DEMONSTRATING TRANSIT SCHEDULE BENEFITS WITH A DSRC-BASED CONNECTED VEHICLE SYSTEM

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Transportation Research Board Submission Date: August 1, 2018

First Published: July 3, 2019 – Transportation Research Record (on-line)
https://doi.org/10.1177/0361198119859321

ABSTRACT

A vehicle-to-infrastructure (V2I), connected vehicle system was installed along Redwood Road in Salt Lake City, Utah, in November 2017 using dedicated short range communication (DSRC) radios to connect transit buses to traffic signals. One of the goals of this system was to improve the schedule reliability of the bus by providing signal priority at traffic signals when the bus is behind its published schedule by a certain threshold. Data for the analysis were obtained from the DSRC communications, the Automated Traffic Signal Performance Measures (ATSPM) system, and the transit operations system. The robust data available from these three systems allow for detailed analysis of priority requests made, requests served, and bus on-time performance in a way that is not possible without these data sets. By comparing actual schedules of the four DSRC-equipped buses over a four month period from April to July 2018 with buses which do not have the ability to request signal priority, it has been determined that the equipped buses meet their published schedule about 2% to 6% more frequently, depending on direction and time of day, with the most significant improvement of 6% in the Southbound PM peak.

Keywords: connected vehicle, transit signal priority, transit schedule reliability, DSRC, MMITSS, ATSPM, automated traffic signal performance measures

BACKGROUND

A 2013 report on connected vehicle systems stated, "The fundamental premise of the Connected Vehicle Environment lies in the power of wireless connectivity among vehicles, the infrastructure, and mobile devices to bring about transformative changes in highway safety, mobility, and in the environmental impacts of the transportation system" (*1*). Over the past five years, dozens of test deployments of connected vehicle systems have made progress toward realizing some of those significant benefits. In November, 2017, the Utah Department of Transportation (UDOT) deployed an operational connected vehicle corridor in the Salt Lake City area involving Utah Transit Authority (UTA) buses. In this deployment, a select number of buses and traffic signals along the corridor were outfitted with dedicated short range communication (DSRC) radios which allowed the buses to request signal priority at intersections under certain conditions. This deployment may be the first vehicle-to-infrastructure (V2I) deployment in the United States using DSRC technology as part of an operational transportation system.

UDOT has been involved in planning and discussions around connected vehicle technology for over 15 years, including participating in the American Association of State Highway Transportation Officials (AASHTO) Connected Vehicle Task Committee and the Connected Vehicle Pooled Fund Study (a cooperative research effort with other states managed by the Virginia Department of Transportation). In late 2014, UDOT decided to initiate efforts to deploy V2I systems. The goals of this initial deployment included: 1) to gain hands-on experience with the procurement and installation of DSRC equipment, 2) to deploy an application that could yield a tangible benefit (to justify the cost of installation), and 3) to build a connected vehicle corridor which could subsequently be used for the development, testing and implementation of other connected vehicle applications, including those that will ultimately be installed in private vehicles. To meet the second goal, UDOT considered a number of potential applications and decided to deploy a transit signal priority (TSP) system, in partnership with UTA, to address schedule reliability issues. A broad evaluation of potential DSRC deployments and applications prepared by AASHTO in 2011 indicated that "transit vehicles represent a good target for early adoption of Connected Vehicle systems, as long as they can be shown to provide value to the operator" (*2*). Those conditions appeared to be true in UDOT's analysis of early DSRC deployment options. A TSP system would also meet the other two original goals and would be scalable to other corridors if it proved to be beneficial.

The implementation of a conditional TSP system on this corridor using DSRC connected vehicle technology provided a unique opportunity to assess the effectiveness of TSP. Using data generated by the buses, transmitted through the DSRC system, and logged by the traffic signal controller, UDOT was able to perform an analysis of priority requests made, requests served, and bus on-time performance in ways that had not previously been possible.

RELEVANT RESEARCH AND NEW APPROACH

TSP has been implemented in a variety of forms for many years. TSP systems are generally classified as being either passive or active. Passive strategies involve modifying traffic signal operations whether or not a bus is present. Examples include dedicated bus lanes, special signal phases, or simply having longer green times for approaches with buses. Active strategies only grant conditional or unconditional signal priority when a bus is present.

