The Use of Intelligent Transportation Systems to Improve Transit Operations; a Discussion Paper

Brendon Hemily, Ph.D.

Final Report — Revised July 18, 2016

Produced by Intelligent Transportation Society of America (ITS America)
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology

Notice

Acknowledgements

This discussion paper is the result of discussions with many experts over the course of many meetings. The author would like to acknowledge the invaluable assistance of all those who participated in these discussions.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
The Use of Intelligent Transportation Systems to Improve Transit Operations; a Discussion Paper

5. Report Date
July 18, 2016

6. Performing Organization Code

7. Author(s)
Brendon Hemily, Ph.D.

8. Performing Organization Report No.

9. Performing Organization Name And Address
Intelligent Transportation Society of America (ITS America)
1100 New Jersey Ave., SE, Suite 850
Washington, DC 20003

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
1200 New Jersey Avenue, S.E.
Washington, DC 20590

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract.

ITS has been used from its earliest deployments to assist transit operations, but there is a need to review recent developments and ongoing challenges, focusing specifically on the following two components that directly affect the quality of transit operations:

- Computer-Aided Dispatch / Automatic Vehicle Location (CAD/AVL) and its use for proactive operational control through Decision Support Systems (DSS), and
- Transit Signal Priority (TSP)

The objectives of this discussion paper are to:

1. Provide a high-level overview of the efforts made to use ITS to improve transit operations, with a particular focus on the use of DSS and TSP,
2. Identify the various challenges and/or opportunities in pursuing these objectives through Transit ITS technologies, and
3. Recommend research and other initiatives that would enable transit agencies to make more effective use and assess the potential impact of ITS to improve operations.

17. Key Words
Public transportation, Intelligent Transportation Systems; Decision Support Systems; Transit Signal Priority

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

orm DOT F 1700.7 (8-72) Reproduction of completed page authorized

GLOSSARY

AFC	Advanced Fare Collection
AI	Artificial Intelligence
APTA	American Public Transportation Association
AVL	Automatic Vehicle Location
BRT	Bus Rapid Transit
CAD	Computer-Assisted Dispatch
DSRC	Dedicated Short Range Communications
DSS	Decision-Support Systems
FTA	USDOT Federal Transit Administration
ITS	Intelligent Transportation Systems
ITSJPO	USDOT Intelligent Transportation Systems Joint Program Office
PCB	USDOT Professional Capacity Building Program
TODSS	Transit Operations Decision Support Systems
TSP	Transit Signal Priority
USDOT	United States Department of Transportation

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1. INTRODUCTION:

1.1. BACKGROUND FOR DISCUSSION PAPER

The Intelligent Transportation Society of America (ITS America) is the nation's largest organization dedicated to advancing the research, development and deployment of Intelligent Transportation Systems (ITS) to improve the nation's surface transportation system. Its Vision is to save lives, time and money and sustain the environment through the research, development and broad deployment of interoperable ITS.

ITS America has been engaged for over fifteen years in tasks to support the U.S. Department of Transportation (USDOT), working with the Intelligent Transportation Systems Joint Program Office (ITSJPO) and the Federal Transit Administration (FTA) in a range of activities related to research, development, and dissemination of information on ITS and its application to public transportation modes. During the course of these activities, ITS America has been asked to develop strategic discussion papers on key topics that might help identify and understand challenges, barriers, and opportunities to ITS deployment as well as suggest recommendations for action to help to achieve the full range of potential benefits that can be derived from the deployment of ITS by the public transportation industry.

These discussion papers build on the knowledge gained from a range of experts, including practitioners in the field, consultants, suppliers, and researchers, through workshops, listening sessions, and interviews, and supplemented by the review of pertinent literature.

1.2. THE ISSUE

ITS has been used from its earliest deployments to assist transit operations, but there is a need to review recent developments and ongoing challenges, focusing specifically on the following two components that directly affect the quality of transit operations:

- Computer-Aided Dispatch / Automatic Vehicle Location (CAD/AVL) and its use for proactive operational control through Decision Support Systems (DSS), and
- Transit Signal Priority (TSP).

CAD/AVL systems have existed in some European and Canadian transit agencies since the mid 1980s, and started being widely deployed in the U.S. since the mid 1990s. In a 2013 USDOT deployment survey, 63% of transit agencies that responded reported having equipped their fleet with CAD/AVL.[1]

[1] The terms Intermodal Transport Control System (ITCS) is equivalent to CAD/AVL, and is commonly used in many countries, and by some North American suppliers.

From the earliest days of the development of Transit ITS, CAD/AVL systems were deployed with two primary goals in mind: 1) to increase security for bus operators and passengers, and 2) to improve the quality of transit operations through more effective incident management and service restoration. To review briefly, CAD/AVL technology enables:

- more rapid identification of service problems and disruptions,
- assessment of the nature and severity of the problem,
- accurate information on the location of the bus experiencing a problem, as well as knowledge of the location of the preceding and following vehicles,
- accurate information on the vehicle number, the bus operator, available nearby road supervisors, etc.

A robust deployment of transit ITS would enable much more rapid and pertinent response to problems, and enable dispatchers to take appropriate actions to deal with various types of problems:

- rapid dispatch of emergency services (e.g. police, ambulance, fire department), to address serious problems (e.g. assault, severe illness, major accidents, vehicle fires, etc.)
- deployment of vehicle deviations to circumvent blocked roads, or bus bridges to replace disabled rapid transit service,
- operational decisions in the case of disabled buses (e.g. mechanical failures, accidents involving bus, etc.)

When compared to the prior situation of limited or total absence of information, one can assume that the deployment of CAD/AVL technology has saved lives and greatly improved the ability to minimize the impacts of disruptions on customers. Unfortunately, there have been no studies to measure these benefits (e.g. the value of lives saved, reduced operating costs, reduced potential loss of ridership by providing more rapid service restoration, etc.) and to quantify the return on investment. The importance of CAD/AVL systems is generally taken for granted by policy boards and senior management.

However, the use of ITS to improve transit operations has evolved very little since the first ITS deployments. For example, even though dispatchers in transit control centers have access today to considerable technological resources, they by and large use the same operational control strategies as in the past, focusing primarily on incident management and post-incident service restoration. However, ITS could be integrated with the use of Artificial Intelligence (AI) to create a DSS that could provide computer-assistance to control center dispatchers in order to suggest strategies for more proactive operational control. Another use of ITS that would enhance transit operations is to use TSP to reduce travel times / or improve reliability. Neither approach has been taken full advantage of by the transit industry, with some exceptions.

The objectives of this discussion paper are to:

4. Provide a high-level overview of the efforts made to use ITS to improve transit operations, with a particular focus on the use of DSS and TSP,

5. Identify the various challenges and/or opportunities in pursuing these objectives through Transit ITS technologies, and
6. Recommend research and other initiatives that would enable transit agencies to make more effective use and assess the potential impact of ITS to improve operations.

