lane. These are Installed based on need.

At intersections with pedestrian call buttons, we use maximum time available. At intersections with pedestrian recalls, we shorten crossing time (4-second minimum) to limits set by MUTCD.

Is TSP integrated with EMS pre-emption?

Yes. High priority is provided to fire trucks only, not regular police vehicles or ambulances. High priority is also provided to two police bomb squad vehicles.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

PLANNING

What sparked an interest in TSP implementation?

There had been some early pilot projects conducted by Tri Met in early 1990's (Powell using transponders, Multnomah), but technology and software were not sufficiently mature, results were inconclusive, and the pilots had not lead to further development.

More recently, Tri Met had implemented the "Streamlining Project" to improve speed on selected corridors which added TSP, assessed stop spacing, looked at individual stop locations, moved nearside stops to far-side stops wherever possible based on a far-side preference policy, and added some new striping and some queue jumping. The reason TriMet began in the city first and added suburbs later is that the city had an funds earmark by Congress for TSP. Emergency vehicles were first implementation and then buses were added with signal priority.

There had previously been some implementation of EMS pre-emption at a few intersections.

Who is the lead agency?

The City Traffic Department was the lead but TriMet often leads in implementation. Additionally, there is the TransPort Group which may take the lead. The TransPort Group is a regional ITS coordinating group composed of three counties and one city as well as Oregon Department of Transportation and Washington Department of Transportation. The state calls the meetings which are held monthly. TransPort maintains the regional ITS architecture and all agencies share fiber and cameras. Each agency maintains its own fiber. TransPort provides the forum to encourage continued implementation of TSP in suburbs.

What were the stated goals?

Transit wanted to reduce operating costs and improve reliability of schedules through reduced variability.

The City wanted to provide priority to emergency vehicle (fire), and to increase the PEOPLE throughput through intersections.

Who are the players/partners?

The project has enabled:

- Extension of Opticom to all fire trucks
- Upgrade to 170E/with HC11 type controllers
- Additional intersections installed with Opticom
- Equipping of all buses with low priority Opticom

City of Portland DOT, TriMet, and Oregon DOT for development of standard controller equipment.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

How did you choose a corridor(s)?	Level of ridership, frequency of service, and amount of schedule deviation (based on analysis of AVL data). The team looked at the behavior and came up with a list of candidates. Then out of all these they chose the corridors with the best possibility of making an impact. The corridor had to be inside city and have a big potential for delay. AVL data was used to determine the potential for delay. Some input was also provided by the fire department.
How did you choose intersections?	Phase 1: Intersections were chosen to get measurable benefits. Phase II will concentrate on "hot spots". TriMet held a "Hot Spot Contest" asking bus drivers which signals bother them most. TriMet analyzed the submitted intersections using AVL and awarded prizes based upon correctly prioritizing the negative impact. TriMet took the top 30 intersections within the City (but outside original corridors) and some additional corridors listed in the TIP as candidates. Intersections that were too close together, downtown, or just too complicated were eliminated.
What technology do you use?	Opticom. Phase selectors had to be upgraded. With an upgrade to 700 series, they will be able to use the class and vehicle identification numbers for determining priority level. The City is upgrading their traffic control system and the suburbs will be able to use the same system. The central system upgrade came with free licenses for all the regional partners.
How did you choose the technology?	Opticom had been used by the fire department all along, so instead of choosing a different technology we made the decision to use Opticom because it made sense. There was no need to look for something new because we already have technology that would be shared by the fire department.
Did you use any simulation or modeling?	TriMet did not use any simulation or modeling. The City of Portland uses Synchro to model timing for signalized intersections. The consultant hired the local university (PSU) to create a TSP simulation to aide in timing plan adjustments.
If so, which tools did you use?	Although there was no simulation, the consultant assessed in detail each intersection to determine plans and timings. Appropriate time to be provided for extension or truncation depended on professional knowledge (using free flow speeds). The consultant used standard times (e.g. 4 seconds is minimum for walk – walk time under flashing is calculated using 4ft/sec) — from ITE manual and MUTCD.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

What were the technical obstacles?

1) Definition (boundaries) of the city:

The initial project was funded for city of Portland only. In addition, agreements have not yet been signed with suburbs, and their controllers have not been set up. Therefore, a bus with its emitter on would be perceived as an EMS vehicle anywhere out side the city boundary.

We needed to define borders for where this system will work, used by AVL firmware. The border is very jagged. We started with 120 points, and eventually simplified to a 15-point polygon. The system has to be enclosed in a continuous polygon in order to function properly.

Another technical problem was the default setting and upgradability of equipment:

High priority is different from the emergency emitter
10 hertz = low priority
14 hertz = high priority

Opticom said the equipment was upgradeable, so TriMet assumed they could replace a chip or upgrade through a serial port. The default state is flash. TriMet wanted the default to be no flash because the default created problems when buses were in the suburbs. Therefore, TriMet wanted to upgrade to default "off" setting. But to upgrade they had to replace the whole back-half of emitter. This lead to a conflict over the definition of "upgradeable". The new generation of emitters is designed with laptop plug-in for firmware upgrading.

Another technical problem was compatibility with J1708. The message collision detection on-board the vehicle area network (VAN) would only retry twice before turning off. Excessive on-board message noise therefore prevented message delivery. This has been rectified with new firmware.

Additional technical problems were related to controller software.

Controller software handled pre-emption but not priority (provided low priority but at the same time used minimum green times for left turns movements).

Controller Software required a different algorithm for low priority. This meant that we had to redesign the CPU and software had to be rewritten.

How did you overcome them?

To overcome the lack of upgrade ability of equipment, TriMet reached an agreement with the supplier.

The controller software problems were addressed by the state. The state had initiated in parallel a process to enhance and standardize controller software and equipment, called the W4IKS. A user group was formed to standardize controllers across the state. Although they considered moving to a 2070 controller platform, it was felt that the 2070 platform was insufficiently mature at the time. They adopted an upgraded 170 platform instead.

The W4IKS process resulted in the development of the 170E controller (with 1 KRAM, 512 EE and A/D of memory, and higher speed) and a software upgrade into the firmware. The software included in the 170E represents a one-step enhancement to existing 170 software, but sufficient to enable desirable TSP features.

What were the institutional barriers?

Not really because of great communication – TransPort and Technical Advisory Committee (TAC).

There was an initial concern from Fire chiefs that providing low priority would compromise their high priority. However that concern was overcome with communications.

TSP implementation still requires time. An intergovernmental agreement (IGA) has to be signed with each suburb for future expansion, and this takes 6 – 18 months, which is longer than anticipated in TIP.

What is/was the training program for bus operators?

There is no bus driver intervention required and no formal training per se. Awareness is provided by sending bus operators articles to read to inform them. The Operator's Report comes with their paycheck. Even queue jump was not perceived to require training. The driver sees the light and proceeds accordingly.

What is/was the training program for signal technicians?

Software that was used for old controllers had 15 tables. There are now two more (17) tables. Signal technicians had to learn the two additional tables, but all the rest is the same. Plans were already optimized, and tables are downloaded by technicians as needed when they go to the controllers in the field. Not a lot of training was or is required. Timing plans for all signals are reviewed every five years by the City.

The new Central System upgrade will include the new tables.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

How was the project funded?

The project was funded by congressional earmark. In the future, other jurisdictions will pay for their own upgrades (or TriMet will pay partial installation costs). The upgraded central traffic control system is being funded/developed by the City of Portland and the suburbs will be able to use it. In addition, decisions concerning 170E controllers simplify decisions for future participants. The City maintains about 1000 intersections.

What was the cost of project implementation?

$5.8M

What is the breakdown in costs?

Numbers are approximate:

$5M total originally (5.8 revised budget):
$3.5M city (3.9)
$960K for consultant work for plans and timings
$250K for upgrade to central system
Rest of 3.5M is for receivers, labor, etc
$1.5M TriMet (1.9)
$868 K hardware for emitter
$515 K installation
$255 K firmware
Cost per intersection is about $10,000 if there is no Opticom at all there.

IMPLEMENTATION

What is the extent of implementations: number of corridors, routes, streets, intersections?

There are eight corridors in Phase I. Phase II started March 2004. There are 250 intersections equipped in Phase 1- There will be 370 at end of phase II. There are 650 buses equipped. That includes all fixed route buses except 20' circulators.

How were tasks assigned for implementation?

