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Executive Summary

Transit signal priority (TSP) is a combination of technologies employed by transit and traffic signal operating agencies to adjust signal timing to prioritize the movement of people. TSP offers transportation agencies a cost-effective means to reduce transit delay, improve service reliability, and provide benefits to non-transit road users. The capital costs of signal priority are modest compared with the lifetime savings associated with its implementation, and transit agency operating cost savings often exceed up-front capital costs altogether. Moreover, there are several unquantifiable savings associated with TSP deployment including reduced pavement wear, fewer emissions, and lower vehicle maintenance costs associated with the elimination of stops at signalized intersections.

The Institute of Transportation Engineers (ITE) entered into a cooperative agreement with the Federal Transit Administration (FTA) in 2011 aimed at improving the integration of transit priority treatments on urban street networks. In partnership with the American Public Transportation Association (APTA), two workshops with local practitioners and leading experts were facilitated to share experiences and lessons learned, identify barriers, and recommend potential solutions. The workshops (in Fort Worth, TX and Atlanta, GA) were specifically targeted at identifying successful partnerships between transit and traffic engineering professionals that have resulted in improved integration of transit operations and traffic control strategies. The following white paper summarizes the issues that were discussed and input that was received.

The intent of this white paper is to highlight several barriers associated with the implementation and maintenance of TSP systems. Three case studies are used to describe the limitations of existing systems. First, the example of Portland, OR is used to describe limitations of a pre-connected vehicle implementation. This was also a system described in both workshops to identify current practice. The second example includes a recently developed system for light rail transit in Dallas, TX. This case study highlights the success of developing a system as well as key decisions that limit potential opportunities for future growth and more intense integration. Finally, recent efforts in the Atlanta, GA region are considered as another state of the practice assessment that shows promise.

While each of these communities has lessons learned, widespread implementation of effective transit signal priority applications has been limited by the reluctance of agencies to invest in technology that works cooperatively between transit and traffic systems. This white paper describes partnerships between transit and traffic engineering professionals that have helped identify and overcome technical and policy-related limitations to implementation.

Further examples are used to highlight integration possibilities between transit and the connected vehicle (CV) technology platform, allowing for growth, expandability, and incorporation of newly evolving technologies to make TSP more effective and easier to maintain. Early adopters of connected vehicle technology provide unique lessons for the industry. These agencies have combined partnerships with technological innovation to yield transit signal priority that can be further expanded within the ITS architecture. A description of these innovative agencies' use of advanced communications is summarized to provide a preview of how connected vehicle concepts may increase the safety, efficiency, and information available to improve the overall transportation system.

Conclusions reached in this effort are as summarized as next steps for advancing the integration of transit into transportation engineering projects. They include:

- ***Share information about connected vehicle research to support transit priority deployments.*** There is a significant role for ITE, APTA, and the Federal Transit Administration in raising the awareness of practitioners regarding the deployment of technology in support of transit preferential treatments. Closing the gap between research and practice is vital to reach the goal of a more effective transportation system. Practitioners need to understand what devices are readily deployable.

- ***Refine data collection techniques to produce performance measurement to focus engineering efforts.*** The credibility of both transit and traffic professionals would be enhanced with data collection and performance measurement systems that provide us with information that can be shared effectively. By developing systems that automate the collection and dissemination of data, the information created will allow us to better focus efforts on trouble spots and increase our credibility in the community.

- ***Identify collaboration opportunities by sharing interagency success stories.*** Collaboration between transit and traffic agencies personnel is important to delivering a transportation system that is responsive to the needs of the community. Several of the agencies contacted as a part of this effort are models in this regard. Increasing awareness of these Best Practices is a key next step. Moving people and goods through our cities is important to increasing the efficiency of the transportation system.

- ***Continue improving transportation network efficiency through implementation of transit-supportive roadway strategies.*** The Transit Cooperative Research Program (TCRP) Project A-39 is intended to document transit preferential treatments, such as queue jump lanes, signal priority, exclusive or shared transit lanes or bypass lanes, and curb extensions. The industry will benefit from this effort and information developed as a part of the initiative should be further disseminated to practitioners through ITE and APTA meetings and webinars. Support for a moderated discussion group/listserv for traffic and transit professionals may be one more way to advance the profession.

Background

The Institute of Transportation Engineers entered into a cooperative agreement with FTA in 2011 aimed at improving the integration of transit priority treatments on urban street networks focused on transit signal priority. ITE, in a partnership with APTA, conducted two peer exchange-based workshops to educate practitioners, share experiences and lessons learned, identify barriers, and recommend potential solutions. The workshops were specifically targeted at fostering relationships between transit and traffic engineering professionals with an overarching goal of improving the integration of transit operations and traffic control strategies. The meetings provided an opportunity to share best practices from leading agencies from the United States and to gather feedback on further efforts that should be taken to advance the integration of TSP in bus rapid transit and other technology deployments. One of the identified actions was to summarize the insights from leading agencies and the missed opportunities from the local agency visits. An example of a missed opportunity would be to use proprietary equipment that limits information sharing amongst agencies or jurisdictions involved in similar activities.

Use of the National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) standards promote data and information sharing among public agencies and private organizations, which is an important element to successful implementation of signal priority.

The purpose of the white paper is to:

- Identify, discuss, and document barriers to implementation.
- Highlight case studies and relevant intergovernmental agreements (IGAs) that resulted in implementation of effective transit preferential treatments.
- Discuss the emerging concepts of the connected vehicle program at the United States Department of Transportation (USDOT) and how it may apply.
- Identify specific areas where additional outreach and training are needed.
- Establish an action plan for future steps to advance the profession’s ability to deliver more efficient transportation that improves environmental quality and reduces costs for the travelling public.

Workshop Summaries

Transit service is a vital part of a sustainable and equitable transportation system; that is, a system that provides mobility and access for all members of society. It is especially important that transit serve as a viable alternative to the private automobile for those members of society who do not drive, whether out of financial necessity, physical limitation, or personal choice. Transit also serves a valuable role in reducing congestion and helping to sustain vibrant urban areas by attracting “choice” riders (i.e., riders with other travel options available, but who choose transit based on convenience or other factors).