1.3. ITS AND TRANSIT FLEET OPERATIONS AND MANAGEMENT

ITS is a suite of different systems that are often inter-related. The USDOT ITS ePrimer Module 7 on Public Transportation is a valuable, but underappreciated, resource providing an overview of Transit ITS functionalities. To access the free ePrimer, follow the following URL:
https://www.pcb.its.dot.gov/eprimer/module7.aspx

It outlines the functionalities for Fleet Operations and Management as follows

> *Fleet Operations and Management covers technologies that are implemented to facilitate transit operations and provide input to senior management in terms of overall system performance;*
>
> ***Fleet Operations and Management Components:***
> - *Communications technologies*
> - *Automatic vehicle location (AVL)*
> - *Computer-aided dispatch (CAD)*
> - *Automatic passenger counters (APCs)*
> - *Scheduling (fixed-route and paratransit) systems*
> - *Transfer connection protection (TCP)*
> - *Transit signal priority (TSP)*
> - *Yard management*
> - *Intelligent vehicle technologies (e.g., collision warning and precision docking)*
> - *Lane control technologies*

Of the ten ITS components identified by the ePrimer related to transit fleet operations and management, this discussion paper will focus specifically on AVL, CAD, and TSP. Module 7 of the ePrimer provides useful definitions of these three components.

Automatic Vehicle Location (AVL)

"[An] AVL system is defined as the central software used by dispatchers for operations management that periodically receives real-time updates on fleet vehicle locations. In most modern AVL systems this involves an onboard computer with an integrated Global Positioning System (GPS) receiver and mobile data communications capability."[3] *AVL systems allow transit managers to monitor the actual or approximate location of transit vehicles in their fleet at any given time. AVL, GPS, and dispatching software are independent technologies, not all one and the same. Essential to an AVL system is the on-board computer*

(known as a mobile data terminal [MDT] or mobile data computer [MDC]) and the means to transmit the data back to a central dispatch location via a communication system for processing, interpretation, and response.

As a backup to GPS-based AVL, dead reckoning uses odometer readings and speed to determine vehicle location[2]. Although AVL systems and related components are usually installed for operational reasons, they can be used for TSP systems and customer information systems.

Computer-Aided Dispatch (CAD)

Computer-aided dispatch (CAD) software provides decision-support tools used by transit dispatchers and supervisors to monitor operations in real-time, allowing them to manage the operations proactively (handling delays, disruptions in service, and incidents as they occur). By having the CAD system notify operations staff of problems by exception, it allows staff to focus on areas of concern without the need to personally monitor operations to identify issues. Further, CAD can facilitate the "adjustment of vehicle headways, dispatching replacement or additional vehicles, or reporting incidences."[4] The key transit technologies that work hand in hand with CAD are AVL and communication technologies. In fact, most agencies refer to CAD and AVL as a combined CAD/AVL system.

A CAD/AVL system typically provides dispatchers with at least two displays: one that shows the locations of vehicles on a map (from the AVL system) and one that shows a queue of incidents or calls from vehicle operators (from the CAD system). Using these screens together, dispatchers can "identify and respond to problems on their routes. When a [vehicle] operator calls, the dispatcher sees a message showing the [vehicle] number on the CAD screen (which prioritizes the operator calls). The dispatcher selects the vehicle calling from the incident list and refers to their Automatic Vehicle Location screen for its location."[4] The CAD/AVL system helps dispatchers track route performance by notifying them of early, late, or off-route buses. Using the communication system (voice or data), dispatchers or supervisors can communicate with vehicles individually, in a specific group (e.g., all buses on Route 5) or with all vehicles.

On board the vehicle, the on-board computer is constantly checking the actual location of the vehicle vs. where the vehicle should be (based on the vehicle's schedule), resulting in the determination of schedule adherence. When the schedule adherence is outside a specific tolerance (set by the transit agency), this exception condition is reported to a dispatcher.

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[2] The GPS is typically used to locate vehicles on the Dispatcher's geographic screen, but in many supplier systems, the odometer is the primary source of information for location-based information to drive schedule adherence monitoring and traveler information, with GPS used for calibration.

Transit Signal Priority (TSP)

TSP systems give authorized transit vehicles the ability to automatically change the timing of traffic signals. This is often limited to extending the green cycle, but can result in red cycle truncation and phase insertion. Further, it may only be done "conditionally" based on passenger load, type of service (Bus Rapid Transit-BRT vs. local), and schedule adherence. The goal of these systems is to give priority to transit, and priority or preemption to emergency vehicles by reducing wait time at traffic signals without having an adverse impact on traffic. (Sometimes, preempting signals for emergency vehicles can have an adverse effect on traffic.).

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 [of] '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."*

Communication between the bus and the signal controller can be via radio frequency (as in DSRC), infrared, sonic, Wi-Fi mesh network, or cellular network. With transit applications, some traffic signal controllers are able use information communicated from the vehicles concerning their on-time status, indicating that the only vehicles that are running a prescribed amount of time behind schedule would be granted priority. This serves to limit the disruption to normal signal timing patterns and progression sequences with other coordinated signals on a roadway.

The following sections will treat the two CAD/AVL and TSP topics separately, and will include:

- a summary description of implementation within the industry
- recent developments, and
- issues and challenges raised through discussions with experts, much of which occurred during workshops and committee meetings organized jointly by ITS America and the American Public Transportation Association (APTA).

The discussion paper will conclude with a section that presents proposed recommendations for research and/or dissemination. A set of key references, along with abstracts, are also listed at the end of the paper.

2. CAD/AVL AND PROACTIVE OPERATIONAL CONTROL

2.1. IMPLEMENTATION

CAD/AVL systems are at the heart of most Transit ITS deployments. These systems continuously track all transit vehicles in real-time, which enables greater capabilities for reacting to service disruptions after they occur through improved incident management, security response, and service restoration. For example, disabled buses can be quickly identified, and appropriate maintenance staff dispatched. Problems caused by ill passengers, accidents, assaults, road closures, etc. can be quickly assessed, and the appropriate responses (e.g. dispatch of street supervisor, notification to emergency services, route deviations, etc.) can be implemented.

However, strategies used by operations management are for the most part reactive to disruptions, and there is little evidence that any systematic efforts have been made to engage in proactive operational control, whereby operations staff would use the tools available to identify problems, such as bunching or excessive gaps, as they develop, and take proactive steps before full disruptions occur. Conceptually, system-level knowledge of the locations of buses and patterns of disruptions to service levels provides a level of knowledge for control center dispatchers that is far superior than that which was formerly available to mobile street supervisors. Real-time knowledge of incidents and disrupted service as well as the location of alternative vehicles enables the use of a broader range of potential response strategies, and can be more rapidly deployed. However, such strategies are not generally well defined nor are dispatchers trained to use the technology for this purpose. This represents only one aspect where Transit ITS is not fully utilized by operations staff.

An additional difficulty may be caused by a shift in the focus of operations management. As the number of on-street inspectors has been reduced over time and replaced by a fewer number of control center staff armed with CAD/AVL, a loss of “service adjustment” skills may have occurred. Veteran on-street supervisors, stationed at key locations, were often quite good at re-deploying buses, holding buses, etc. to restore service to good schedule adherence, even though they didn’t have an overall picture of service status that is now provided by CAD/AVL. Control center staff are fewer in number and have to deal with more lines and buses than their on-street counterparts, and despite having better tools, find themselves spending most of their time on incident management. Over time, these dispatchers get promoted up the line, with their experience mostly based on incident management; the challenge may not be that they don’t understand the importance of proactive service control, but that they have never spent much time doing it and don't understand the capabilities offered by the new technology.

Dispatching of drivers in real-time to respond to a service disruption adds more complexity to the problem. The CAD/AVL system does not work directly off the scheduling database, but rather imports the schedule from the scheduling software. As soon as driver changes are required, operational control becomes more complicated since it is often not integrated with scheduling or human resource management software. The CAD/AVL systems are not able to estimate the impact of measures taken on the rest of the operations that can have a 'ripple effect' throughout the network, on both passengers and on the scheduling of vehicles and crews.