The consultant prepared plans and timings and marked each intersection. Technicians then provided the installation. The truck that electricians/technicians use has an emitter at about same height as a bus emitter, so they can check placement of the receiver in the field. They read the intensity from emitter and then add 50' to the reading and enter it into the laptop.

What kinds of controllers?

State uses 170's. City of Portland bought new 170E ATC's with 68000 microprocessor. This is the same CPU that was supposed to run on the 2070.

Safe trans and McCain Traffic supply CPUs. It was necessary to add more memory. The City changed the microprocessor 64HC11 with 1 KRAM, 512 EE, and A/D memory, and upgraded firmware based on Wapiti software.

The State has now adopted 170E controller as standard for the whole state.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

Was there a test phase?	Line 4 and Line 12– were test phase – Had two corridors and tested about 20 + 26 +13 (59 controllers) This occurred prior to finalization of federal grant, and City spent its own money to implement on 2 corridors, and used that as a test phase. They had to keep working at the software to fix it. The problem was that it would get out of coordination and sometimes it would get stuck. Some signals acted like they were preempted. The problem was overcome by tweaking the software.
Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)	Priority is granted for buses that are running 30 seconds or more late. TriMet had originally set a 90-second late criteria but found that buses had difficulty recovering from this level of lateness.
Are bus turning movements considered/impacted?	There is one intersection that's minor to major that is controlled by Opticom.
What is the policy concerning near side and far side stops?	As a result of the previous "Streamlining project", Tri Met had adopted a "far-side" stop policy wherever possible.
To what extent was updating, installing and/or replacing signal equipment required?	TSP required upgrading to standardized 170E controller boards, but that was a relatively minor operation once the standard had been developed through state process. TSP also required Opticom phase selectors at all intersections.
Who paid for controller equipment installation and upgrades?	This was included in earmarked federal grant.
How do you ensure that TSP is working on the equipment at the intersection?	This is covered with regular maintenance in the field. Signals are checked every 6-12 months to ensure that everything is working mechanically.
How do you ensure that TSP is working on the vehicles?	There are on-board diagnostics that indicate whether the emitter is operational and sending a message. The weekly maintenance cycle generates fault reports for various things including TSP. Also, if the emitter doesn't provide data, it's not working.
Was the project publicized?	Not intentionally but it has been mentioned in conjunction with the "Streamlining Project"
What data do you collect?	On-board diagnostics will show when priority is requested. However, there is no way at this time to indicate if controller actually granted priority and how. This data loop needs to be closed. This is a major problem from an analytic point of view so that effectiveness of TSP can be more closely assessed.

Local phase selector logs the class of requesting buses, time, action, etc., but data can only be downloaded by going to the controller in the field to download info. A project is underway so that Central can see data logged by controller: request to controller, by which bus, when, and actions that have been implemented.

TriMet collects a tremendous amount of data through its AVL (Orbital) system. Red Pine APC's are on 75% of the fleet. All new buses have APC and TriMet is moving toward 100% of the fleet equipped with APC's.

How is the data used?

Data is used to adjust schedules.

This brings up an important issue. At first TriMet time pulled too much time off the adjusted schedules. When schedules are too tight, variability rises. This caused some problems so schedulers have learned to take minutes out of the schedule gradually until variability goes up. Then they can add some back in to find the right balance. TriMet has "driver shake-up" each quarter.

MAINTENANCE

What are your maintenance agreements?

None - TriMet maintains buses and the City maintains signals.

What in the cost of maintenance?

650 buses - 0.2 FTE – The hardware is under warranty for 5 years. A new emitter costs about $1000 and should last 12 years or more.

There is no additional cost for the signal maintenance. Phase selectors and receivers are very durable. One doesn't have to clean them or anything. The City has a task for the consultant to check if the receivers need cleaning.

How is the system monitored?

When the ignition turns on, the bus is interrogated as to what priority it has. The emitter knows how it is programmed and it can tell bus whether it is functioning and whether the priority is high or low.

A3.7 CASE STUDY – TRIMET, PORTLAND, OR

EVALUATION

What Measures of Effectiveness do you use?	TriMet MOE was reduced variability. Reduce recovery time at end of run is now a goal but was not an initial goal. Note: it is important to distinguish between "layover time" defined by the bus operator's contract and "recovery time" which is added to ensure on-time departure when variability exists. As variability is reduced, recovery time can be reduced as well. TriMet projected potential savings in recovery time and removed it at outset, but this created new variability problems. Since then they have been proceeding incrementally, ratcheting it down with each sign-up, to returning it when variability starts increasing again. However, because of lack of data from controller actions, TriMet is unable to assess directly the impact of specific strategies on reduced variability and running time..
What are the benefits?	Reduced recovery time and increased reliability. For Line 4 in Nov 2000 TriMet was able to avoid adding one more bus. This adds up to savings. There are also benefits to emergency response and on-time performance for transit vehicles. Bus operations removed too much schedule time at first which created problems and complaints from bus operators. TriMet has since proceeded incrementally.
What complaints have you received?	There are no complaints from the traffic side.
What is the impact to non-priority street traffic?	Very little. Plan to upgrade software to be able to collect data directly from controllers. After that, a formal evaluation study will be conducted.
What has been the overall public reaction/response?	No reaction.
How have your bus operators (or union) responded?	Little reaction.
How do you maintain on-going communication among partners?	The TransPort Group TAC meets every other month maintaining communication across modes and across the region.

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A3.7 CASE STUDY – TRIMET, PORTLAND, OR

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

For TriMet obstacles include:

Getting the activation points into TriMet data – it's a new piece of software – the firmware makers had moved on – this is not a small task to add to the AVL system. TriMet must define the business rules for creating activation points and then maintaining them.

Defining usage parameters – what is the default in the emitters? How late do I want the bus to be? How to define city polygon?

For the City obstacles were that:

Controllers had to be upgraded and software had to have the proper algorithm..

Deployment or installation problems? Initially there was water damage to the electronics on the emitters caused by bus washers. The problem was resolved by drilling a hole on bottom of each emitter to allow the water to drain.

What do you feel were the keys to success?

Stakeholder partnerships!

The project was accepted by transit and traffic and was even proposed by the traffic side. There is a champion in the traffic department.

Extensive inter-agency cooperation and trust in the region created an environment where dialogue already existed to a large extent and there was a strong commitment to cooperation. Examples include:

The TransPort ITS working committee brings all agencies involved in ITS (traffic and transit) to the same table and prepared the regional architecture.

The city implemented a 800mhz trunk radio that was built with sufficient capacity to meet the needs of all agencies in the region. Access will be provided to all, and participating agencies will share in maintenance costs

TransPort adopted a single GIS standard for the region.

The new upgraded city traffic control system is being made available to all suburban communities. This will facilitate traffic coordination and future extension of TSP to suburban communities.

Additional keys to success were pitching the right ideas from the begin-

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ning. The important issues are (1) people throughput, and (2) passenger wait time (as opposed to passenger load). We know that high variability creates anxiety in passengers who have to arrive early. With TSP one can reduce passenger wait time and increase people throughput.

How long did the various phases take: planning? procurement? deployment?

This whole project happen quickly because there was a sole source procurement. The City had Opticom already.

If you were starting from scratch, what technology would use you and why?

We would still go with 3M's Opticom product. However, we wish there were two way communications so we could confirm that the signal received the call from the vehicle.

We would actually prefer another form of detection/communication because of limitations of one way IR technology. One possible technology would be DSRC. It would be nice to have something that sends more data.

We are not interested in a centralized system because it would require too much bandwidth.

If you were starting from scratch, what would be your planning strategy?

We would emphasize a systems engineering process and would use a concept of engineering. That is, we would define the problem first and then write a functional spec based on the concept of engineering. We would pick some corridors, segregate the fleet, and choose certain vehicles in fleet. Then we would have a successful test case which we would then expand.

What are your future plans for TSP implementation?

The suburbs are committed to implementing TSP as part of TransPort plan. An IGA needs to be developed with each individual municipality. That usually takes 6-18 months. Actual implementation will be facilitated by standardized 170E controller, Wapiti software, and access to Portland's upgraded central traffic control system.

Phase 3 TSP development will upgrade the present system to giving priority based on ID class; and depending on how the bus is running and what the circumstances are.

Oregon has a state law saying one has to have jurisdictional approval to have signal priority. We plan to bring in three counties very soon and 10 cities in future. Some counties control signals and some cities operate their signals.

What are their expectation with respect to NTCIP/TCIP TSP standards?