Transit signal priority is a combination of technologies employed by transit and traffic signal operating agencies to adjust signal timing to prioritize the movement of people. By reducing operating costs, speeding transit service, and increasing service reliability, TSP has the potential to better serve existing transit customers and help transit agencies attract choice riders.

Public support is necessary to implement right-of-way reallocation or significant changes like exclusive bus lanes, especially where vehicular traffic lanes are removed. The TCRP Synthesis 83 (*1*) cited that of the agencies implementing transit preferential treatments, only 46% are using exclusive bus lanes, where 67% are seeking to implement TSP. Lack of public support is commonly cited as an issue or barrier to implementation when visible physical transit improvements (bus lanes, queue jumps, etc) are being considered. There are several examples of projects that have been changed or reduced in their effectiveness by concerns from the public. Transit signal priority and other traffic signal timing changes are less visible and can be effective to improving transit service.

Traffic engineering support for transit preferential treatments remains mixed, depending on the extent that policies are clearly defined to encourage implementation. There remains a gap between many communities’ transportation policies of increasing efficiency and the understanding of how transit improvements and preferential treatments are integral to this goal. The workshops conducted as a part of this initiative highlight examples of projects and the degrees of success where this occurs. These examples provide us with useful insights into further efforts that should be taken to encourage the profession to take a leadership role in the implementation of community goals.

Discussions throughout both workshops focused on applications of a number of different transit preferential treatments in mixed traffic. In addition, participants offered insights into the decision-making process that can be applied in deciding which preferential treatment might be the most applicable in a particular location.

Opening Session

The FTA staff welcomed the participants to the workshops (Jeffrey Spencer in Fort Worth, TX at the TransITech Conference and Ronald Boneau in Atlanta, GA at the ITE 2012 Annual Meeting).

The speakers provided a summary of some of the federal actions that had taken place on the subject and the goals for the workshops. There was participation from both APTA and ITE staff depending on the workshops.

Bus and Rail Transit Preferential Treatments in Mixed Traffic

The results of research on the topic of transit preferential treatments were summarized by the Transit Cooperative Research Program (TCRP) Synthesis 83 Project Team, lead by Alan Danaher. He described the TCRP 83 effort as one to help transportation professionals understand the importance of transit preferential treatments. A survey conducted as a part of the TCRP 83 Synthesis provides a snapshot of the state of the practice. It includes results from a survey of transit and traffic agencies related to the perception of the planning, design, operations, and maintenance of transit preferential treatments. The Project Team took a unique approach to inquire with traffic agencies on their perspective regarding the treatments in each phase (planning, design, operation, and maintenance). It was documented that TSP is the most common type of transit preferential treatment being used (67% of agencies surveyed) and over half of those are unconditional (meaning priority requests are not based on any criteria, such as lateness, etc). In most cases, the transit agencies are involved with the front end (planning and design) and the traffic agencies are involved in the detection maintenance. Other tasks depend greatly upon the Intergovernmental Agreements that establish the relationship of a successful partnership. More discussion related to the importance of this work is included later in this white paper to provide insights on the case studies that were presented as a part of the workshops and those that were researched to support the effort.

State of the Practice Review

Peter Koonce summarized the implementation of transit signal priority and other transit preferential treatments in Portland, OR. The intent of the presentation was to summarize the various participants in the program, the technological elements used, and the arrangements between transit and traffic agencies in Portland. The implementation was initiated more than ten years ago, thus the links to new technologies were highlighted for future consideration.

The City of Portland, in collaboration with TriMet (Portland’s regional transit service provider), and the Oregon Department of Transportation (ODOT) implemented transit signal priority at over 240 intersections on seven transit routes as a part of TriMet’s Streamline program. The Streamline program is a comprehensive transit priority system that utilizes transit signal priority, an automatic vehicle location system, bus stop consolidation, and improved scheduling in a comprehensive manner to improve service to passengers. The program resulted in “Smart” buses that selectively request priority depending on the status of the bus with respect to its schedule. The Streamline program improved service reliability on key transit corridors throughout the City (*2*).

The TSP project resulted from several years of study with various upgrades of equipment starting in 1999 and fundamentally completed in 2003 and is a good example of a first generation[1] TSP system. As a part of the project, the traffic signal controller software used by the City, ODOT, and most of the neighboring jurisdictions was updated to allow green extension for the bus phase and red truncation for non-bus phases while maintaining coordination (*3*). The detection system used for the project was the 3M Opticom system, and an Automatic Vehicle Location (AVL) system is used to control the emitter and facilitate conditional priority (such that priority is only requested when a bus is behind schedule).

The selection of Opticom units for the project resulted from discussions with key stakeholders throughout the Portland-metropolitan area. The Opticom system by 3M was chosen for several reasons:

- Opticom units are standard in the suburbs for emergency vehicle preemption, making expansion easy.
- The City of Portland Fire Bureau desires to reach 100% coverage for signal preemption within the City to improve emergency vehicle response times.
- The optical detectors allow flexible range setting.
- The City did not want another piece of hardware that would increase maintenance costs.

The detection system has been very effective and reliable for the past ten years. Despite its success, there are several limitations of the existing system. The communication technology severely limits the complexity of the data that can be transmitted between the transit vehicle and the signal. This both reduces the system's reporting capability and excludes conditional priority from being applied at the signal controller itself (e.g., the controller serves requests on a first-come, first-served basis rather than by lateness or loading). It would also be advantageous if the software interface could provide automated performance measurement and feedback to staff in order to monitor and adjust settings.

The effectiveness of the existing system is partially due to ongoing maintenance of the TSP equipment, including the Opticom communication system. Given the on-going costs to maintain the system, it is important to periodically review the potential benefits of replacing or upgrading the system to achieve greater functionality.