The capacity of Transit ITS greatly outstrips the capacity of transit staff to use this technology. As a result, this is an area that would be ideally suited to the application of AI tools for transit service control processes through the development of a DSS.

2.2. RECENT DEVELOPMENTS

2.2.1. Transit Operations Decision Support System (TODSS)

The Transit Operations Decision Support System (TODSS) is a system concept developed to support control center dispatchers, field supervisors, and operations managers to respond in real-time to incidents, special events, and other changing conditions in order to improve operating speeds, reduce passenger wait times, and restore service when disruptions occur. In 2003, the FTA and ITSJPO sponsored a project to develop core functional requirements for service disruption identification and provision of restoration options in order to build a TODSS. In 2006, Pace Suburban Bus (Pace) in Chicago was selected to lead a demonstration project to develop and evaluate a prototype TODSS and to validate the TODSS core functional requirements. Subsequent USDOT-sponsored reports evaluated the Pace TODSS demonstration, refined the TODSS core requirements, and developed a How-To Guide to apply System Engineering to support planning and deployment of a TODSS module. The following description is derived from these reports [listed in the Key References section at the end of the Discussion Paper]

In the Pace deployment, TODSS is integrated with Pace's CAD/AVL system and is designed to make better use of the existing CAD/AVL by evaluating events based on Pace operating rules to determine incident priority. Sources of information are continuously monitored and only those events requiring dispatcher attention are displayed along with corresponding service restoration options. When incidents are selected, the TODSS expertly guides the dispatcher through the CAD/AVL system to quickly gain situational awareness. The TODSS then provides a checklist of action items to perform in order to resolve the incident. External events are integrated into the CAD/AVL system by the TODSS and communications with other centers and systems are automated through the web, email, etc..

Through advance configuration of incidents, triggering rules, priority, and restoration strategies that conform to Pace's operating procedures, the dispatchers are guided through the CAD/AVL tools and the specific data related to an incident. The amount of data presented to the dispatchers is reduced, yet the pertinent information being evaluated to maintain and restore service has increased, enabling a more uniform response throughout the system.

When service is impacted and deviates from the baseline schedule the dispatcher must determine what restoration strategy to apply based upon constraining factors. They must consider:

- Demand for service including peak loads, the load of the entire route, or load over a segment of the route
- Traffic Conditions
- Characteristics of the route including turn around points, detour routes, scheduled deadheads, route branches, common trunks, and the length of trip
- Operating environment including the garage location, relief points, headway intervals, and vehicle and operator availability
- The level of service affected such as arterial, feeder, express circulator, or planned special event routes

The dispatcher's initial actions include gathering all pertinent information. They may communicate with operators or other support personnel to ask a series of questions suggested by TODSS to gather a complete understanding of the disruption. TODSS guides them through the CAD/AVL system views to assist with determining the impact on service including transfers, schedule adherence, vehicle spacing, vehicle health, operator assignment, and historical data related to the TODSS notification.

Once all information is gathered the service restoration strategy is decided upon and implemented.

For scenarios that require a transit center or terminal solution, techniques include:

- Vehicle jumping that uses an available vehicle (parked, staged, pulled-in) to replace one that became unavailable (breakdown, delayed)
- Shift the schedule time frame (i.e. timetable shift)
- Eliminate a departure
- Insert a departure

Restoration techniques made along the route may include:

- Modify schedule running times
- Wait at a bus stop or transfer point
- Bus changes
- Pass on the route
- Exchange drivers
- Route deviations
- Short-turns
- Relay vehicles
- Re-routing

Follow-up activities require the dispatcher to monitor the system until the schedule returns to normal. Customer relations and the customer information center are notified of the service impacts and the actions taken are recorded in incident reports, logs, and legacy systems for later analysis. Many operational scenarios have related reference materials such as service bulletins. The TODSS will provide links to dispatcher documents for quick and easy access to supplemental information.

2.2.2. Transit Decision-Support Systems Using Artificial Intelligence

Recent research has determined that even more advanced DSS have been deployed in many transit operations in France. These systems use AI to identify patterns as they emerge using pre-defined performance metrics for each route, such as percent of on-time vehicles on the route. The system incorporates a wide range of knowledge on route profiles, historical travel times between stops, and ridership patterns to suggest detailed response strategies that are tailored to the specific route, such as decision points for short-turns, deadheading, insertion of replacement buses, etc. Such sophisticated DSS enable proactive control and thus minimize disruptions, and increase the consistency of the strategies used by different dispatchers.

An equivalent operational control DSS is being deployed as part of the Montreal STM's iBus ITS project. The iBus project will also provide a DSS tool to develop a multi-criteria optimal solution for removing buses from existing routes and re-assigning them to bus-bridging services when there are major disruptions to subway service.

2.2.3. Use of ITS Data for Near Real-Time Operational Control

An emerging application of Transit ITS data is its use for real-time, or near real-time, operational control of bus and rail services. These would also qualify as DSS.

New York City Transit's System Data & Research Unit has been using a fast, agile software development process, using open source formats and software, and a highly dynamic and flexible collaboration between internal analytical experts and operations end-users, with great success.

Various historic and real-time data sources are being integrated into the various DSS for bus and subway control. These include:

- Schedules
- BusTime (on-time schedule adherence for buses)
- Countdown clocks (subways)
- Timekeeping
- Roadcalls
- Integrated Vehicle Network data (can be used to examine dwell and running times)

These sources of data are integrated to create various near-real-time reports to support operational control. These reports include:

- Reporting and visualization platform
    - Bus Bunching Dashboard

- Pinpoint problem routes and locations
- Allows Road Operations to investigate and take quick action

- Stringlines chart
  - A stringline chart represents each train trip by a "string" plotted with time on the horizontal axis and distance on the vertical axis
  - This tool is used for analysis of subway train movements

- Gap Table
  - Identifies the largest gap in service by line, direction, and console dispatcher's territory
  - Allows immediate action for improving headway regularity

A key lesson learned has been to improve data quality by integrating multiple sources. Not all data sources are available in real-time, but using what is available, and incorporating existing historic knowledge, can be valuable for quick decision-making and short-term analysis. The Data & Research Unit estimates near-real-time reports to be 80-85% correct in representing actual service performance. Special processes and algorithms are then used to connect several data streams for a more complete picture, and long-term analysis planning studies. The long-term goal is to have all data available in real-time for a comprehensive picture of service as it unfolds.

In another example, Transport for London has been working with MIT faculty and staff to explore the many ways that Advanced Fare Collection (AFC) data might be used. Much of the analyses have focused to date on origin-destination patterns and planning information. However, more recently, innovative ways are being developed to use historic and real-time AFC data, in combination with other ITS data to assist with operational control, in particular for the Underground. Information on network path choices, crowding, transfer patterns, etc. can then be used to assist with service disruptions with respect to modifying operational plans, providing alternative path suggestions to customers, and management of transfers and crowding.

Unfortunately, these developments are generally only feasible at the largest transit agencies that have sophisticated staff and the necessary resources to pursue such efforts. This is more difficult for smaller agencies; some suppliers are developing tools but it is usually difficult for them to work on an experimental research basis with transit agencies because of constraints imposed by procurement rules. An alternative approach would be to standardize and open up interfaces with and between CAD/AVL, scheduling, and other systems through the use of standard APIs[3]. This could enable the development of third-party applications that would be more accessible to smaller systems, similarly to open-source developments for passenger information and trip planning.