We had great hopes for standard process, but now are waiting to see what happens. We are committed to Opticom which has only one-way communication and is not formally recognized by current TCIP definition.

A3.8 CASE STUDY – VIRGINIA - ROUTE 1

Interviewer:
Hallie Smith

Respondents:
Bob Sheehan, VDOT
Doug Hansen, Fairfax County
John Collura, UMass/Amherst (formerly VaTech)

BACKGROUND

Number of corridors involved	One Corridor — Route 1, Richmond Hwy, Fairfax County
Number of intersections equipped	25
Number of buses equipped	6 buses in first contract. 6 buses in second contract including REX Also, emergency vehicles equipped at the three firehouses serving U.S. Route 1.
Do you use conditional or unconditional priority?	Signal priority is not dependent on the bus lateness. Green extension is given only if priority is requested in the last 10 seconds of the phase. Capacity, schedule, etc. are not considered. Plans are to convert system to a GPS/AVL/bus schedule system so that priority will only be requested when buses are actually behind schedule.
Is the system centralized or decentralized?	Decentralized
What is the PRG/detection technology?	Optical. 3M Opticom system.
What is the communications technology?	Optical signal, strobe (EMS)/Infrared (bus). We have leased line communication to each intersection; however, data/information from the phase selectors is not transmitted. Data from the phase selector is not communicated to the controller and thus not collected centrally. Data can be printed out on a laptop with the appropriate software. This is a very simple system. The bus must place the request at end of cycle during last 10 seconds. The call will extend the green 10 seconds more.
Is the system integrated with AVL?	Not yet, but it is planned for the future.
What strategies are used? (Early green, green extension, phase hold, etc.)	Green extension (bus); green extension and red truncation (emergency)

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A3.8 CASE STUDY – VIRGINIA - ROUTE 1

Is TSP integrated with EMS pre-emption?

Yes. EMS pre-emption typically called Pre-emption. The order in which pre-emption is granted is: Railroad #1, Emergency Pre-emption #2 (hardwired or remote), Bus priority #3. If two requests of same priority level are made, the first is granted and the second is denied.

PLANNING

What sparked an interest in TSP implementation?

Emergency vehicle pre-emption was the original impetus. Before this, pre-emption occurred only at isolated intersections through Fairfax County, not on a corridor. At the request of FCDOT, ITS funds were appropriated for this study. Bus priority was added after the first phase began due to the recent interest and advancement in priority technology.

Who is the lead agency?

Fairfax County. VDOT is an integral partner. Virginia Tech was responsible for procurement and evaluation.

What were the stated goals?

The goal was to determine whether TSP would be beneficial and whether there would be any adverse impacts.

The RFP describes exactly what green extension is and limits the signal priority to this type of service and no other. In addition, it specifically states emergency pre-emption shall be an "unconditional" green interval. The transit vehicle shall be provided a "conditional" green interval…

The underlying goal, essentially the reason for installation and the stated goal for Virginia Tech's evaluation was "To Improve Emergency Vehicle and Transit vehicle travel time, and to increase safety along U.S. Route 1." Virginia Tech then evaluated the system's performance to determine if there was a detrimental impact on traffic, either on side street or mainline. Any ill-effects were noted.

Part of the impetus of the study was a desire by VDOT to have some documentation that corridor operation was not unduly impacted by pre-emption or priority requests. Initial Va. Tech study revealed that there was minimal negative consequence to side-street traffic (i.e. queues cleared next green phase). In addition, there was a slight reduction in bus operating time although it was hard to gauge this over just six intersections, hence the decision to expand the study from 6 to 25 intersections.

Who are the players/partners?

Fairfax County DOT, Fairfax County Fire and Rescue, Fairfax Connector, WMATA, Virginia Tech, Virginia DOT

A3.8 CASE STUDY – VIRGINIA - ROUTE 1

How did you choose a corridor(s)?

The area was a perfect test site due to the number of bus routes: 3 basic (fixed route, local service), and now several express routes (Richmond Highway Express bus service (REX)), and the number of Fire houses. One fire house was within the system boundaries for first test and a second one was included for the second part. Also, Route 1 had been the specific target for Fire & Rescue for years for signal pre-emption. Fairfax County requested inclusion of Route 1 for funding through the ITS Management and Operations Technical Committee of COG.

First 6 intersections were equipped for pre-emption and then priority for buses was added later. It took about a year to get all the study information together and to get funding moving. The additional 19 intersections were for transit priority only – not for pre-emption. One reason for extending the corridor 19 more intersections was that VA TECH thought the corridor needed to be longer to get any transit improvement.

How did you choose intersections?

Proximity to fire house. Proximity to each other. The first six intersections (North Kings to Collard/Popkins) are in the vicinity of Fire House (#11) and are very close to each other. The distance between North Kings and the next intersection north on Rt. 1 is long and platoons break down. The distance between Collard/Popkins and the next intersection south is also very long. As for priority, there were existing Connector and Metro bus routes along U.S. Route 1.

What technology do you use?

The first contract was technology independent. However, the RFP requested security features and other requirements that precluded many bidders. The system had to be optical-compatible. 3M Opticom was the only respondent to the RFP.

Fairfax County had requested that an optical based system be specified as there was already 3M Opticom in use through other areas of the County.

How did you choose the technology?

The technology choice was determined based on the bids submitted. The technology was governed by the use of existing optically based equipment.

Did you use any simulation or modeling?

Virginia tech was responsible for the pre-installation and post-installation analysis.

The purpose of the study was for simulation of results. VA TECH used VISSIM to see what would happen on the corridor.

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A3.8 CASE STUDY – VIRGINIA - ROUTE 1

What were the technical obstacles?

Controller software. We had to wait over a year for our 170E Controller firmware revision to allow green extension signal priority.

VDOT was very cooperative in getting the software modified (which was a part of a larger VDOT modification of software on other uses). Another current problem is the coding of emitters for the new version of emitter software (which identifies vehicles as being from Fairfax County.)

How did you overcome them?

See above. We tested several revisions from our software vendor, BiTrans, before finally accepting the currently installed version.

What were the institutional barriers?

System ownership and maintenance (VDOT vs. Fairfax County) is a problem. Also internal Fairfax County logistics since two departments (EMS and Fairfax DOT) are now sharing the same equipment).

How did you overcome them?

Ongoing. System maintenance issues continue to be a topic of discussion.

What is/was the training program for bus operators?

No formal training.

What is/was the training program for signal technicians?

We received training from 3M. The purpose of the training was to identify problems with the equipment and also diagnose whether a problem is caused by the pre-emption equipment or VDOT's controller. The VDOT repair shop did extensive testing of the 3M unit to confirm compatibility with our controller and our conflict monitors. This in-depth testing provided a great opportunity to learn the functionality of the 3M unit.

FUNDING

How was the project funded?

ITS funding through COG (see above).

What was the cost of project implementation?

Equipment for 25 intersections and 12 buses was approximately $220,000 (including installation).

IMPLEMENTATION

What is the extent of implementations: number of corridors, routes, streets, intersections?

So far, one corridor and 25 intersections have Bus Priority technology. There are approximately 35 other isolated intersections in Fairfax County that utilize the 3M Opticom system for emergency vehicles only.

A3.8 CASE STUDY – VIRGINIA - ROUTE 1

How were tasks assigned for implementation?

Based on logical responsibility. VDOT took the lead to test the compatibility with our controllers since we serve as the actual vendors of our control boxes and controllers. VDOT also coordinated with Virginia Tech to manage the construction, evaluation, and system testing schedule. VDOT technicians and engineers performed the system testing. Virginia Tech procured the equipment and performed evaluation; however, VDOT downloaded the logs from the phase selectors.

What kinds of controllers?

170E controller. BiTrans 233 software modified for use in Northern Virginia.

Was there a test phase?

Yes. The contractor was required to verify operation of all equipment before pre-emption/priority activated.

Under what circumstance(s) is TSP used? (For late buses, all buses, express buses, etc.)

All buses. (Now included express (REX) buses)

Are bus turning movements considered/impacted?

No. The buses only get green extension of the through movement phase.

Queue-jumping may be considered in future as part of the U.S. Route 1 highway and transit development projects.

What is the policy concerning near side and far side stops?

Far side bus stops are encouraged for TSP intersections. However, most bus stops now are near side. Bus stop location is under consideration in a separate Fairfax County Bus Stop Inventory Study. Right now there is no policy in place. Currently queue jumping is not used.

To what extent was updating, installing and/or replacing signal equipment required?