Transit detection systems of the future should consider the connected vehicle framework as vetted by USDOT. Moreover, there are several agencies with recent TSP experiences that can inform any agency's procurement of a "2nd Generation" system (some of them described in this

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[1] First generation is used to describe a system that was ground-breaking for its time, but based on current technologies available would be considered outdated.

white paper), suggesting that there are several feasible options for the detection system to be a part of a robust and multi-purpose connected vehicle system.

The workshops in Fort Worth and Atlanta featured presentations by practitioners involved in local efforts. The efforts of each local agency were completed well before the connected vehicle framework was established. The connected vehicle concept may not require complete replacement of the existing technology. Thus, evaluation of the existing infrastructure in each of these locales provides a window into how further integration of transit can improve the efficiency of the system.

Dallas Light Rail Signal Priority

Dallas Area Rapid Transit (DART) is a regional transit agency serving the Dallas Fort Worth metroplex. DART light rail operates in downtown Dallas on city streets with conflicts between rail and vehicular traffic. An expansion of the system necessitated more efficient movement of trains in downtown to provide capacity for the additional service. Implementation of signal priority was intended to provide early green and green extensions by installing detection and some limited peer-to-peer communication between signals.

The Dallas Case Study is representative of most major metropolitan areas in that DART operates across multiple jurisdictions. The goals of the transit agency and those of the City traffic department weren’t aligned at the onset of the project. The City’s highest priorities included pedestrian service, maintaining vehicular level of service, vehicular progression, and minimizing intersection blockage. DART’s primary goals were to support the 2.5 minute peak headways and to achieve non-stop station-to-station train movement (*4*). It is common for local traffic and regional transit agencies to have conflicting goals. In this case, the pursuit of reduced transit travel time to improve capacity of the train system in downtown requires some compromises to the objective of reducing auto delay on the intersecting streets. One important lesson learned was the need for objectives that provide for compromise and a set of performance measures that can be used to assess the project.

The implementation of signal priority in Dallas was successful using legacy equipment. To improve the applicability of the system on a regional scale, the City is working with its regional partners on a Concept of Operations that will consider a broader range of potential applications.

The implementation of TSP required that the agencies build relationships by defining a common goal. Presentations at the workshop highlighted that the City needed to think regionally, understanding that their decisions would likely affect the other agency’s decisions and regional partners. One lesson learned from the project was that a regional concept of operations could have resulted in a system that was expandable and met the immediate needs and future considerations for elements of the system including the traffic signals and the detection system. The existing signal controllers had limitations that would not support a National Transportation Communications for ITS Protocol

(NTCIP) 1211 standard. The decision to use a magnetometer that was modified from industrial control applications was also inconsistent with the standard messages defined in NTCIP. Following the experience, the City and regional partners worked together to develop a Concept of Operations for Traffic Signals that includes three types of preemption and two different types of signal priority (*5*).

Atlanta Metro Area Applications of Transit Preferential Treatments

The Metropolitan Area Rapid Transit Authority (MARTA) is the principal rapid transit system serving the Atlanta region. It is currently the ninth-largest system in the United States offering both heavy rail and bus service. MARTA operates buses on Memorial Drive within DeKalb County as a feeder service to the Kensington Station. The service is called the Q and operates as a limited stop express service that features signal priority. In this case, implementation of signal priority was combined with queue jump lanes and reduced the total travel time by nearly 12 minutes in the peak hour (*6*).

The success of this project is attributed to the previous experience the County and MARTA had working together on similar efforts with shared goals (offering improved air quality and cost-effective transit service while minimizing impacts in added delays for vehicular traffic). The first implementation of signal priority was several years earlier along Candler Road.

For this project, DeKalb County implemented the queue jump lanes and signal priority by upgrading to the current standard signal controller (Type 2070). The new controller offers an open architecture that is compatible with software from multiple vendors. It is also capable of multitasking a variety of functions and enables communication via Ethernet. The upgraded software offered additional signal phases that minimized disruption for all other traffic, which was a goal of both agencies (*7*). This particular case study exhibits the importance of the NTCIP standards in a project of this nature.

Use of Connected Vehicle for Transit

TSP is a well-documented area within the field of transportation. Its implementation requires significant attention to details associated with the technological elements of each project. Context is especially important, which warrants evaluative studies to determine the effectiveness of the service in FTA-sponsored projects. One of the limitations of TSP is the need to operate the system and maintain the detection equipment. A system based on the Connected Vehicle principles offers shared responsibility for this maintenance and a wider range of applications that can reduce these burdens.

In 2009, USDOT, in association with American Association of State Highway and Transportation Officials (AASHTO) and ITE, prepared its IntelliDrive^{SM} Strategic Plan (*8*). Among the specific actions identified in the plan was the need to analyze the potential approaches for state and local transportation agencies to deploy the infrastructure components of “Connected Vehicle” systems (defined by USDOT as a “fully connected transportation system that makes the most of multi-modal, transformational applications and requires a robust, underlying technological platform). This early research stimulated a good deal of interest and consideration of adoption of advanced communication capabilities that would result in broader connected vehicle applications.

The outcomes and benefits of a connected vehicle system are many ***(9)*** and several of them are specific to transit systems. Those that are of particular interest include:

- Reduced likelihood of collisions at intersections
- Increased reliability of transit schedules[2]
- Increased availability of information for performance measurement

The second and third bullets are key limitations to the existing system in Portland, OR. The potential for improving safety is always of paramount importance to the City and TriMet, so this is of particular importance to the agencies. The fundamental research conducted by USDOT for the development of a system addresses the core limitations of early TSP systems.

Implementation of connected vehicle technology has been limited to date. The primary efforts have included six federal test bed sites throughout the country and a few early adopters that are demonstrating the effectiveness of the concept. However, these initial efforts have focused primarily on vehicle to vehicle (V2V) communication with only limited work on the vehicle to intersection (V2I) communications that comprise TSP.

The USDOT implementation scenarios assume that public agencies will deploy the field infrastructure for connected vehicle systems in order to achieve near-term benefits from applications to enhance mobility, provide localized safety improvements, or improve the operational performance of the agency in some manner. Public agencies are expected to deploy Dedicated Short Range Communication (DSRC) field infrastructure in recognition of its long-term value in safety applications, but will leverage that investment to support a variety of near- and long-term applications including TSP.