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[3] Mishra, S. *Augmenting the Transit Operations Management Tools with Emerging Technologies*, Proceedings, ITS World Congress, Detroit, September 2014

2.3. ISSUES AND CHALLENGES RELATED TO PROACTIVE CONTROL

ITS America and APTA co-organized an ITS Best Practices Workshop in Portland, OR in April of 2015 and in Atlanta, GA in November of 2015 that involved focused and structured discussions on using ITS for proactive control, with a special emphasis on TODSS. The following section outlines some of the most pertinent points captured during the workshop discussions.

2.3.1. Confusion over TODSS and the general issue of real time control

USDOT initiated a research and development project in 2003 to develop a draft set of requirements for a transit DSS, called TODSS. Culminating in 2012, Pace in the Chicago region was selected to demonstrate the use of this TODSS. Unfortunately, to this day, TODSS remains largely unknown by the industry, and there is confusion among those who are aware of it concerning its nature and impact.

The TODSS requirements were designed to be universal and generic in nature, and were not designed for any specific supplier product or platform. However, it was discovered at the Workshops that many people thought TODSS was a specific module from a specific vendor, though this was not the case – it was designed, using Federal funding, to be a generic set of requirements. Most CAD/AVL systems have pieces of these requirements but it seems like there's a step missing in that most transit agencies have not gone through a systematic process to identify the set of possible incidents and to standardize the business processes for responses to each incident. When asked, the transit agency participants in the Workshops concurred that they have not gone through the exercise of identifying incident types and the business processes and responses to them.

TODSS provides the dispatcher with a series of messages that could be sent to the driver's display – e.g. instructing he or she to go on a detour that is predefined, etc. Pre-formed messages can also be sent to others, such as street supervisors. Over time, if the responses and directions are captured, it helps to refine the response strategies over time.

TODSS formalizes the messages and messaging processes, but there has to be an internal institutional process to define types of incidents and business processes to respond to each type of incident. This effort is valuable in its own right. It forces the agency to develop a consistent set of responses, and to go through the steps to define those responses beforehand. Any CAD/AVL can support the messaging, but the intent is to force an agency to go through the response definition process beforehand.

Sometimes additional research is needed to determine the cause of problems. In the case of one bus route, off-line data identified a recurring problem at the same time. A new bus was assigned with a mid-bus camera (facing forward), which helped determine that the bus was being delayed by the parents turning in and out of a high school parking lot, causing traffic congestion at the school. As a result, Pace decided to add more running time to that segment, and a business rule through TODSS, where a driver can initiate a “need detour” message, and then can obtain permission to adjust his route to a predetermined detour.

2.3.2. Effective use of TODSS requires change management

The technology is available, but requires carefully working with the staff that will be affected. Expert knowledge to identify incidents and build that knowledge into the business rules comes essentially from the dispatchers.

Pace also chose to involve the operators at the outset to avoid any "big brother" perceptions. Including the APC data to calculate real-time loads was also valuable since it provides dispatchers with information to estimate what will be the impacts on the route later on, and helps ensure response decisions do not make things worse by overloading a bus and make it incapable of picking up any more passengers.

The Operations Department took the lead on the TODSS program. They worked with training supervisors and held workshops where drivers were informed of and could discuss intended actions. The operations people were key.

TODSS helps develop consistency among dispatchers and standardizes their training. This can be important even in small systems, for example where the evening dispatcher may be relatively unsupervised. This can help during litigation where lawyers will argue that an agency has no standard training procedures, inconsistent responses, etc. The TODSS addresses that weakness and records whether the operator followed the standard business rule and response for a given incident.

2.3.3. Using TODSS for Emergency Response

Pace is now engaged in a project with many other local agencies and the Argonne Labs to build on the existing TODSS and build a new set of methodologies to respond to major disasters.

The intent is to input transit information into the Argonne model in order to improve internal decision making and develop more accurate solutions. The emergency response operator would have 2 or 3 scenarios to redirect buses to deal with floods, heavy snow, or other major event. The intent is that the Argonne model will also feed back into and improve the TODSS. For example[le, the new system will also provide Pace dispatchers with all pertinent traffic and weather information.

3. TRANSIT SIGNAL PRIORITY (TSP)

TSP technology started being deployed in a small number of transit agencies 15 years ago. ITS America conducted an in-depth study for USDOT starting in 2003 to assess the state of the implementation of TSP. The result of this study was the preparation of a document, published in 2005, entitled: **Transit Signal Priority: A Planning and Implementation Handbook**.
http://nacto.org/wp-content/uploads/2015/04/transit_signal_priority_handbook_smith.pdf

The handbook provides a detailed analysis of the process for planning and implementing TSP, discusses key questions and issues encountered, and includes a national survey as well detailed case studies outlining actual experience in planning and deploying TSP. Case studies included in the handbook documented the implementation strategies and experiences of the following agencies:

- AC Transit, Oakland, CA
- King County Metro, Seattle, WA
- MTA, Los Angeles, CA
- PACE, Chicago, IL - Cermak Road Corridor
- Pierce Transit, Tacoma, WA
- TransLink, Vancouver, BC
- TriMet, Portland, OR
- Virginia - Route 1

Also contained in the handbook are a variety of resources on traffic engineering terminology and concepts to facilitate dialogue on TSP. It is intended for both transit and traffic engineering staff interested in TSP. Though new GPS-based technologies have emerged, the core of the report, which discusses the process for planning and implementing TSP remains largely valid today.

3.1. IMPLEMENTATION

USDOT conducts a survey of ITS deployment every few years; the last survey on Transit ITS occurred in 2013. This resource is practically the only way to ascertain Transit ITS deployment in the industry.

As of 2013, the survey found that 26% (37 agencies) of respondents operated TSP for buses. However, it is believed that this under-represents actual deployment since the TSP Handbook, included a national survey in 2004 that had identified 36 transit agencies that had already deployed TSP in that year. Unfortunately, there is no way to determine the accurate level of deployment since TSP suppliers do not divulge client lists. One could assume, though, that due to the growth of TSP technologies in the industry, additional sites have begun to implement such strategies.

3.2. RECENT DEVELOPMENTS

3.2.1. GPS-Based Detection for TSP

First generation TSP systems generally use optical-based fixed-point detection for transit signal priority. A new generation of TSP involves using GPS-based dynamic detection for both approaching and exiting intersections. This is more accurate, requires less maintenance of hardware, and uses accurate location monitoring to trigger priority requests, resulting in fewer requests, or greater effectiveness of requests.

GPS-based detection represents more state-of-the-art technology. The next step will be to take full advantage of the more accurate GPS-based detection technology, but the transit industry is just starting to evaluate these strategies. This is sometimes constrained by the unavailability of data at the controller, which hinders the measurement of the effectiveness of TSP strategies. A cutting-edge approach uses sophisticated micro-simulation tools to measure the benefits and impacts of more sophisticated TSP strategies; such strategies take advantage of real-time and dynamic detection enabled by GPS-based TSP systems. One can conceive that more aggressive TSP strategies could be deployed since they would be requested less often.