The controllers did not have to be replaced. However, all controllers required a software update. When signal controller software firmware is updated, it requires an on-site installation. The intersection is put into a flash condition, and the software upload/download is performed. Then an extensive in-field test is performed to confirm field functionality, communication to central system, conflict monitor performance, etc.

Who paid for controller equipment installation and upgrades?

VDOT

How do you ensure that TSP is working on the equipment at the intersection?

There is shop testing at the beginning of the installation. But there is no communications back to the traffic center except under some very specific circumstances. These circumstances include instances in which there is a pre-emption request or a priority request that occurs at a specific time in the signal cycle. The "phase selector log" logs everything at the controller. However, no one gathers the logs because it is time consuming and not a high priority. To capture the log one must take a laptop to the site and download the log. Also, periodic test runs can be conducted by emergency vehicles.

A3.8 CASE STUDY – VIRGINIA - ROUTE 1

How do you ensure that TSP is working on the vehicles?	There is a confirmation light that comes on when the pre-emption/priority is activated (installed on the additional 19 intersections). If the light does not come on, Fire and Rescue will report it.
Was the project publicized?	Yes, most specifically as part of the REX Express bus system which began in September 2004.
What data do you collect?	VDOT collects no data although logs are automatically retained at the signal location. Virginia Tech used the logs during the evaluation period. No additional post-evaluation log downloads are performed.
How is the data used?	Early in implementation we looked at the logs to determine if the system was working and what vehicles were using the system. Virginia Tech is compiling the results of their study.

MAINTENANCE

What are your maintenance agreements?	Currently being discussed.
Was in the cost of maintenance?	Currently being discussed with Fairfax County.
How is the system monitored?	The system cannot be monitored remotely due to communication constraints. Call-in reports.
How do you optimize/adjust the system?	Adjustments need to be made on site.

EVALUATION

What Measures of Effectiveness do you use?	Queue. Number of cycles to clear a queue before/after. Queue on mainline. Delay to vehicles. Reduction in accidents. Travel time of emergency vehicles through specific section of Rt. 1. Reduction in travel time for buses a plus. Travel time for buses. Reduced accidents. Added emergency responder confidence.
What are the benefits?	The VA TECH study looked at side street delays for pre-emption only. Now they are looking at side street delays for priority as well.

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A3.8 CASE STUDY – VIRGINIA - ROUTE 1

What complaints have you received?

Little to none from traveling public.

What is the impact to non-priority street traffic?

This response concerns pre-emption only. The impact of transit signal priority has not been analyzed yet.

The difference in delay or the additional delay is small. Example, without pre-emption being granted, sometimes it would take 2 cycles for a queue to clear anyway. One impact noted was when multiple emergency vehicles responded to a call. The headway between the vehicles was such that as each pre-emption was granted and the transition back to coordination was occurring, the second or third or fourth emergency vehicle would request pre-emption. In this scenario an impact on side street traffic was more noticeable. Also the impact on the mainline could be noticed during peak hours.

What has been the overall public reaction/response?

Board of Supervisors very pleased. Also has gotten the attention of congressional legislators.

How do you maintain on-going communication among partners?

Phone conversations between VDOT, FCDOT, Fire & Rescue, and/or Transit

LESSONS LEARNED and KEYS TO SUCCESS

What were the greatest obstacles overall?

A major hurdle was the modification to the controller firmware. Also, the institutional issues associated with VDOT and Virginia Government in general have contributed to cause a delay in deployment because of the denial of maintenance responsibility.

The biggest obstacles were obtaining funding (sought for years), and the issue of implementing corridor pre-emption without an official study.

Deployment or installation problems?

System functions fine. However, the codes for the buses have been programmed incorrectly a few times.

What do you feel were the keys to success?

Keep moving ahead despite the obstacles. Communication.

How long did the various phases take: planning? procurement? deployment?

Planning – no formal planning period.
Procurement: Maybe 1 year.
Deployment: Only a few months, with several months dedicated to evaluation. The project could or should have been completed much earlier; however, the controller firmware upgrade delayed the project extensively. Working partnership with VDOT.

A3.8 CASE STUDY – VIRGINIA - ROUTE 1

If you were starting from scratch, what technology would use you and why?

Same technology. However, we would like to have communication to the devices. We would like phase selector information then we would know when priority was granted. Would like to make the priority more conditional. In the future, any advanced priority system will require updated communications and severe upgrades the controller firmware and most likely new controllers.

If you were starting from scratch, what would be your planning strategy?

First we would lay the foundation with a concept of operations that defines the project philosophy. We would get all major parties to understand the need for TSP. We would talk with all partners and (assuming we have funding) we would set up a pilot and not force it on anyone. This would help break down resistance. One always needs a political champion. Once the system is proven it is much easier to expand it.

One should know your goal in terms of technology. Some consultants are ten years behind in their technology and so the buyer needs to know the capability of technology.

What are your future plans for TSP implementation?

All Connector buses to be equipped with emitters. Pending success of U.S. Route 1 study, expansion to other corridors in Fairfax County.

What are their expectation with respect to NTCIP/TCIP TSP standards?

I would expect future modifications and upgrades to the signal system and the traffic management system in Northern Virginia in general will require updated standards.

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TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

The following survey forms were used during the months of June and July 2004 to conduct phone interviews with transit agency and traffic engineering personnel in areas in the United States and Canada where Transit Signal Priority (TSP) and emergency vehicle pre-emption systems are operational. The interviews were conducted in order to identify, inventory and classify TSP and emergency vehicle pre-emption systems currently in operation in the United States and Canada. In the cases where contact was not possible by telephone, the survey was emailed to the appropriate personnel for completion

The following transit systems or municipalities were surveyed:

Alameda-Contra-Costa Transit District
Ben Franklin Transit
Calgary Transit
Central Florida Regional Transportation Authority (LYNX)
City of Glendale
Charlotte Area Transit
Houston Metropolitan Transit Authority
Illinois DOT (Regional Transit Authority) (RTA)
Jefferson Transit Authority (Port Townsend, WA)
King County Metro
LA County Metropolitan Transportation Authority
Metropolitan Transit (Minneapolis, MN)
City of Ottawa
PACE Suburban Bus Service
Pierce Transit
Port Authority of Allegheny County
Sacramento Regional Transit District
Santa Clara Valley Transportation Authority (VTA)
Skagit Transit
Southeastern Pennsylvania Transportation Authority (SEPTA)
St. Cloud Metropolitan Transit Commission
Tri-County Metropolitan Transit District (TriMet)
Utah Transit Authority
Washington Metropolitan Transit Authority(WMATA)

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Alameda-Contra-Costa Transit District

City, State:
Oakland, CA

Contact:
Jon Twichell,
Transportation Planning Manager,
(510) 891-4801
jtwichell@actransit.org
http://www.smartcorridors.com

Background

Type of Transit:
Rapid Bus (1st Level BRT)

Date of implementation:
June 2003

Number of routes:1
Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
BRT

Number of signalized intersections:
62

Mixed flow or exclusive ROW:
Mixed flow on city streets.

Number of lanes:
4-lane arterials (2 lanes each direction)

Headways:
12 minute peak period headways.

Signal Controls

Centralized/Decentralized:
Centralized. Half of the signals are controlled by CalTrans and half are controlled by the Alameda County Congestion Management Agency.

Fixed/Actuated:
Actuated

Hardware:
Type 170 controllers

Software:
BiTran software for local portion of corridor. Caltrans C-8 software for CalTrans portion of corridor.

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used
Green Extension
Early Green (Red Truncation)

Additional Comments
There are two published documents available regarding TSP - one discussing the Pilot Study and one that highlights the Deployment Study. For this project, most of the hardware was already in place, however approximately 30 intersections had no pre-emption equipment. New controllers were later purchased and installed at these locations.

A memorandum of understanding proved to be an effective tool in the success of the TSP implementation.

After the implementation of TSP, the San Pablo Rapid bus service experienced an 18% reduction in total travel time and an increase in ridership by 22%. It should be noted that other factors other than TSP could have influenced these travel time and ridership changes.

Next Steps

The "International Telegraph Corridor" is a 19-mile route that is currently being planned and is scheduled to open during the Summer of 2006.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Ben Franklin Transit

City, State:
Richland, WA

Contact:
Barbara Hays
Pete Beaudry
(509) 585-4249 (City of Kennewick)
(509) 735-4131
bhays@bft.org
John Deskins
(509) 585- 4400 (Traffic Engineer)

Background

Type of Transit:
Bus

Date of implementation:
1995

Number of routes:
Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Route is in the regular flow of traffic.