The auto industry has actively participated in these meetings. Their primary interest is in the National Highway Traffic Safety Administration (NHTSA) plans to make two decisions relating to DSRC deployment. The decision on what message will be included in the DSRC message will be for light vehicles in 2013 and for heavy vehicles in 2014. NHTSA is not calling this a regulatory decision, but rather an “agency” decision, and has committed to analyzing research results before making these decisions to determine whether subsequent action is merited. Subsequent action could include a rulemaking to require V2V safety equipment in vehicles. However, action could take many forms, with rulemaking being only one option.

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[2] The USDOT document highlights freight in addition to transit reliability improvements.

While DSRC technology is believed necessary for the V2V and V2I safety applications, it is not an absolute requirement. In partnership with auto companies and other stakeholders, USDOT is exploring a wide range of possible alternative solutions. These alternatives may leverage existing telecommunications capabilities alone or in combination with DSRC, or phase-in implementation to be consistent with the availability of technology in vehicles over time.

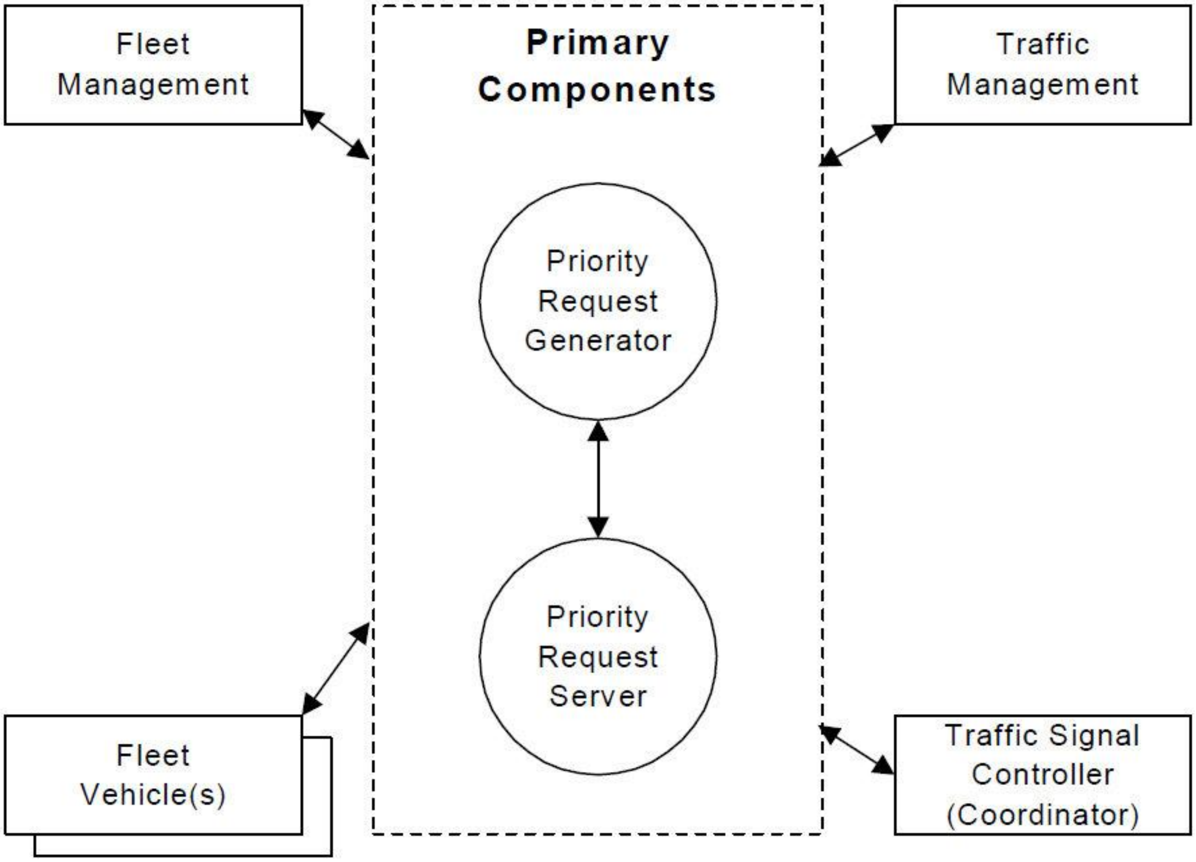
There are several examples of early work that is being done in this area. The Maricopa County Department of Transportation and its Systematically Managed ARTerial (SMART) Drive Program (*10*) has a project established to provide a test bed for Connected Vehicle technologies. The research conducted by the University of Arizona is a part of the MultiModal Intelligent Traffic Signal System Concept of Operations Cooperative Transportation System Pooled Fund Study. This Pooled Fund group represents several states and regions that are working with USDOT to advance the state-of-the-practice through research, demonstrations, and evaluations of transformative signal control operations, among other Connected Vehicle focus areas. Two such models for transit vehicle implementation have been developed in Los Angeles, CA and King County, WA (Seattle).

Case Studies of 2nd Generation TSP

Innovation of traffic signal control and detection is largely a function of investment in transportation projects such as those mentioned in the case studies. The examples provided indicate that many of the communities developing transit preferential treatments use existing equipment with slight modifications. Only one of the 11 agencies included in the transit priority detection survey of the TCRP Synthesis 83 used a detection device that relies on detection that meets the NTCIP 1211 specification for Signal Control Priority. Three of the 11 agencies in the same survey upgraded their traffic controllers to an Advanced Traffic Controller capable of meeting the NTCIP 1202 standard.

The key distinction for the functional standard is that the system must prioritize different Priority Requests based on the vehicle class, vehicle level, and time of service desired (*11*). The generation of a smart request enables a TSP system to resolve conflicts between competing transit priority requests (or other non-transit requests) and to implement an improved TSP solution. Figure 1 shows the relationship of messages between the various elements of the TSP system.