Unfortunately deployment of GPS-based TSP has been slow. As mentioned above, there is no accurate picture of how many transit agencies have adopted TSP at all, and even less so of GPS-based detection systems. An important obstacle is that TSP is very often combined with signal pre-emption for emergency vehicles, such as fire trucks. Historically, these vehicles rely most often on optical-base detection and have been deployed at many more intersections than required for transit priority. They also do not benefit as much from the greater accuracy in detection since they are merely pre-empting the signal to a green phase, not trying to maintain coordination of phases. This means that transitioning to a GPS-based system for both transit and emergency vehicles represents a very costly capital investment, and has been resisted by the emergency services. Some suppliers have as a result developed a hybrid system that can accommodate either type of detection.

3.2.2. Recent Transit Agency TSP Developments

In recent years a few transit agencies have incorporated extensive deployment of TSP as part of a comprehensive effort to reduce bus travel times along major corridors. These projects typically involve not only TSP, but also bus stop relocation and/or consolidation, queue jumps, etc. Examples include:

- King County Metro's RapidRide (BRT)
- Portland's Streamline program
- San Francisco MTA's MUNIFORWARD program
- Chicago CTA's Jeffrey Jump (BRT) project

The Jeffrey Jump project in Chicago is of particular interest. TSP technology suffers from several proprietary patents, which make deployment more complex and expensive. The CTA have been working with Pace and the Regional Transportation Authority to develop an open source TSP message protocol for the Chicago region.

> *The Jeffery Jump project was installed using a minimum amount of new equipment because many of the functions required for TSP are provided through the use of software running on existing on-bus and traffic signal control systems. Use of a message structure that the CTA and the City of Chicago have full rights to distribute makes the system, effectively, open source, requiring no sole source procurement or license fees for future TSP implementations in the region.* [Phillips, 2014]

The project has now been deployed on three corridors and 150 intersections in Chicago. Based on the preliminary success of the project, a similar version is being tested at Pace. The CTA and Pace demonstrations will eventually lead to a regional open-source TSP message standard. [Phillips, 2014]

It should be noted as well that some European technologies for communicating between the bus and the controller are based on non-proprietary "over the air" interfaces (e.g. VDV IBIS in German-speaking markets, KAR in the Netherlands, etc.). These have been successful in lowering the cost per vehicle / intersection for TSP deployent.

3.2.3. Multi-Modal Intelligent Traffic Safety System (MMITSS)

The Multi-Modal Intelligent Traffic Safety System (MMITSS) is being developed under the Connected Vehicle Research Program. This application will provide the next generation of traffic signal systems to service all modes of transportation, including general vehicles, transit, emergency vehicles, freight fleets, as well as provide communication mechanisms with pedestrians and bicyclists in a connected vehicle environment.

Advances in connected vehicle technologies provide the first real opportunity for transforming traffic signal control in terms of the traffic signal controller logic, operations, and performance. The advent of Dedicated Short Range Communications (DSRC) in vehicular communication provides a critical component that, when coupled with meaningful messages (SAE Standards J2735-2009), has the potential to provide detailed information required for intelligent traffic signal control. DSRC can be leveraged to provide real-time knowledge of vehicle class (passenger, transit, emergency, commercial), position, speed, and acceleration on each approach. The widespread availability of other wireless communications media (such as WiFi, 3G/4G, and Bluetooth-enabled Smartphones) provide coverage for other users including pedestrians and cyclists as well as coverage for other longer-range messages from vehicles that can support traffic signal system management in areas with sparse deployments of DSRC roadside equipment. The potential for safer and more efficient multimodal traffic signal operations is finally possible.

To realize these new opportunities, a MMITSS applications bundle has been conceived. This bundle incorporates, at a minimum, the following arterial traffic signal applications:

- Intelligent Traffic Signal System (ISIG)
- Mobile Accessible Pedestrian Signal System (PED-SIG)
- Emergency Vehicle Preemption (PREEMPT)
- Freight Signal Priority (FSP), and
- TSP

The proposed MMITSS-TSP application allows transit agencies to manage bus service by adding the capability to grant buses priority based on a number of factors (e.g. type of service, schedule adherence, passenger load, etc.). The proposed application provides the ability for transit vehicles to communicate passenger count data, service type, scheduled and actual arrival time, and directional information to roadside equipment via a DSRC-enabled on-board device.

The MMITSS application represents a bold new development. Unfortunately, knowledge of the MMITSS concept and demonstration program is virtually non-existent within the transit industry, and there have been no discussions to date to explore and discuss among transit agency staff how MMITSS compares to existing TSP technologies, and the practical issues that might affect its deployment.

It should be noted that parallel developments are also occurring in Europe to develop network approaches to TSP whereby total traffic flow is taken into consideration when evaluating TSP strategies.

3.3. ISSUES AND CHALLENGES RELATED TO TSP

ITS America and APTA organized an ITS Best Practices Workshop in Portland, OR in April 2015 that involved a focused and structured discussion on TSP. It brought together many of the leaders who were interviewed as part of the TSP Planning and Implementation Handbook project, in order to discuss their perspectives on TSP ten years after the publication of the Handbook. The following section outlines some of the most pertinent points made by participants during the workshop discussion.

3.3.1. Technical Challenges

There are **many complex technical choices** when deploying TSP, including:

- Detection and check out,
- Communications between vehicle and controller,
- Control strategies (i.e. conditional or unconditional priority)
- Integration with other systems (e.g. emergency response, traffic)
- Integration with BRT, physical priority (e.g. queue jumps)

The choices should be worked out through the Concept of Operations.

The following points were highlighted.

Conditional vs. unconditional priority: The choice depends to some extent on the objectives being pursued (e.g. reducing travel time vs. ensuring reliability).

Queue Jumps: These sometimes create their own problems if they include right-turning traffic; the buses may get caught in the queue of turning vehicles defeating the advantage of the TSP.

Delay at stops: Lengthy delay at stops presents a difficult challenge for TSP, especially for near-side stops and fixed point detection systems that use average time settings. King County Metro has used off-board fare collection to try and minimized stop dwell time on its RapidRide BRT routes.

Adaptive Control: There is growing use of adaptive control, but in the U.S., adaptive control systems can't provide TSP. Timing plans with adaptive control are based on volumes of traffic, not types of vehicles (e.g. emergency vehicles, buses)

3.3.2. Challenges Created by Traffic Engineering Perspectives and Practices

There was consensus among the Portland workshop participants that TSP provides significant benefits in terms of reduced travel time and/or increased reliability. However, there was participant consensus at the same time that TSP continues to face very significant challenges, and in particular resistance by local and (especially) state traffic engineers for a number of reasons.

Measuring Effectiveness: Person-Based Capacity:
The traffic engineering community continues to use Level of Service measures that are vehicle-based, rather than person-based. As a result, a single automobile on a minor side-street carries the same weight in traffic signal setting as a bus carrying 40 passengers.

The traffic system should however be designed to maximize *person-based capacity*, not vehicle-based capacity. The emphasis should be on transit and pedestrians. In this perspective, there should be more priority on transit and pedestrians rather than for cars. Portland has for example a pedestrian-first policy.

In addition, traffic engineers often acknowledge that they are very sensitive to phone complaints received from the public, though this hardly qualifies as an objective measure of effectiveness. As a result, single drivers who complain about increased delay on minor intersecting streets are often given more weight in traffic timing decisions than assessing the impact on the 40 persons that may be on the bus. It therefore remains a challenge to encourage using "person-based " rather than "vehicle-based" capacity as a basis for timing plans.