Number of signalized intersections:
31

Near Side / Far Side Stops:
Approximately 11 far side stops

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
Two lanes in each direction of travel with a shared center turn lane along the majority of the corridor

Headways:
30 minutes

Signal Contols

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
Actuated

Hardware:
Econolite ASC/2S (NEMA TS-2, Type I)

Software:
NEMA proprietary software

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Green Extension
Early Green (Red Truncation)

Additional Comments

TSP is only used in the City of Kennewick and is only used when buses are running behind schedule.

Next Steps

Planning expansion to the City of Richland

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Calgary Transit

City, State:
Calgary, Alberta, Canada

Contact:
Neil McKendrick
Hamid Radmanesh
(403) 268-1501
(403) 537-7727, (403) 268-2180
neil.mckendrick@calgary.ca
http://www.calgarytransit.com

Background

Type of Transit: Bus and LRT

Date of implementation:
September 2000

Number of routes: 7

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Route 3 service operates 18 hours per day, 7 days per week on major 4 lane arterial roads and within the downtown. Stop spacing every 300 feet. North express routes - Limited stop express service from north Calgary to and from the downtown during weekday peak periods.

Number of signalized intersections:
50 outside of the downtown (Route 3 corridor). 17 signals along the express routes

Near Side / Far Side Stops:
Far side (transit policy for all stops to be far side)

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
4

Headways:
5 minute (peak), 10 minute (weekday midday), 15- 20 minutes (evenings and weekends.) Express routes include 4+ trips for each route during peak periods

Signal Controls

Centralized/Decentralized:
Both centralized and decentralized controllers are used. The inner third of traffic signals operate via the central traffic center control. This was developed by PB Farradyne and is referred to as Management Information System for Traffic (MIST).

Fixed/Actuated:
Both fixed and actuated signals exist

Hardware:
NEMA LMD9200 controllers by Peak Traffic Control Systems

Software:
Proprietary software provided by controller manufacturer (Peak Traffic)

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Green Extension (up to 20 seconds). Early Green (Red Truncation) (up to 20 seconds)

Additional Comments

Optical (Opticom) detection systems are also being installed for the Calgary Fire Department along key response routes. All Opticom installations will provide dual priority - Fire vehicles receive higher priority (preemption) than transit vehicles, which receive transit signal priority. Work also done to favor LRT operation in the downtown (optimized signals). In suburban Calgary, LRT preempts traffic signals with protected gate arms at roadway crossings.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Central Florida Regional Transportation Authority (LYNX)

City, State:
Orlando, FL

Contact:
Doug Jamison

Chris Kibler
(407) 841-2279 x3071
(407) 246-2334
djamison@golynx.com
chris.kibler@cityoforlando.net

Background

Type of Transit: Bus

Date of implementation: 1997

Number of routes:
1 route (10 buses) (TSP route is called "Lymmo")

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Functions as a BRT service. Single lane, 1.5 mile loop that runs parallel to traffic and stops at major destinations within the City.

Number of signalized intersections:
19 signals along the route that have TSP capabilities.

Near Side / Far Side Stops:
Mandatory bus stops, 19 stops in total. Stops are a mix of near and far side.

Mixed flow or exclusive ROW:
Operates along exclusive right-of-way

Number of lanes:
1

Headways:
5 min peak/10-15 min off-peak & weekends

Centralized/Decentralized:
Originally operated as a centralized system, but now runs decentralized.

Fixed/Actuated:
Actuated

Hardware:
Naztec – NEMA controllers (model 980)

Software:
Naztec "Streetwise" proprietary software

Vehicle Detection Type:
Loop Detection

TSP Strategies Used

Signal pre-emption.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
City of Glendale

City, State:
Glendale, CA

Contact:
Wayne Ko
(818) 548-3960 x8360
wko@ci.glendale.ca.us

Background
Type of Transit:
"Beeline" Bus

Date of implementation:
2001

Number of routes:
1

Physical Characteristics

General description of route:(geo-metrics, exclusive bus lanes, left turn lanes)
Approximately 3-mile route, consisting mostly of downtown arterials

Number of signalized intersections:
17

Near Side / Far Side Stops:
Relocating existing near side stops to far side

Mixed flow or exclusive ROW:
Mixed Flow

Number of lanes:
4-lanes (2 each direction) with a center shared turn lane

Headways:
N/A

Signal Controls

Centralized/Decentralized:
Centralized system using the QuicNet4 system from Bi-Tran

Hardware:
Type 170

Software:
Bi-Tran 233 (modified for TSP)

Vehicle Detection Type:
GPS NextBus system

TSP Strategies Used

Green Extension
Early Green (Red Truncation)

Additional Comments

Information is sent to the control center where comparisons are made between the actual arrival time and the scheduled time. If the bus is running on schedule then signal priority is not requested.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Charlotte Area Transit

City, State:
Charlotte, NC

Contact:
William Finger, Charlotte DOT
(704) 336-3893
wfinger@ci.charlotte.nc.us

Background

Type of Transit:
Express Bus

Date of implementation:
1985 – 1998

Number of routes:
1

Physical Characteristics

General description of route:(geometrics, exclusive bus lanes, left turn lanes)
3-Mile corridor. Exclusive bus lanes in conjunction with left turn lanes. "Closed Door" express peak-hour service. Inbound service during AM peak; outbound service during PM peak.

Number of signalized intersections:
17

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
4-lane arterials

Near or far side stops
No stops (express service)

Headways:
Varies, 5 minutes to 20-30 minutes

Signal Controls

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
Fully actuated

Hardware:
Traconex 390 NEMA Type-I

Software:
Low-level pre-emption included with the NEMA controller (proprietary)

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Pre-emption only

The green time is truncated on the priority street to prevent vehicles from trying to ride behind the buses.

Additional Comments

This service was planned in anticipation of an HOV lane and was very successful. The service is now in 2-way operation on an incomplete barrier-separated reversible HOV facility.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Houston Metropolitan Transit Authority

City, State:
Houston, TX

Contact:
Lloyd Smith/John Olson
(713) 615-6305 / (713) 615-6309
LS03@ridemetro.org
jolson@ridemetro.org
http://www.ridemetro.org

Background

Type of Transit:
Bus and LRT

Date of implementation:
Bus system under construction as of June 2004. LRT system operational January 1, 2004.

Number of routes:
1 LRT Line (8 mile corridor)

90 local and express routes for buses (TSP is not used on point-to-point commuter bus routes using motor coaches traveling primarily on freeways.)

Physical Characteristics (per route)

General description of route:(geometrics, exclusive bus lanes, left turn lanes)
Bus Routes: Variety of arterial mixed traffic lanes located outside the Central Business District. (In the CBD and along six radial freeways, buses use exclusive bus lanes and HOV lanes within the ROW.)

Generally near side stops for bus, though some far side.

Light Rail Corridor: Arterial streets through three major activity centers: downtown, Texas Medical Center, Reliant stadium

Number of signalized intersections:
1,500 for bus, 63 for LRT

Mixed flow or exclusive ROW:
Bus Route: Mixed flow

Light Rail Corridor: Predominately semi-exclusive ROW adjacent to roadway with at-grade street crossings. Three-block section is separated by fences or barriers from the adjacent traffic lane, which is opened to pedestrian traffic for scheduled events. One ? mile section has trains operating in mixed traffic with left turn lanes shared by trains and traffic.

Number of lanes:
Varies

Headways:
Bus headways vary widely based on route and time of day (peak/off-peak).LRT headways vary between 6 minutes during peak periods and 12, 15 and 18 minutes during off-peak periods.

Signal Controls

Centralized/Decentralized
System is hardwired into signals along route, which are connected to each other and central computer via Ethernet.

Fixed/Actuated:
Actuated

Hardware:
Type 2070 controllers with wireless communications to central communications center

Software:
NextPhase by Siemens ITS

Vehicle Detection Type:
Bus detection: Optical (3M Opticom).

Light Rail: TWC system supplied by Siemens Transportation

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

TSP Strategies Used

Bus: Conditional Priority - buses contain GPS, stored route maps and time tables.

Only contacts upcoming signal if bus falls behind schedule by several minutes.

LRT: utilizes a predictive priority methodology instead of pre-emption. Trains run on green band through corridor; contacts upcoming signals if falls out of band; all red needed at times to prevent conflicts. (Nine gated crossings use railroad pre-emption due to roadway geometry or rail speeds.)