FIGURE 1. NTCIP 1211 Signal Control Priority System Diagram



The community surveyed that most closely met the NTCIP 1211 specification is Los Angeles, CA, which evolved its TSP throughout the implementation between the City and the County deployments.

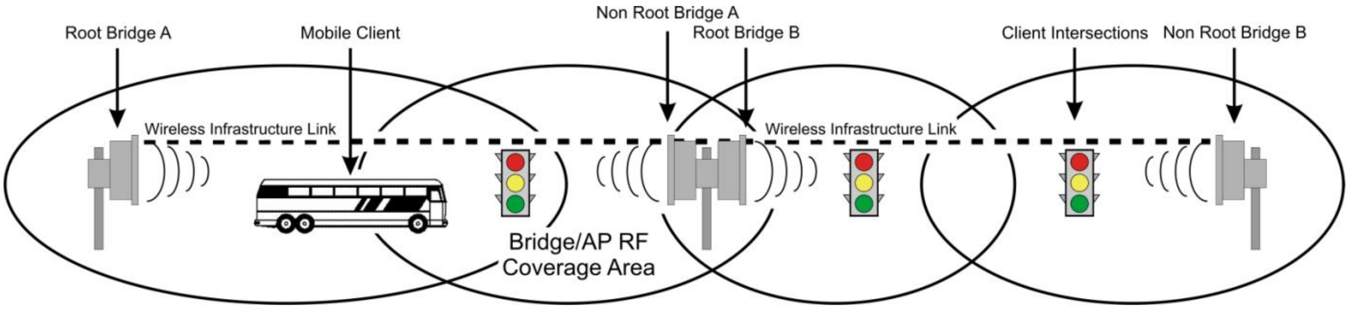
Los Angeles, CA

Los Angeles has a rich history as an early adopter of new technology. LADOT first implemented its version of TSP in 1998 when they began their Metro Rapid system. Yet, what worked in the City of Los Angeles with the Department of Transportation's central signal system wouldn't work in the neighboring suburbs. The Los Angeles County Metropolitan Transportation Authority (LACMTA) desired a cross-jurisdictional TSP system that could operate independently of the existing controller type and without a centralized signal system. To this end, their pilot project brought together multiple jurisdictions to develop wireless signal priority standards within the County (*12*).

The LACMTA field implementation for its Metro Rapid service utilized a decentralized communication system similar to the connected vehicle concept. This system provided LACMTA with a high degree of flexibility by pairing elements of the system in the field rather than centrally. While some data are passed to the centralized MTA operations center, this data flow is for monitoring purposes only. Three components are necessary to operate the distributed MTA TSP implementation: bus to intersection detection/communication; on-board AVL system to generate priority requests based on schedule adherence; and TSP equipped software/firmware in the local controller.

MTA implemented TSP using a Wireless Local Area Network (WLAN) system for the bus to intersection communication. Communication from the bus to the intersection uses a spread spectrum wireless LAN, specifically 802.11b. Each bus (mobile client) and each individual intersection (terminal client) has a unique IP address. A wireless bridge is created by placing a directional access point at every fourth or fifth intersection. Figure 2 presents a schematic of the communication that occurs between the bus (mobile client), the communications system (root bridge), and the traffic signals (wireless from the root bridge).

FIGURE 2. Wireless Local Area Network Application for LA MTA TSP ([13])



King County, WA

The Seattle area’s King County Metro has a similar story of evolving systems associated with transit signal priority. The first generation system developed in Seattle was based on a wayside radio frequency identification (RFID) toll tag reader that was expensive to implement because of the physical structures and overhead readers needed. The TSP system set the framework for how a traffic signal controller would respond to a priority request by establishing the logic within the controller. The primary benefit to the local agency was that the RFID tag system allowed the engineers to become familiar with the changes the traffic signal controllers would provide in order to prioritize the movement of requesting buses. This is an example of the system design, which was built to detect buses for a singular and non-scalable purpose.

The prospects of expanding the system to another corridor resulted in a systems engineering process that identified that the wayside communication provided detailed data about where the bus was at a single point, but was difficult to extend for other purposes, such as transit arrival prediction. The systems engineering process and field visits to Los Angeles and Portland yielded the concept for a wireless communication system based on the 4.9 GHz public safety band. The second generation system uses a modified connected vehicle concept for communication providing support for multiple systems beyond TSP and more accurate information for a variety of applications (*14*). The multipurpose wireless network deployed by King County Metro supports many systems with varying communication needs, not only for vehicles, but also for 'last-mile' communications. King County Metro has taken the approach that if they build a communication infrastructure with the capacity to handle future, it will have the capacity that will allow them to avoid costly sidewalk replacement or road resurfacing by building the system with ample capacity the first time.

A key feature of the approach taken by King County Metro was to build a network that unifies communications though a multipurpose medium. The design provides for a wide variety of communication exchanges in the National ITS Architecture:

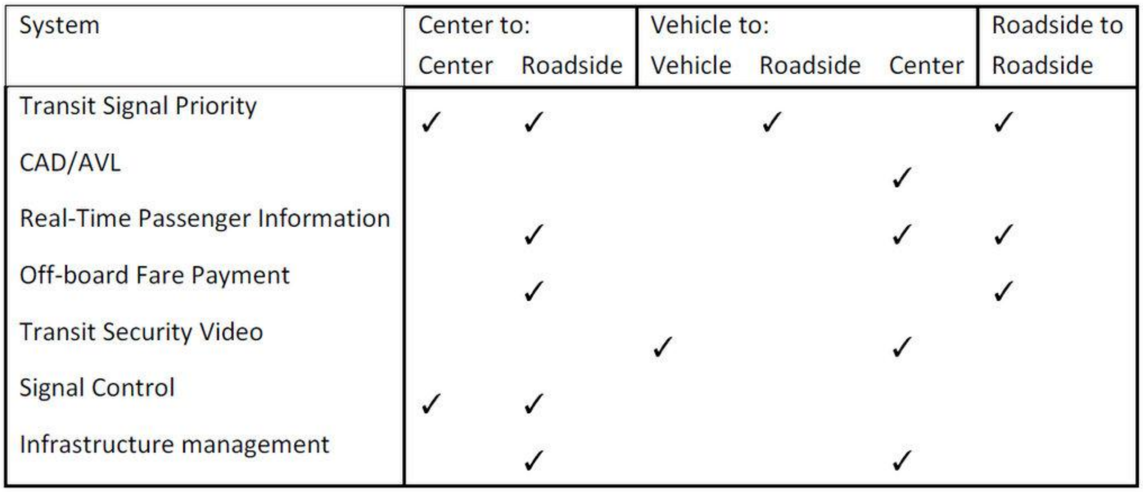
- wireless communication for vehicles to other vehicles, the roadside, and centers;
- wired communication from centers to the roadside; and
- from center to center, video, and multimedia.