Signal Coordination
Signal coordination is also a major challenge. It has become a sacred concept among traffic engineers, but imposes huge constraints on TSP. Workshop participants, including traffic engineers, felt that it would be very useful if this constraint could be lessened. Perhaps one could encourage a "coordination diet" similar to the "road diet" concept that is being increasingly promoted. In this perspective, an isolated intersection might merit being given pre-emption rather than just priority.

As a result, ittle priority is actually given to transit in practice. Given all the constraints imposed by the traffic engineers (e.g. maintenance of coordination, recovery, limited green extension, etc.) and the limitations of the controller devices and the TSP systems themselves (in particular those using fixed point optical detection), workshop participants perceived that little actual priority is given in practice to transit buses.

3.3.3. Difficulty in Measuring Effectiveness and Benefits

Conditional priority systems provide much data, in terms of when priority requests are generated by transit vehicles. Unfortunately, most traffic controllers remain extremely limited in their data collection capabilities. In many cases, data is only stored for a week at the intersection controller, and someone has to physically go to the controller box to collect the data with a laptop. This makes it virtually impossible to measure the effectiveness of the TSP system since one cannot compare, at an individual bus level, what actions were taken by the Priority Request Server and the controller in response to a request by the bus. This makes it very difficult to measure effectiveness and beenfits of TSP systems.

And the problem is compounded when different jurisdictions use different controller equipment with different capabilities. It is therefore difficult to estimate in advance the marginal cost and benefit of deploying TSP. Micro-simulation models are useful but are complex, and everyone lacks accurate data.

3.3.4. Organizational Challenges

This above-mentioned challenges are further compounded by complex inter-organizational and human challenges, such as:

- Lack of interactions with counterparts,
- Lack of common knowledge about traffic engineering and transit operations,

- Lack of knowledge about TSP,
- Multiplicity of traffic jurisdictions,
- Fear of downgrading carefully-balanced timing plans, etc.

Many of these challenges were already identified in the TSP Planning and Implementation Handbook, published in 2005.

In response to a growing interest in TSP, but recognizing the challenges noted above, the Florida DOT, commissioned a *TSP Implementation Guidance* report, published in 2014. This report focuses on the organizational and human factor aspects that enable the building of successful partnerships. To access the report, utilize the following URL: http://www.dot.state.fl.us/transit/Pages/FDOTTSPImplementationGuidelinesFinalReport.pdf

Within the Florida report, it states

> *By its nature, implementing a TSP program is a collaborative practice, requiring coordination between multiple stakeholder agencies on key elements ranging from planning to operation to system evaluation. As interest in implementing new TSP systems gains momentum throughout Florida, there is an increased need for guidance concerning interagency coordination between the transit agencies (who often champion the development of a TSP system for the benefit of their services) and local transportation, traffic, and/or public works departments (who often operate the traffic control signals). The implementation guidelines presented in this report serve to enhance interagency coordination between transit agencies and local transportation/traffic operations departments during the planning, implementation, operation, and evaluation phases of a TSP system.*

The Florida DOT report proposed and discussed, in some detail, the following implementation guidelines for enhancing interagency communication and coordination during the planning phase of a TSP system:

- Leverage Existing Relationships
- Identify Core Stakeholders / Project Team
- Identify and Leverage TSP “Champions”
- Hold Regular Communication/Meetings
- Establish a Bottom-Up Process for Information Flow
- Provide Early Fundamental Education
    - For areas where TSP is a brand new concept, it will be important to provide a more broad-based fundamental educational component very early in the project process, often when TSP is initially being considered or explored.
    - Conduct a solid analysis (such as a simulation) to demonstrate the benefits of TSP and include in educational process. Demonstrable planning evidence for operations will help illustrate the quantifiable benefits of TSP to all parties.
- Balance Existing and Future Stakeholders in the Education and Planning Process
- Educate from All Perspectives

- Leverage Peer Experiences and Exchanges of Information
- Identify Appropriate Professional Resources
- Understand Technology Goals and Limitations
- Maximize Financial Benefit for All Parties
- Develop the Public “Message” and Outreach Plan
- Educate Internally within the Transit Agency and Traffic Operations Departments
- Begin the Interagency Agreement Process Early On
- Establish Communication Protocol for Reconciling System Issues and Efficiencies
- Identify and Agree Upon Parameters for Giving Priority
- Establish Performance Measures
- Establish Pre-Implementation Testing Process
- Conduct Periodic Monitoring and Maintenance Review

3.3.5. Transit Agency Leadership Needed to Promote TSP

TSP requires a champion to promote its use and ensure consistent support through the complex and lengthy process of decisions and negotiations required to carry if from concept to deployment. The champion must also ensure that TSP is included in the ITS Regional Architecture.

The champion must also encourage TSP at the municipal level in multi-jurisdictional regions. Some regional transit agencies have for example an explicit policy that links responding to requests from individual municipalities for more bus service with the requirement to deploy TSP in their municipality. This provides a win-win solution for all.

4. RECOMMENDATIONS

After thorough consideration of relevant materials and findings documented within this paper, the following recommendations, are presented in an effort to address some of the challenges of ITS implementation, and enable the transit industry, individually and as a whole, to make more effective use of ITS to improve transit operations through using ITS and DSS for proactive control, and increased use of TSP.

4.1. RESEARCH NEEDS

A few specific topics for research have been identified. These include:

4.1.1. Benefits and Return on Investment of Deploying ITS in Transit Operations

There have been extremely few studies in the last 15 years to measure the benefits derived from deploying ITS in transit operations, and this remains a significant barrier to promoting the use of ITS. Transit policy boards and senior management don't always understand the role of technology and the benefits to be derived from it, and this makes it difficult to obtain the resources and support to effectively use ITS. One can hypothesize a range of benefits including the following: the value of lives saved through improved security and more rapid emergency response, reduced delay and resulting operating costs for addressing disruptions, reduced potential loss of ridership by providing more rapid service restoration, increased ridership from more reliable service, etc.). There would be considerable benefit to research and document such benefits, and this would help technology and operations managers to build a more robust business case, and promote more effective use of the technology.

4.1.2. Enhancing Transit Service Quality through Proactive Operational Control and Decision Support Systems

CAD/AVL systems have been in existence for two decades or more, but there has been no research that has looked how ITS are specifically used in practice by transit operations staff and to identify the best practices by transit leaders who are effectively using the technology for operational control. This research should examine the system functionalities, the training and activities of dispatchers, and the strategies and business rules used. It should also identify best practices; measures of effectiveness, and the potential benefits that have been derived from effective use of ITS. The research might also consider the respective functionalities, interfaces, and enhanced integration between the scheduling and CAD/AVL systems. This should naturally lead to an examination of the application of DSS, such as TODSS or more sophisticated ones in existence in France or being implemented in Montreal, and explore any measurable benefits from the use of the DSS. The research could also examine the growing role of real-time data being used by transit agencies like New York City Transit and Transport for London, to assist dispatchers to recognize gaps and bunching as they occur.

4.1.3. Revisiting TSP

It has been over ten years since ITSA prepared for USDOT the *TSP Planning and Implementation Handbook*. Since then, there have been several technological developments such as GPS-based detection, the Chicago Region open source message standard, and the prototype development of the MMITSS connected vehicle traffic control concept. There have also been a very small number of individual TSP project evaluations. However, there has been no comprehensive document to look at TSP, its use and technical evolution, new technology developments of more open standards, etc.. There is not even an up-to-date inventory of the transit agencies that have deployed TSP. This research could help to encourage more transit agencies to adopt this cost-effective ITS technology.