Additional Comments

Currently conducting testing for bus TSP system to optimize operations.

LRT results are mixed so far – working well when stays near established green band, but not as efficient when gets far off band.

Next Steps

Completion of roadway TSP system late 2004, bus TSP installation in 2005.

- Article on VISSIM analysis for LRT system in November 2002 issue of ITE Journal.
- Preliminary planning for a limited number of BRT / premium routes is underway.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Illinois DOT (Regional Transit Authority) (RTA)

City, State:
Chicago, IL

Contact:
Duana Love, PE
(312) 913-3248
loved@rtachicago.org
http://www.rtachicago.org

Background

Type of Transit:
Bus

Date of implementation:
2003

Number of routes:
17

Physical Characteristics
General description of route: (geometrics, exclusive bus lanes, left turn lanes)

Number of signalized intersections:
84

Mixed flow or exclusive ROW:
Mixed Flow

Number of lanes:
Headways:

Signal Controls

Centralized/Decentralized:
Both centralized and decentralized routes exist.

Hardware:
Econolite ASC/2, Eagle EPAC 300, Type 2070 controllers, PEEK LMD40

Software:
NEMA proprietary software; Type 2070 controller firmware

TSP Strategies Used

Early Green (Red Truncation)

Green Extension

Conditional priority is used, where requests are made only when buses are operating behind schedule.

Additional Comments

Some information derived from the "Regional Signal Priority Location Study – Phase II, Model Simulation" and the "TSP Implementation Plan".

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Jefferson Transit Authority

City, State:
Port Townsend, WA

Contact:
Curtis Stacey
(360) 385-3020
cstacey@jeffersontransit.com

Background

Type of Transit:
Bus

Date of implementation:
1996/97

Number of routes:
N/A

Physical Characteristics
General description of route: (geometrics, exclusive bus lanes, left turn lanes) TSP is implemented on 2 traffic signals to facilitate left turns out of the Park-n-Ride lot.

Number of signalized intersections:
2

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
4

Headways:
Varies- 20 minutes to 2 hours

Signal Controls

Centralized/Decentralized:
Decentralized

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Phase insertion is used to accommodate heavy left turn movement out of the Park-n-Ride lot.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
King County Metro

City, State:
Seattle, WA and vicinity

Contact:
Ron Atherley
(206) 263-4954

Background

Type of Transit:
Bus - 40' and 60' articulated rubber tire diesel buses; Electric trolley

Date of implementation:
1999

Number of routes:
Multiple

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Varies

Number of signalized intersections:
Currently 26, with plans for expansion

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
Varies

Near or far side bus stops:
Far side

Headways:
Varies from 7-15 minute

Signal Controls

Centralized/Decentralized:
Decentralized (closed loop)– local controller software provide priority response. Working with Computran central traffic system in Bellevue – needs software enhancements

Fixed/Actuated:
Actuated and semi-actuated

Hardware:
Controller Types vary (NEMA: Eagle, Econolite and Peek; and Type 2070)

Software:
King County/McCain Traffic RF Transit Priority Request (TPR system) – with local TPRG software and central TPR system software

NextPhase

Vehicle Detection Type:
Radio Frequency RF 900 MHz

TSP Strategies Used
Green Extension
Early Green (Red Truncation)

Additional Comments
The results of TSP implemented along the portion of Route 7 has reduced travel times by approximately 8%.

Next Steps

Working on central TSP applications with Eagle (Actra) and Econolite (icons)

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
LA County Metropolitan Transportation Authority

City, State:
Los Angeles, CA

Contact:
Sean Skehan
(213) 977-7845
sskehan@dot.lacity.org

Background

Type of Transit:
LRT

Bus

Date of implementation:
Since 1990

2000

Number of routes:
2 LRT lines

8 routes totaling approximately 100 miles

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
LRT service operates on exclusive ROW

The bus service is a cross-county route operating within three different agencies. All service operates on major arterials, mostly 4-lane.

Number of signalized intersections:
20

The system includes approximately 400 intersections

Mixed flow or exclusive ROW:
Exclusive ROW

Mixed flow

Number of lanes:
N/A

Typical section of roadway varies, operates primarily on 4-lane arterials.

Near or Far Side Stops:
N/A

Mainly far side stops, near side stops are used only when far side is not possible.

Headways:
5 minute peak period headways

20 minute off-peak headways

90 second headways on the heaviest route during the peak period

20 minute headways on the lightest off-peak route.

Average headways are approximately 5 minutes

Signal Controls

Centralized/Decentralized:
Centralized

Fixed/Actuated:
Fixed in the central business district (CBD)

Actuated outside the CBD

Hardware:
Exclusively uses 2070 controllers on the LRT lines and all intersections using TSP

Software:
Custom design – City of Los Angeles Software

Vehicle Detection Type:
Loop-based system with transponders on the buses.

TSP Strategies Used

Early Green (Red Truncation)
Green Extension
Phase Insertion

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Metropolitan Transit

City, State:
Minneapolis, MN

Contact:
Aaron Isaacs
(612) 349-7690
Aaron.isaacs@metc.state.mn.us

Background

Type of Transit:
Hiawathath Light Rail Line: LRT service with 12 stations

Minnesota – St. Paul Campus Shuttle:

3-mile shuttle bus operation between both campuses

Lake Street Demonstration Project (bus)

Date of implementation:
Hiawatha Light Rail Line planned to open June 26, 2004

Number of routes: 3

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Hiawatha LRT runs along its own ROW throughout the line and within the downtown operates as a rail-type priority with signal pre-emption.

Number of signalized intersections:
The campus shuttle includes 2 signals along the 3-mile route. The remaining intersections along the route are unsignalized. The Lake Street Demonstration project includes 20 signalized intersections.

Mixed flow or exclusive ROW:
The Hiawatha Line operates exclusively on its own ROW. The bus systems operate in mixed traffic.

Number of lanes:
The Hiawatha Line runs on its dedicated lane and in some locations operates within the median.

The campus shuttle runs typically along 2-lane arterials.

Headways:
The Hiawatha Line operates on a 7-1/2 minute headway during the peak hour and a 10 minute headway during the midday and Saturdays. During the off-peak and on Sundays, this service assumes a 15-minute headway.

The campus shuttle runs on a 5 minute headway on weekdays during school hours.

Signal Controls

Vehicle Detection Type:
Optical and Loop detectors

TSP Strategies Used

Both services utilize signal pre-emption as their strategy.

Additional CommentsProblem with optical bus detection system triggering the emergency vehicle pre-emption systems.

Next Steps

Currently coordinating with the University of Minnesota's Center for Transportation Studies in developing a GPS-based vehicle identification system.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
City of Ottawa

City, State:
Ottawa, Ontario, Canada

Contact:
Kornel Mucsi
(613) 580 2424 x 23032
kornel.mucsi@ottawa.ca

Background

Type of Transit:
Bus

Date of implementation:
1990s

Number of routes:
See notes below

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Mixed

Number of signalized intersections:
40

Near Side / Far Side Stops:
mixed

Mixed flow or exclusive ROW:
Mixed flow with exclusive bus lanes for queue jump at certain intersections.

Number of lanes:
varies

Headways:
varies

Signal Controls

Centralized/Decentralized:
Centralized

Fixed/Actuated:
Both.

Hardware:
Enhanced Type 170 Controllers

Software:
Developed in house with a number of TSP capabilities: extension/truncation for coordinated and actuated phases, phase insertion, queue jump phases

Vehicle Detection Type:
Double loop and single loop in exclusive bus lanes

TSP Strategies Used

The focus of transit priority is on congested locations. TSP is an element of a wider transit priority approach. The primary objective is to eliminate or reduce congestion delay to buses, and the secondary objective is to reduce or eliminate signal delay.

Congestion delay is reduced by bus lanes and queue jumps with or without signal priority. There are queue jumps on arterials for straight through movement and queue jumps at "T" intersections for the left turn movement.

In corridors with a large number of buses there is passive signal priority. There are intersections with actuated transit phases, truncation/extension on the actuated phase, half cycle lengths, two transit actuated phases within the same cycle. There is one intersection with a bus actuated "pedestrian signal".

Future plans: Improved bus detection, extension and truncation on the coordinated phase

Several different TSP strategies are used for key locations along bus routes. The focus is to improve the most congested locations instead of focusing on specific bus routes.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Queue jump strategy for buses on the main street. Four intersections operational and four under construction. Various geometric designs.