Some TSP systems in use today require a transit vehicle to be a specified amount of time behind schedule in order to request TSP. These systems use optical emitters or radio frequency identification tags to send requests to the signal. A TSP system based on a "lateness" criteria was operating in Vancouver, British Columbia, in the early 2000s, and a similar system in Portland, Oregon in 2004. Both used infrared technology. Los Angeles, California, had a headway-based conditional priority in the early 2000s, where priority was granted if a certain interval of time had passed since the previous bus detection. This system used loop detection (*3*). In the past few years, other technologies have emerged to facilitate priority. The *Transit Capacity and Quality of Service Manual, 3rd ed.,* published in 2013, states that "the combination of global positioning system (GPS) and wireless technology are emerging technologies for TSP application" (*4*). At the time the Utah project became operational, the authors were not aware of any other TSP system which was actively using wireless DSRC communication, although several were being planned.

While it is common to analyze the impact of TSP prior to deployment, few TSP operations are actually evaluated post-deployment (*5*). Post-deployment evaluations that have occurred are focused primarily on bus travel time, bus delay, and bus reliability with results indicating significant potential benefits for buses (*4*). Analyses seeking to determine the impact of TSP on general traffic rely almost exclusively on simulations.

Within the last five years, the availability of high-resolution traffic data has made it possible to systematically evaluate general traffic conditions using field data instead of simulations. With advanced signal controllers and robust detection systems, the use of high-resolution data within Automated Traffic Signal Performance Measures (ATSPM) systems allows for detailed analysis of vehicle arrivals, signal operations, split failures, TSP service and many other conditions (*6*).

Two-way communication using wireless DSRC radios provides additional, time-specific, granular data about bus location, factors justifying priority requests, and the actual requests made.

The analysis described in this paper employed data generated by three unrelated sources, described later in more detail: 1) operational data from the buses, 2) data transmitted through the DSRC system, and 3) high-resolution data logged by the traffic signal controller and evaluated in the ATSPM system. This represents a new approach. Other unique features of this deployment include: 1) the green extension can be truncated upon receipt of a priority request cancellation message, 2) the amount of green extension is variable, is known, and can be analyzed, 3) the analysis uses actual, operational data rather than putting historical field data into a simulator, and 4) the availability of this operational data can facilitate an analysis of impacts of TSP on other traffic without simulation. A traffic impacts analysis is underway using this data but is not reported here pending completion of the analysis.