4.2. ENHANCED DISSEMINATION AND SHARING OF KNOWLEDGE

In addition for research, there is also a great need to expand the dissemination and sharing of knowledge concerning the use of Transit ITS to improve operations. There has been relatively little focus or discussion on the use of Transit ITS to improve operations, and there is little to no knowledge within the transit industry of pertinent developments such as TODSS, and MMITS. Suggestions for expanding dissemination include the following:

- Find mechanisms to reach those that do not typically attend APTA conferences and workshops.
- Use the USDOT Professional Capacity Building (PCB) Program to have a series of webinars to share information on relevant topics.
- Develop workshops that would bring together suppliers, transit agency staff, and especially consultants that support transit agencies in developing Transit ITS specifications, in order to discuss TODSS and/or TSP.

KEY REFERENCES

General Transit ITS References

USDOT, 2013, ITS ePrimer Module 7: Public Transportation, Authored by Carol Schweiger**,**
https://www.pcb.its.dot.gov/eprimer/module7.aspx

The ITS ePrimer provides transportation professionals with fundamental concepts and practices related to ITS technologies. This online resource can help practicing professionals and students better understand how ITS is integrated into the planning, design, deployment, and operations of surface transportation systems. The ITS ePrimer is both a stand-alone reference document for the practitioner as well as a text for education and training programs.

The learning objectives for this module are as follows:

- *Understand public transportation technologies, how they function, and how they can be applied to facilitate or improve operations, customer service, and management;*
- *Recognize the dependencies among specific technologies;*
- *Understand the relationship between nontransit (e.g., highway-related) and transit technologies; and*
- *Realize the potential of transit ITS technologies to facilitate multimodal travel.*

Parker, Doug, 2008, TCRP Synthesis on Automatic Vehicle Location (AVL) systems (TCRP Synthesis 73), Transportation Research Board
http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_syn_73.pdf

Explores the uses of computer-aided dispatch/automatic vehicle location (CAD/AVL) systems in fixed-route and demand-responsive services (bus AVL), as well as changes in agency practices related to the use of AVL systems.

Transit Operations Decision Support System (TODSS)

Mitretek Systems, 2004, *Transit Operations Decision Support Systems (TODSS); Core Functional Requirements for Identification of Service Disruptions and Provision of Service Restoration Options*, Prepared for USDOT
http://ntl.bts.gov/lib/jpodocs/repts_te/13964/13964.pdf

This document provides core functional requirements for AVL/CAD systems to use in identifying and prioritizing service disruptions and providing options service restoration strategy options to in response. When these are incorporated into Core TODSS AVL/CAD systems they should assist dispatchers in responding to service disruptions more quickly and effectively than they are able to do today. Once finalized these functional requirements should also:

- *Provide for a common understanding between vendors and agencies concerning TODSS.*
- *Help vendors reduce the cost of customization*
- *Help agencies with procurement specifications*

Hiller, William and Kevin Luc, 2009, *Transit Operations Decision Support System (TODSS) Core Requirements Evaluation and Update Recommendations*, Prepared for USDOT
http://ntl.bts.gov/lib/54000/54600/54618/Technical_Memorandum_TODSS_Core_Requirements_Evaluation_and_Update_Recommendations_Final_Report_v4__final___2_.pdf

Transit Operations Decision Support Systems (TODSS) are systems designed to support dispatchers and others in real-time operations management in response to incidents, special events, and other changing conditions in order to improve operating speeds, reduce passenger wait times, and restore service when disruptions occur. In 2003, as part of a joint Federal Transit Administration and Intelligent Transportation Systems Joint Program Office effort, the transit industry developed core functional requirements for service disruption identification and provision of restoration options for TODSS. In 2006, Pace Suburban Bus was selected to lead a demonstration project to develop and evaluate a prototype TODSS and to validate the TODSS core functional requirements. This report documents the evaluation of the TODSS demonstration project with respect to the core requirements and impacts of TODSS, and includes recommended changes and lessons learned for the transit industry to better understand the TODSS core requirements for future implementations.

Hiller, William, 2010, *Transit Operations Decision Support System (TODSS) Core Requirements Prototype Development Case Study, and Lessons Learned*, Prepared for USDOT
http://ntl.bts.gov/lib/54000/54600/54619/Task_7_Final_TODSS_Report_V3.pdf

Transit Operations Decision Support Systems (TODSS) are systems designed to support dispatchers and others in real-time operations management in response to incidents, special events, and other changing conditions. As part of a joint Federal Transit Administration and Intelligent Transportation Systems Joint Program Office effort, the transit industry developed core functional requirements for service disruption identification and provision of service restoration options for TODSS in 2003. Pace Suburban Bus was selected to lead a demonstration project to develop and evaluate a prototype TODSS and to validate the TODSS core functional requirements. This report summarizes the TODSS Core Requirements Prototype development and provides lessons learned from the implementation and operation of the system. The summary highlights Pace's transit service and operating environment, the final TODSS prototype concept of operations, the system's architecture, issues encountered during the prototype development and implementation, the TODSS core requirements evaluation and update recommendations, and the operating experience from the time of implementation.

USDOT, 2010, *Transit operations decision support systems (TODSS) reduce false and low priority incident reports sent to dispatchers by 60 percent, allowing dispatchers to focus on higher priority incidents.*
http://www.itsbenefits.its.dot.gov/its/benecost.nsf/SummID/B2011-00714?OpenDocument=&Query=Home

Jackson, D., Semler, C., Ryus, P., and B. Nevers, 2014, *How-To Guide - Transit Operations Decision Support Systems (TODSS)*, Prepared for USDOT
http://ntl.bts.gov/lib/54000/54400/54471/FHWA-JPO-14-144_v1.pdf

Transit Operations Decision Support Systems (TODSS) are decision support systems designed to support dispatchers in real-time bus operations management in response to incidents, special events, and other changing conditions in order to restore service when disruptions occur. This How-To Guide is intended for use by agencies planning, deploying, operating, and maintaining (TODSS). It was developed based on the outcomes and lessons learned from the USDOT sponsored TODSS Prototype project with Pace in Chicago IL, and from interviews with agencies and vendors that have recently deployed TODSS and TODSS-like systems.