T-intersection queue jumps. Buses arriving on side street to the main arterial and making left turn onto arterial street have queue jumps. Queue jumps exist for signalized and unsignalized intersections. One T-signalized intersection operational and two under construction and three unsignalized intersections operational. A bus arriving on the side street receives high level priority (but lower priority level then emergency vehicle pre-emption). This TSP strategy does not include phase skipping capabilities. Implemented on 15 intersections throughout city.

A number of locations have left turn phase insertion. Left turn can be activated as a lead or lag phase. Lead phase can be activated by both buses and other vehicles, while lag phase can be activated only by buses.

Intersection pedestrian signal with bus actuation is a rather rare concept. This intersection layout has a traffic light for the main arterial but the side street has no traffic light; instead it has stop signs. The main arterial always has a green light unless a pedestrian pushes the button or a bus is detected on the approach. This approach is used in one intersection.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
PACE Suburban Bus Service

City, State:
Arlington Heights, IL

Contact:
Taqhi Mohammed
(847) 228-4287
Taqhi.Mohammed@PaceBus.com
http://www.pacebus.com

Background

Type of Transit:
Bus

Date of implementation:
1985

Number of routes:
4 routes along one corridor

Physical Characteristics

General description of route:(geometrics, exclusive bus lanes, left turn lanes)
Linear corridor; Demonstration project

Number of signalized intersections:
12

Mixed flow or exclusive ROW:
Mixed Flow

Number of lanes:
N/A

Near or far side bus stops:
N/A

Headways:
N/A

Signal Controls

Centralized/Decentralized:
N/A

Fixed/Actuated:
N/A

Hardware:
NEMA ASC-2 controllers by Econolite

Software:
N/A

Vehicle Detection Type:
LoopComm vehicle identification system

TSP Strategies Used

Early Green (Red Truncation)
Green Extension

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Pierce Transit

City, State:
Tacoma, Washington

Contact:
Eric Phillips
(253) 983-2721

Background

Type of Transit: Bus

Date of implementation: 2002

Number of routes: 6

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
All routes are corridor-based and operate along a linear route.

Number of signalized intersections:
There are 110 signalized intersections along the 6 bus routes

Mixed flow or exclusive ROW:
Currently, all buses operate within the general purpose lanes.

Number of lanes:
Typical sections range from 2-5 lanes

Near or far side bus stops:
Both near and far side bus stops exist along the corridor, although there is a preference for far side stops. Many stops have been relocated to far side of the intersection.

Headways:
15 to 30 minutes during the peak hour

Signal Controls

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
Both fixed and actuated controls are used within the corridor.

Hardware:
Traconex TMP-390 (NEMA-TS-1 controller),Econolite ASC-2 (NEMA TS-1 controller),Peek LMD 9200 (NEMA TS-1 controller) used within the majority of corridors

Software:
Various

Vehicle Detection Type:
(Optical) Opticom and Loop (LoopComm)

TSP Strategies Used

Green Extension
Early Green (Red Truncation)
Low priority preempt algorithm (LPPA with the 390 controllers)

Additional Comments

TSP has been utilized very effectively by Pierce Transit, which can be attributed in part by early coordination between jurisdictions. The transit corridor encompasses three different city governments, a county government, and a state DOT. The TSP program has not only decreased travel times among transit riders, but has improved the level of service at the intersections as well. Some problems were encountered with buses' optical detection system activating the emergency vehicle pre-emption systems outside of the TSP routes.

Next Steps

Additional implementations are planned.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Port Authority of Allegheny County

City, State:
Pittsburgh, PA

Contact:
David Wohlwill, AICP
Lead Transit Planner
(412) 566-5110
dwohlwill@portauthority.org

Background

Type of Transit:
Bus

Date of implementation:
Mid 1990's - early 2000's

Number of routes: 47

Physical Characteristics

General description of route:
(geometrics, exclusive bus lanes, left turn lanes)
Signals at four locations in downtown Pittsburgh to facilitate left turn movements for buses.

Liberty Avenue/Stanwix Street/Forbes Avenue for 3 eastern express routes

Smithfield Street and Fort Pitt Boulevard for 22 southern local and express routes most of which use the South Busway.

Liberty and Smithfield Street for11 local and express eastern routes most of which use the Martin Luther King, Jr. East Busway. This signal facilitates movements for buses entering the Smithfield Street bus lane.

Sixth Avenue and Grant Street for 9 eastern routes. (Note these 9 routes are included in the 11 routes which pass through the Liberty and Smithfield intersection).

West Busway Entrance at West Carson Street for 11 routes to allow buses entering Carson Street from the West Busway on their way to downtown Pittsburgh.

Number of signalized intersections:
5

Mixed flow or exclusive ROW:
Mixed flow at 3 intersections and exclusive ROW at 2 intersections

Number of lanes:
Liberty Avenue/Stanwix Street/Forbes Avenue: Two lanes

Smithfield Street and Fort Pitt Boulevard: Two inbound lanes on Smithfield Street Bridge, three inbound lanes on Fort Pitt Boulevard; buses use one lane.

Liberty and Smithfield Street: Two travel lanes and one left turn lane on Liberty Avenue and one lane on Smithfield Street.

Sixth Avenue and Grant Street: Two outbound lanes on Sixth Avenue, two outbound lanes on Grant Street.

West Busway Entrance at West Carson Street: One lane in each direction on West Busway and two lanes in each direction on West Carson Street.

Near/Far Side Stops:
Both near and far-side stops are on these routes

Headways:
Smithfield Street and Fort Pitt Boulevard is the busiest intersection in terms of the number of bus movements with 58 trips during a peak hour (almost one-minute headway).

Signal Controls

Centralized/Decentralized;
Decentralized

Fixed/Actuated:
Fixed

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Hardware:
Type 170 Controllers (Safetran)

Software:
Wapiti

Vehicle Detection Type:
Standard in-pavement loop for bus use only

TSP Strategies Used

Phase insertion is used at all four intersections to prioritize heavy left turn movements in downtown Pittsburgh and at the West Busway/West Carson Street intersection to facilitate bus movements off the West Busway.

Additional Comments

City of Pittsburgh owns and operates the signals in downtown Pittsburgh.

The buses do not have equipment to activate signals.

Port Authority has three busways. Bus routes operating on all three busways benefit from the TSP applications.

Next Steps

1) Consider TSP as a component of on-street Bus Rapid Transit in Downtown to Oakland Corridor, Port Authority's most heavily traveled corridor.

2) Pursue additional opportunities for TSP in downtown Pittsburgh.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Sacramento Regional Transit District

City, State:
Sacramento, CA

Contact:
Doug Mass, PE
(916) 875-5545

Background

Type of Transit:
Bus

Dates of implementation:
2002

Number of routes:
4

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
A few exclusive bus lanes

Number of signalized intersections:
600

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
Varies between 4-6 lanes

Near or far side bus stops:
Mostly far side

Headways:
Vary

Signal Controls

Centralized/Decentralized
Centralized

Fixed/Actuated:
Actuated

Hardware:
Multisonics VMS 330 Controllers
Multisonics 820A Controllers
Type 2070 controllers

Software:
Various field controller software with
Eagle Actra central software

Vehicle Detection Type:
Inductive loops

Video at selected locations
Optical (3M Opticom)

TSP Strategies Used

Extended Green
Early Green (Red Truncation)

Additional Comments

Also provide a light rail service which was created approximately in 1989

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Santa Clara Valley Transportation Authority (VTA)

City, State:
San Mateo County, CA

Contact:
Casey Emoto
(408) 321-5744 x5564
casey.emoto@vta.org

Background

Type of Transit:
LRT

Bus

Date of implementation:
Approximately 1990

Currently in the implementation stage

Number of routes:
One main route with several extension routes added.Upon completion, the full corridor will be approximately 20 miles

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
LRT service operates on exclusive ROW

The bus service is a cross-county route operating within three different agencies.

Number of signalized intersections:
50+ TSP operation will be phased in, the first segment to include 27 signals over 6 miles.

Mixed flow or exclusive ROW:
Exclusive ROW

Mixed flow

Number of lanes:
N/A

Typical section of roadway varies, operates primarily on 4-lane arterials.