Following the National ITS Architecture model in the development of the Transit ITS Architecture led naturally to the use of the connected vehicle concept. Using the model and planning for future message-sets prepares the agency for future technologies and systems. Having the structure in place, King County Metro expects to be able to more easily take advantage of ongoing growth and development in the ITS industry.

Data Flows of a More Complete System

Building a connected vehicle system, like the Los Angeles and King County examples, allows multiple data flows to occur. Communication exchanges used in the King County Transit ITS Network architecture are shown in Figure 3.

FIGURE 3. King County Transit ITS Communication Exchanges



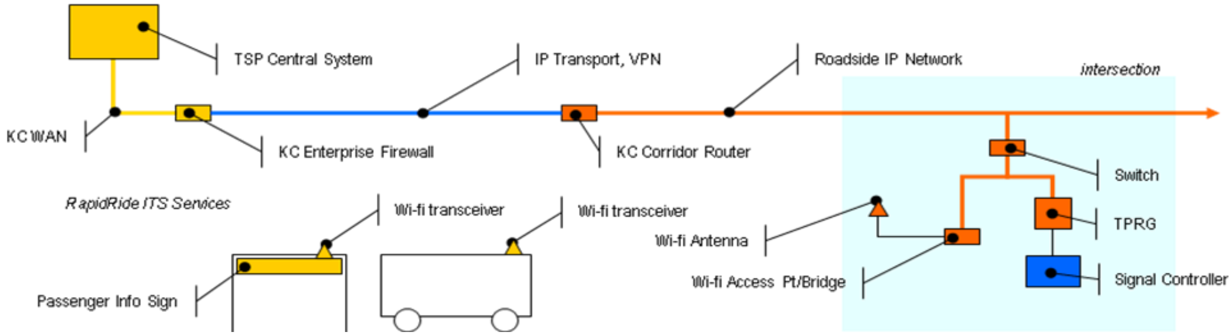
System	Center to:		Vehicle to:			Roadside to
	Center	Roadside	Vehicle	Roadside	Center	Roadside
Transit Signal Priority	✓	✓		✓		✓
CAD/AVL					✓	
Real-Time Passenger Information		✓			✓	✓
Off-board Fare Payment		✓				✓
Transit Security Video			✓		✓	
Signal Control	✓	✓				
Infrastructure management		✓			✓	

This model communications system allows multiple messages sent throughout the system, enabling a wide variety of applications. Buses (vehicle) send information to the Automatic Vehicle Location system (center) about direction, speed, and passenger loading. These messages can be combined with information about schedule, historic performance, and real-time status for selecting the bus that needs priority. Information from the traffic signal is sent to the Center to identify potential delay savings that could result from adjustments to traffic signal timing.

Information from the vehicle (stop requested from on-board the bus and passenger loading data) is used to estimate when a bus will arrive at the next stop. Transit stops farther downstream get updated information about the forecast arrivals of future buses. Dispatchers also receive information from buses that fall behind to such an extent that headways may have reached a point where additional service is needed to ensure passengers experience reliable service. All of these characteristics of a system rely on the robust communication system, afforded by a connected vehicle communication system.

The importance of a connected vehicle framework can be clearly demonstrated to system users. On-board the bus, passengers receive updates about delays and information about opportunities to transfer to crossing lines. Transit agency management uses relevant bus data to analyze engine performance and vehicle diagnostics. Bus operators, in the event of an emergency on-board the bus, can activate security notices to local police. Transit agency staff also benefit from on-board cameras that record the activities of patrons and can be used to deter criminal activity. Monitoring systems of this nature can also be used to evaluate operating characteristics to ensure safe conditions, thereby managing liability for the agency.

FIGURE 4. King County TSP System Architecture



Updating Traffic Signal Controllers

The examples of King County and Los Angeles give the profession a model to work from. To develop an effective long-term technology solution for our connected vehicle, future practitioners should work toward updating traffic signal controllers with transit signal priority as a key component; establishing high speed communications to the controller that permits information sharing; and developing an appropriate interface to provide data that can be used for system monitoring and maintenance.

The traffic signal controller in a connected vehicle world should be able to complete multiple functions, TSP being one of them. The controller must accept communications from a priority request generator (PRG), receive the message, and implement a decision on whether and how to grant priority based on message content. The messages communicated to the traffic controller ideally would be easy to update and would enable more intelligent decision-making. The signals will prioritize requests from more than just transit vehicles. There will be requests from eco-driving cars, disabled pedestrians, and emergency vehicles, and rail will trump them all. Ideally, the traffic controller would also be able to:

- Process data from a priority detection system and use conditional priority logic to determine if and how much priority should be granted at a local intersection.
- Process and prioritize multiple requests for priority and prompt the local controller to carry out the most critical function (e.g., a bus late by 60 seconds over one late by 10 seconds).
- Override all priority requests when a preemption request is registered.
- Transition to normal signal operations as soon as possible when the priority/preemption vehicle has left the intersection.
- Accept and process input from the traffic signal system related to arterial performance.

- Accept updated messages related to predicting the bus arrival at the TSP intersection's stop bar.