Transit Signal Priority (TSP)

Smith, H., Hemily, B. & M. Ivanovic. 2005, *Transit Signal Priority (TSP): A Planning and Implementation Handbook*. ITS America. Prepared for US Department of Transportation, Washington, DC: 2005.
http://nacto.org/wp-content/uploads/2015/04/transit_signal_priority_handbook_smith.pdf

> *This handbook, prepared for the U.S. DOT, has four objectives:*
> *1) 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, 2) To provide more extensive information on the current state of the practice of TSP in North America, 3) 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 and 4) 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*

Florida DOT, 2014, *TSP Implementation Guidance*
http://www.dot.state.fl.us/transit/Pages/FDOTTSPImplementationGuidelinesFinalReport.pdf

Pessaro, Brian and Caleb Van Nostrand, 2011, *Miami Urban Partnership Evaluation Report Agreement (UPA) Pines Boulevard Transit Signal Priority*, Prepared for USDOT
http://ntl.bts.gov/lib/55000/55500/55531/FTA_Research_Report_No_0002.pdf

> *The Miami Urban Partnership Agreement included the conversion of high occupancy vehicle (HOV) lanes on I-95 to high occupancy toll (HOT) lanes and additional express bus service. It also included funding for the installation of transit signal prioritization (TSP) at 50 intersections on Pines/Hollywood and Broward Boulevards in Broward County. This report summarizes the findings of TSP data collection on Pines/Hollywood Blvd. from December 2010 to February 2011. The data showed an average time savings of 4 minutes in the AM peak period due to TSP, which amounted to a 12 percent reduction in travel times. On-time performance improved from 66.7 percent to 75 percent. In the PM peak period, the travel time and signal delay were similar with or without the TSP activated. This could be an indication that afternoon traffic volumes on westbound Pines/Hollywood Blvd. are so heavy that TSP is of only marginal benefit.*

Phillips, David, 2014, Implementation of Open Source TSP, Proceedings 21st ITS World Congress

> *The transit signal priority system installed on the Chicago Transit Authority's J14 Jeffery Jump project is an example of a system that was installed using a minimum amount of new equipment because many of the functions required for TSP are provided through the use of software running on existing on-bus and traffic signal control systems. Use of a message structure that the CTA and the City of Chicago have full rights to distribute makes the system, effectively, open source, requiring no sole source procurement or license fees for future TSP implementations in the region*.

Stevanovic, A. Dr. Peter T. Martin, P. and M. Zlatkovic, 2013, *Evaluation of Transit Signal Priority Strategies for Bus Rapid Transit Project on 3500 South Street in Salt Lake County, UT*, Prepared for USDOT
http://ntl.bts.gov/lib/48000/48500/48544/MPC_09-213C.pdf

Bus Rapid Transit (BRT) is becoming one of the most popular transit services in the United States. BRT is a viable option for many cities and can offer commuters travel times comparable to those experienced in private cars. With about 100 miles of BRT service scheduled for deployment in future years, Utah Transit Authority (UTA) for the first time is facing questions related to BRT service. How will the service interact with private traffic? Will passengers accept unfamiliar features of the new service? We looked at the new BRT deployment in West Valley City, Salt Lake County, UT. Lacking BRT operational data from the field, but with a need to estimate operational challenges before the actual implementation, we used estimates generated from a microsimulation model. In addition, a series of surveys were conducted to gain feedback from the users of the BRT system. Results from the microsimulation runs show that the new BRT line leads to significant improvements of transit operations, with reductions of close to 20% in travel times and 40% in dwell times. An additional transit signal priority (TSP) feature is estimated to reduce travel times another 15%. The results showed that TSP has minor negative impact on side-street traffic and no impact or minor positive impact on main traffic. Results from the surveys show a high degree of acceptance of the new MAX buses among passengers and drivers. In short, the first BRT system in Utah can be qualified as another success story for the BRT systems in the United States.

Yue Li et al., 20018, *Transit Signal Priority Research Tools*, Prepared for USDOT
http://www.dot.ca.gov/newtech/researchreports/reports/2008/tsp_research_tools_final_report.pdf

This report presents the results of a research project that addresses Transit Signal Priority (TSP) deployment issues. The report reviews National Transportation Communications for ITS Protocol (NTCIP) 1211 Signal Control and Prioritization (SCP) standards, defines five SCP scenarios, and describes how the SCP scenarios can be applied differently based on TSP priority and operating policies. The report provides an overview of a number of TSP systems, including centralized TSP, two discrete TSP systems based on loop detection and Global Positioning System (GPS) technologies, and an Adaptive Transit Signal Priority (ATSP) system. A comparison of the different TSP deployments, and guidance on the necessary infrastructure required to implement these TSP systems, are provided. The report also discusses TSP evaluation methodologies, including recommended measures of effectiveness (MOE's) and data required for performing a quantitative assessment. Evaluations of a number of TSP deployment sites are documented to demonstrate how the benefits of TSP to transit and the impacts of TSP to traffic operations are assessed using the recommended approaches. Finally, the report provides guidance on TSP planning and analysis methods, such as simulation and regional modeling tools.

Hedden, Christopher, 2009, *Transit Signal Priority Systems Application and Technology Investigation; Final Report*, Prepared for New Jersey DOT
http://ntl.bts.gov/lib/31000/31700/31727/FHWA-NJ-2009-002.pdf

This report describes the process and results of research to develop an evaluation process that will assist NJ Transit in quickly determining which intersections are good candidates for Transit Signal Priority (TSP). This evaluation process is applicable for passive and active TSP and could be applied to a variety of roadways, including urban arterials, state routes and county roads.

H. Rakha and K. Ahn., 2006, *Transit Signal Priority Project, Phase II : Field And Simulation Evaluation Results*, Prepared for Virginia Transportation Research Council
http://ntl.bts.gov/lib/37000/37200/37285/06-cr6.pdf

> *Transit Signal Priority (TSP) is recognized as an emerging technology that is capable of enhancing traditional transit services. Basic green-extension TSP was implemented on U.S. Route 1 in the Northern Virginia Area (or Washington, DC metropolitan area). This study quantifies the impact of TSP technology on transit-vehicle performance using field-collected Global Positioning System (GPS) data and evaluates the system-wide benefits of TSP operations using computer simulations to expand on the field evaluation study. The field study demonstrated that overall travel-time improvements in the order of 3% to 6% were observed for TSP-operated buses. However, the results also demonstrated that green-extension TSP can increase transit-vehicle travel times by approximately 2.5% during congested morning peak periods. In addition, the study demonstrated that TSP strategies reduce transit-vehicle intersection delay by as much as 23%. The field study demonstrated that the benefits associated with TSP were highly dependent on the roadway level of congestion and were maximized under moderate to low levels of congestion. However, the simulation results indicated that TSP did not result in statistically significant changes in auto or system-wide travel times (differences less than 1%). Furthermore, a paired t-test concluded that basic green-extension TSP did not increase side-street queue lengths. An increase in the traffic demand along Route 1 resulted in increased system-wide detriments; however, these detriments were minimal (less than 1.37%). The study demonstrated that an increase in side-street demand did not result in any statistically significant system-wide detriments. Increasing the frequency of transit vehicles resulted in additional benefits to transit vehicles (savings in transit vehicle travel times by up to 3.42%), but no system-wide benefits were observed. Finally, TSP operations at near-side bus stops (within the detection zone) resulted in increased delays in the range of 2.85%, while TSP operations at mid-block and far-side bus stops resulted in network-wide savings in delay in the range of 1.62%. Consequently, we recommend not implementing TSP in the vicinity of near-side stops that are located within the TSP detection zone. The simulation results indicated that a TSP system generally benefits transit vehicles, but does not guarantee system-wide benefits. In this study, a maximum transit vehicle travel-time savings of 3% to 6% was observed with the provision of green-extension TSP from both the field and simulation evaluation studies. However, the green-extension TSP operation did not benefit nor damage the non-transit vehicles in most cases. Also, it should be noted that the results of the study may be specific to Route 1 corridor because of the unique characteristics of the study corridor, the specific traffic demand, and TSP logic implemented. Finally, the study recommends the calibration of current TSP settings to improve the effectiveness of TSP operation. Also, different transit priority strategies or a combination of other TSP strategies should be investigated to increase the benefits of TSP operations. A conditional TSP system that only provides priority to transit vehicles behind schedule and an intelligent transit monitoring system are also recommended to improve the TSP system on the Route 1 corridor.*