Near or Far Side Stops:
N/A

All stops are far side stops

Headways:
15 minute peak period headways

12-15 minute peak period headways

Signal Controls

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
All actuated

Hardware:
NEMA Type TS-2 controllers (McClain Vector, Naztech, Traconex)

Software:
NEMA software with external pre-emption logic controllers to perform the transit prioritization. Based on a modified version of the CALTRANS C-8 software

Vehicle Detection Type:
Loops

TSP Strategies Used

LRT
Full priority: permits the skipping of phases and the shortening of phases

Bus
Early green (Red Truncation)
Extended Green

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Skagit Transit

City, State:
Burlington, WA

Contact:
Wade Mahala
(360) 757-4433
(360)336-6217 (City of Mt. Vernon)

Ben Haigh
bhaigh@skat.org

Background

Type of Transit:
Bus

Date of implementation:
1993

Number of routes:
10

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Mainline system – usage of right hand lanes

Bus service has recently been included in DOT planning – changes TBA

Number of signalized intersections:
80

Mixed flow or exclusive ROW:
Mixed flow

Near or far side bus stops:
Near side bus stops

Headways:
1-direction headways

Deadheads located about 40 miles east of Burlington

Signal Controls

Centralized/Decentralized:
Mostly centralized

Fixed/Actuated:
Fixed

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Green Extension
Early Green (Red Truncation)

Additional Comments

Also provide a van pool service, a ride-chair service and a dial-a-ride service

APPENDICES

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Southeastern Pennsylvania Transportation Authority (SEPTA)

City, State:
Philadelphia, PA

Contact:
John Bukowski
(215) 580-7619
jbukowski@septa.org

Background

Type of Transit:
Trolley (Route 10)
Trolley (Route 15)
Bus (Route 52)

Date of implementation:
Route 10 Trolley - Late 2003
Route 15 Trolley - Late 2002
Bus (Route 52) – Late 2005

Number of routes:
2 Implemented; 1 being implemented

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Mixed flow

Number of signalized intersections:
61 current; 24 additional planned for late 2005

Mixed flow or exclusive ROW:
Mixed flow

Number of lanes:
varies

Near/Far Side Stops:
Both

Headways:
New headways to be determined. Expecting 1-2 trolley vehicles and 1 bus could be removed.

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
Both. Intersection equipment is fixed, vehicle emitter actuates the cycle.

Hardware:
Trolley routes: Type 170 Controllers
Bus: Not yet bid

Software:
Trolley: BiTran 233 software
Bus: Proprietary

Vehicle Detection Type:
Trolley: Optical.

TSP Strategies Used

Route 10 Trolley - Green Extension; Early Green (Red Truncation)

Route 15 Trolley - Green extension is the only TSP strategy being used due to minimum green requirements for pedestrian crossings.

Bus: Not yet bid

Additional Comments

Fiber Optic cable run through each location for City loop back to their Traffic Control Center.

Next Steps

Planning to go to a centralized system.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
St. Cloud Metropolitan Transit Commission

City, State:
St. Cloud, MN

Contact:
Tom Cruikshank
Director of Planning
(320) 529-4483
tcruikshank@stcloudmtc.com

Background

Type of Transit:
Bus (Fleet of 31 buses)

Date of implementation:
November 2002

Number of routes:
18

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Traditional hub and spoke design with most transfers occurring at the downtown St. Cloud Transit Center with secondary hub at St. Cloud State University.

Number of signalized intersections:
89

Mixed flow or exclusive ROW:
All buses operate in a mixed flow environment.

Number of lanes:
Routes vary from local streets to state highways

Headways:
1- hour headways off-peak and Saturday with 1/2-hour headways typical during weekday peak hours.

Signal Controls

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
Actuated

Hardware:
Econolite ASC-2S (NEMA TS-2, Type I)

Software:
Econolite customized TSP software. Initial software was based on the Cermack Road, Chicago Area, IL application and was later upgraded to current King County, WA version.

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Green Extension
Early Green (Red Truncation)

Additional Comments

There are 2 documents available regarding St. Cloud's TSP deployment; one describing a Pilot Study conducted in 2000, the other a Deployment Study in 2001. For this TSP project, most of the hardware was already in place, however 28 intersections received new 3M Opticom pre-emption equipment and 30 intersections received new Econolite ASC-2S controllers.

A Memorandum of Understanding between the MTC and local roadway jurisdictions (Two Cities, Two Counties and Mn/DOT) proved to be an effective tool in the success of the TSP implementation.

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Tri-County Metropolitan Transit District (TriMet)

City, State:
Portland, OR

Contact:
Willie Rotich
(503) 823-5382
willie.rotich@trans.ci.portland.or.us

Background

Type of Transit:

Bus

Date of implementation:
2002

Blue Line opened in 1987
Red Line opened in 2002
Yellow Line opened in 2004

Number of routes:
1

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
Three bus routes service east-west movements and the airport.

Number of signalized intersections:
Bus service includes 370 signals, however only a minority of them have TSP.

Mixed flow or exclusive ROW:
Some portion of the LRT are on dedicated ROW. The majority of the LRT and all of the bus service operates on mixed flow roadways.

Number of lanes:
Data Not Available

Near/Far Side Stops:
Data Not Available

Headways:
Data Not Available

Signal Controls

Centralized/Decentralized:
Decentralized

Fixed/Actuated:
Data Not Available

Hardware:
Type 170E Controller

Software:
Wapiti

Vehicle Detection Type:
Loops (LoopComm), Optical (3M Opticom)

TSP Strategies Used

The LRT preempts the signal via loop detectors and Vetag
Green Extension
Early Green (Red Truncation)
One intersection has queue jump

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Utah Transit Authority

City, State:
Salt Lake City, UT

Contact:
Richard Hodges
(801) 287-2354
rhodges@uta.cog.ut.us

Background

Type of Transit:
Bus

Date of implementation:
Currently being installed (Summer 2004)

Number of routes:
1 (prototype; enhancement pending)

Physical Characteristics

General description of route: (geometrics, exclusive bus lanes, left turn lanes)
High volume.

Number of signalized intersections:
12

Mixed flow or exclusive ROW:
All buses operate in a mixed flow environment.

Number of lanes:
Typically 6 lanes with a center turn lane

Headways:
Plan includes headways;
Presently: 22 min (peak), 40 min (off peak)
Future Plans: 15 min (peak), 30 min (off peak)

Signal Controls

Centralized/Decentralized:
Centralized

Fixed/Actuated:
Actuated

Hardware:
Type 2070

Software:
Central software = ICONS by Siemens

Local intersection controller software = NextPhase

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Green Extension
Early Green (Red Truncation)

Additional Comments

Light Rail uses the check in/check out system

The system is very similar to the system implemented in Los Angeles

Next Steps

TBA – pending results and observations

5-year plan includes 3 BRT lines as well as 12 priority corridors

TRANSIT SIGNAL PRIORITY (TSP) SURVEY FORM

Agency:
Washington Metropolitan Transit Authority(WMATA)

City, State:
Washington, D.C./Suburban Maryland/Northern Virginia

Contact:
Will Raine - ITS Coordinator, WMATA
(202) 962-1637
wraine@wmata.com

Glen Hazinoziski – Project Manager for Demonstration Project
Wilbur Smith Company
(703) 645-2982

Background

Type of Transit:
Bus

Date of implementation:
Currently being implemented (during Summer 2004)

Number of routes:
Four routes are being implemented as part of this demonstration project.

Physical Characteristics

Number of signalized intersections:
Depends on corridor

6 currently, 25 planned on Route 1 corridor in Fairfax County

Near Side / Far Side Stops:
Data Not Available

Mixed flow or exclusive ROW:
Mixed Flow

Number of lanes:
Data Not Available

Headways:
Data Not Available

Signal Controls

Centralized/Decentralized:
Centralized

Decentralized on Georgia Avenue and Route 1. The demonstration project will communicate with the traffic center in Arlington, VA via a Remote Data Management System (RDMS)

Fixed/Actuated:
Fixed

Hardware:
NEMA TS-2 (Eagle EPAC 300)

Software:
SCOOT Adaptive Control Software being customized as part of this demonstration project by Siemens

BiTrans on Georgia Avenue

Vehicle Detection Type:
Optical (3M Opticom)

TSP Strategies Used

Green Extension
Early Green (Red Truncation)

Additional Comments

WMATA is implementing TSP along four major corridors in the metropolitan Washington region as part of a demonstration project with 3M, Siemens and The Wilbur Smith Company. The corridors include Georgia Ave., Columbia Pike, and the Route 1 Corridor.

The projects are still underway, installation of the emitters may start as early as September 2004 along the Columbia Pike Corridor.

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