Building Communication Systems through Partnerships

To date, incorporating connected vehicle communication concepts into existing transit systems has been limited because of the emphasis on DSRC. The strength of DSRC is in its ability to deliver low latency messages quickly for safety functions. Communication design for transit systems is often the opposite, with low frequency polling of vehicles (every 90 seconds or even 120 seconds is common) to monitor vehicles. This is a key limitation of existing transit communications infrastructure, which defines real-time based on application rather than a diverse set of applications. "Real-time" passenger information at a bus stop can utilize information from an AVL system that is updated every 30 to 90 seconds. In contrast, TSP systems require real-time data with less than one-second resolution to be effective. Use of a systems engineering process that considers both transit and traffic functions would result in a different set of requirements and functions that would build more capabilities into the system.

The paradigm shift of connected vehicle requires a thoughtful approach to upgrading equipment and systems. In the Portland example presented previously, updates to the on-board transit vehicle detection would require changes both on the bus and at the traffic signal. Even if the transit vehicle detection technology was capable of transmitting a richer message, most of today's traffic signal controllers have not been designed to receive or process such a message, as most controllers are limited to simple contact closure inputs and outputs.

A more robust transit detection system, easily afforded within the connected vehicle environment would yield more effective management of the priority requests.

A more robust transit detection system, easily afforded within the connected vehicle environment, would yield more effective management of priority requests that would allocate green time more effectively than a "First-In, First-Out" system. The NTCIP 1211 Signal Control Priority standard defines the need for an intermediary Priority Request Server (PRS) that could address request messages that are more complex than a simple contact closure signal. The development of a communication system that serves this detection function may also be used in partnerships that meet multiple objectives.

Building Partnerships through Staff Interactions

A key challenge to implementing transit signal priority is that it requires the expertise of transit operations and traffic engineering, which is not a commonly held skill set in North America. Most professionals are either transit or traffic professionals, much in the same way as many engineers clarify their role as compared to that of planners. The integration of multidisciplinary staff is critical to the implementation of a strategy that meets the policy objectives. As transit preferential treatments are developed, it is helpful to have the expertise in place to ensure that each objective is evaluated. As with any strategy, it is important to be clear as to the objectives before the strategy is implemented, since the combination of policy instruments suitable for, say, the pursuit of reduced transit travel time will differ from those which reduce auto delay on the intersecting streets. If effective integration is to take place between authorities, it will be important for them to have a common understanding of their objectives, and of their relative importance. Most approaches to strategic integration focus on one of two types of principle: the pursuit of synergy and the removal of barriers (*15*). Several examples are provided to illuminate the issues associated with successful implementations.

San Francisco, CA Example

The primary reason San Francisco is seen as one of the most successful cities for the implementation of transit preferential treatments is that they have merged transportation professionals from different departments into the same agency. In the early 1970s, San Francisco had a committee that included representatives of Muni (then responsible only for transit operations), the Department of Public Works (then responsible for traffic engineering operations), the Police Department (responsible for traffic and parking enforcement), and the Department of City Planning, which was responsible for the City's Master Plan and Preferential Streets Program (*1*). The difficulty in getting these diverse agencies together resulted in less than optimal implementation on the street. To deal with this, the SFMTA created an organization that merged Muni and a revised Department of Parking and Traffic into a single agency.

As a result of the merger, the SFMTA was able to create a team of engineers and planners who had expertise in both traffic engineering and transit planning and operations. The new team, named "Transit Engineering," has been given the responsibility of developing and implementing transit preferential street treatments to reduce transit delays and improve service reliability. Other cities may also have their own transit preferential street treatment programs, but what makes the SFMTA unique is that the transit engineering team is fully integrated into the transit planning and operations team as opposed to being in a different city department. As a result, such projects as installing transit signal priority, timing traffic signals for transit, and expanding the city's transit-only lane network can happen in a much more efficient and effective manner.

The Transit Effectiveness Project (*16*) Web page has several examples of the group's transit/traffic work. It is important to stress that these projects are a result of Intergovernmental Agreements based on partnerships between the agencies. TSP in San Francisco has required coordination between bus equipment, traffic signal hardware, and the Muni radio to give transit green signals as vehicles approach the intersection. This effort has elements of implementation in a number of programs, such as SFgo and the Muni Radio Replacement.

Los Angeles, CA Example

One of the most often-touted success stories in implementation of bus rapid transit (BRT) is the City of Los Angeles and its Metro Rapid system. The Los Angeles County Metropolitan

Transportation Authority (Metro) has worked with numerous traffic agencies to successfully implement a system that has combined several different treatments to deliver effective service to its customers.

The agency has used a wide variety of treatments and the implementation of these is dependent on the type of a project. On the most recently implemented Orange Line, an evaluation found that the system is “generally successful at reducing signal delay.” Along the Orange Line, messages are routed through a centralized TSP system, which oversees the entire corridor, allowing priority requests that are sensitive to the headway management objective. The centralized nature of the requests results in more efficient choices than using peer-to-peer communication. The technology deployment results in requests being granted more often and improved signal progression (*17*).

An attribute that sets Los Angeles apart is its working relationship between the regional transit operator and the City’s transportation department LADOT. The City is unique in that it has developed its own traffic controller software and traffic control system. This system has required modification to implement TSP. The agencies have demonstrated effective cooperation in development and refinement of the traffic controller software, building in performance measurement as a part of the traffic signal system.

Building in Performance Measurement

Performance measures are criteria whereby an organization determines its effectiveness. Performance measurement systems for both the signal and transit systems are critical for effective operations and maintenance. After deploying a TSP system, it is important for both the traffic and transit agencies involved to review performance measures that define system effectiveness in carrying out the desired policies. By establishing expectations regarding performance and reviewing measures that are both agreed upon prior to deployment and easily collected, partnerships will be able to reach mutually beneficial changes. Furthermore, a feedback and monitoring mechanism enables system operators to identify and address problems as they arise. Three main aspects of TSP operations require consideration for effective performance measurement:

1. Functional evaluation – Is the selected technology working as expected?
2. Outcomes assessment – Is TSP providing measurable benefits for buses and passengers?
3. Ongoing monitoring – What changes can be made to improve the system?

Automating feedback from a TSP system is the component most often overlooked in deployments. Designing a robust monitoring system would provide feedback from both the traffic and transit systems. All requests would be logged while the corresponding response would be recorded and compared against the expected response.

The development of a concept of operations using the systems engineering process leads to the identification of performance measures that can be quantitatively collected by the system being built. The identification of when a vehicle is detected by the traffic signal and when it passes through the intersection is one approach to measuring travel time or delay. An ideal monitoring system would provide system or corridor level travel times and finer detail at intersections. The key challenge with the Portland, OR system is its lack of relevant data from the Automatic Vehicle Location system built more than a decade ago.

Smarter Systems and Staff Training

Advancements in local traffic signal controller logic occurred in all of the examples presented. These pioneers of the industry will make it easier for communities with similar interests, because they won’t have to develop new software from scratch. The performance measurement system will also require training for staff that is responsible for maintenance of the system. In developing the system in Portland, the issue of performance measurement was never fully resolved for the traffic agency, because the GPS units did not provide sufficient accuracy. This remains a limitation in traffic operations troubleshooting and ensuring that the system is as effective as possible.

The introduction of new systems requires staff training to ensure effective deployment. Relevant training is key for effective maintenance. Part of that training is familiarization of staff with the objectives and intent of the system and ensuring that training is hands on and ongoing. This is where organizational structures, such as those in San Francisco, may be more successful over the long run, because the objectives remain with staff within the agency as opposed to a temporary project where these may be forgotten.

Conclusion

Transit signal priority implementation lessons from these communities are transferable to other cities and more should be done to ensure that the professionals of APTA and ITE are more engaged with each other. This can be accomplished by creating forums for discussion of this subject matter at both APTA and ITE conferences and meetings. As public agency staff training budgets continue to be significantly limited due to fiscal constraints, it will be important that both professional societies seek ways to engage their members in local meetings, webinars, and through offering assistance of peer agencies on projects.

The Transportation Research Board (TRB) has sought to identify “practice ready papers” that are directly implementable. This practice is one of many needed to accelerate adoption of policies and new approaches that leads to increased efficiency in the

There remain opportunities to provide more application-ready research projects and guidance to the practitioners. Too often, research completed is impractical for direct application in the field, because the efforts are not grounded in oversight by the practitioners. In the past year, the topic of connected vehicle technologies in traffic signal control has been a priority within AASHTO. Through the Connected Vehicle Pooled Fund Study, a research team from the University of Arizona will field test/demonstrate a multimodal Intelligent Traffic Signal System at two locations. The placement and installation of DSRC Roadside Equipment stations at signalized intersections will further advance some of the concepts described in this white paper. Further documentation of this and other efforts being completed by Caltrans need further dissemination to practitioners. Traditionally, practitioners look to APTA and ITE as their primary source for technical guidance. This could be accomplished by the development of an informational report prepared jointly by APTA and ITE, with the possibility of advancing to a recommended practice. This document would complement the TRB papers by raising the awareness among practitioners regarding the deployment of technology in support of transit preferential treatments, reflect the latest data collection and successes in delivering a transportation system that is responsive to the needs of the community, and have the endorsement of both professional communities. The coming year will be a period of opportunity during which ITE can further work with APTA and FTA to identify what the industry needs to better understand the applicability and potential for deployment of these devices that can serve multiple needs at a signalized intersection. The early interest in DSRC combined with the potential for telematics based on enhanced cellular based services (such as 4G) provide new opportunities that must be more fully explored in the coming months.

Local transit agencies working with FTA on Small Starts would benefit from technical oversight of proposals for technology investments. A coordinated group of peer agencies that could inform transit agencies on best practices for working with traffic agencies could enable more efficient deployment of transit preferential treatments. Similarly, the group could provide critique of systems engineering documentation that recommends technologies that are consistent with the NTCIP and TCIP standards.

Next Steps

There is a significant need for research to build knowledge and capacity about the connections between traffic engineering, transit preferential treatments, and technology. Such research holds great potential to help professionals better prepare for the future connected vehicle world. At the same time, the research and transportation communities need to make existing research findings available to transportation decision-makers. While our policy language is often clear, our implementation of measures to meet the objectives has lagged behind. To improve this connection, outreach should be conducted to improve awareness of the changing landscape of technology and the tools available to improve the transportation system.

Outreach

The need is great for improved understanding of how technology can support transit preferential treatment implementation and efficiency of the transportation system. Because transportation decisions and investments are most often made at local and regional levels, broader understanding of the relevance of the connected vehicle framework is important to its long term acceptance. It will not be enough to implement on a pilot set of intersections; the benefits will be most extensive when the coverage is widespread. Generating greater awareness of both the Maricopa County SMART*Drive* project and the potential for using municipal wireless networks like the NYCWiN communication system (*18*).

Transportation managers need improved tools to effectively incorporate impacts to transit into their decisions regarding planning and operations. Techniques to assess the change to different aspects of the transportation network will allow decision-makers to appropriately target resources to the most significant infrastructure and systems. Refinement of Automatic Vehicle Location systems, or refinement of existing ones, can provide invaluable data for decision-making. Development of a communication system, such as the example of King County, benefits a wide variety of users and provides real-time information from the infrastructure used for multiple purposes including performance reporting.

Collaboration with regional efforts within USDOT, such as Integrated Corridor Management, Regional Transportation Systems Management and Operations, and Planning for Operations, would be beneficial for communicating the importance of this concept to practitioners. A possible incentive for greater interaction among both traffic and transit engineers regarding best practices and ongoing deployment of transit preferential treatments would be to establish a Web-based dialogue for transit signal priority. This site could be hosted by ITE with a link to APTA, and other relevant groups, and would serve as the overall information source for dialogue and current events related to transit preferential treatments. Access to and awareness of training on research is quite limited in this era of limited staff education budgets, so there may be an opportunity to use ITE and APTA webinars to further disseminate information about the concepts described in this white paper. The list of possible topics is as follows:

- Traffic modeling in support of Small Starts (summary of best practices and policies)
- Transit signal priority / Traffic signal timing training
- Regional transit signal priority deployment
- Transit preferential treatments (beyond transit signal priority)

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