DEPLOYMENT DESCRIPTION

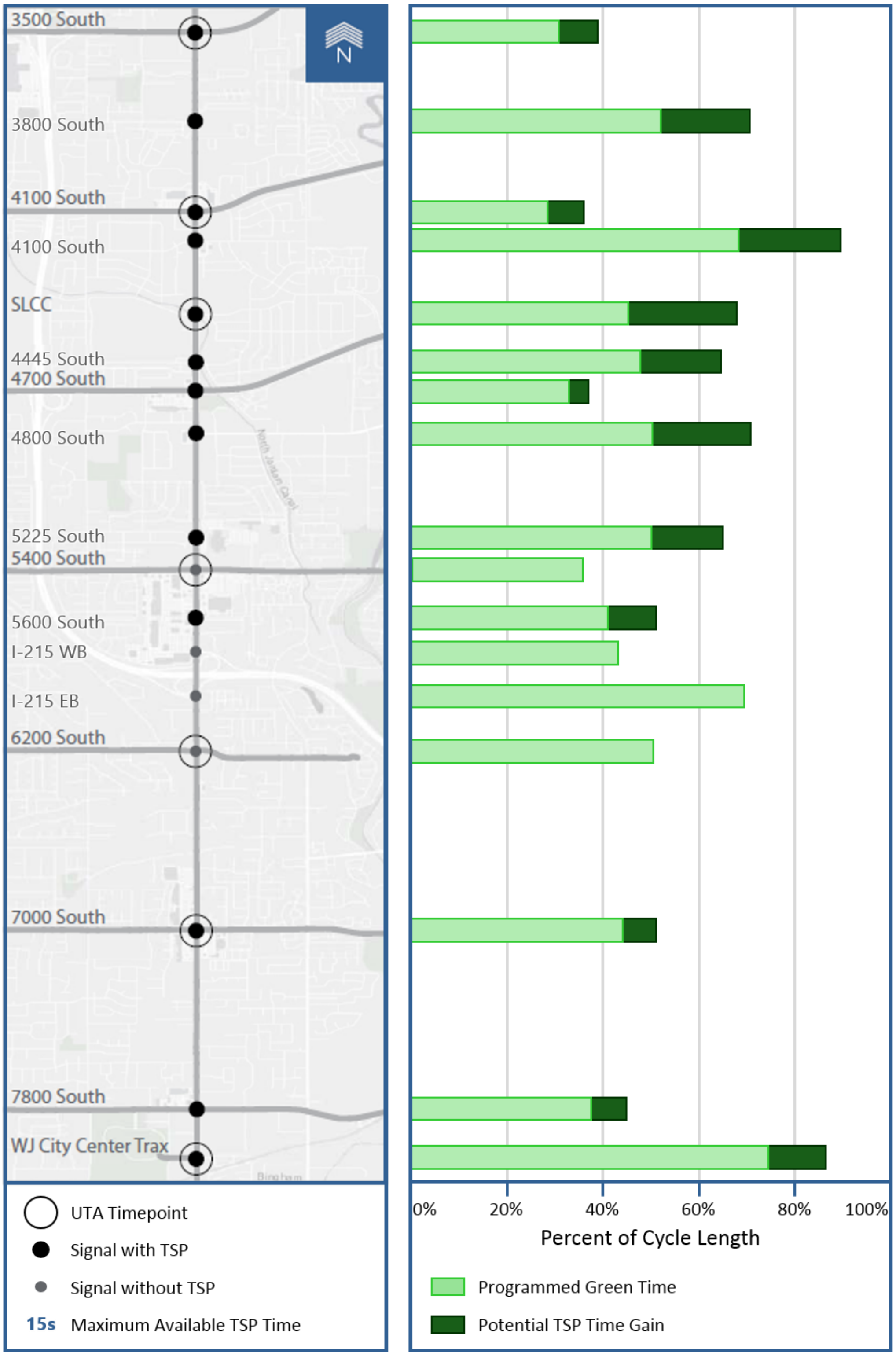
Corridor Selection

Three criteria were used to select a corridor for the installation of a TSP system using connected vehicle technology: 1) an urban corridor with a regular bus route which experienced challenges in maintaining adherence to its published schedule, 2) availability of traffic signals connected to the UDOT central traffic control software, and 3) a variety of traffic conditions along the corridor. UTA proposed several bus routes in the Salt Lake City area which regularly experienced performance delays, and UDOT used the above criteria to select Redwood Road from these routes.

Redwood Road is a state-owned, north-south arterial just west of downtown Salt Lake City, Utah. The portion of Redwood Road selected for installation of connected vehicle technology is about 11 miles long with 30 signalized intersections, extending from 400 South to 8040 South. Evaluation of transit schedule performance in this study is focused on only 6 miles of the corridor, shown in Figure 1(a). The corridor traverses industrial areas, commercial districts, residential neighborhoods, and passes a large community college and a high school. Redwood Road ranges from five to seven lanes, including a two-way left turn lane for most of the corridor. Average annual daily traffic (AADT) ranges from 18,000 at the north end, which is less densely populated, to 40,000 at the south end, with a peak of 60,000 at the I-215 interchange. Trucks make up 24% of that traffic.

Traffic signals along Redwood Road are operated using two brands of signal controllers: Econolite Cobalt and Intelight MaxTime. These controllers are connected to a fiber optic network and are controlled by the Intelight MaxView central signal software at the UDOT Traffic Operations Center. In addition, each controller provides high-resolution signal data to the UDOT ATSPM system, which facilitates the analysis and management of signal operations (6).

UTA Route 217 travels along Redwood Road through the full extent of this project. During most of the day, buses run on 15-min headways. During early morning and late evening hours, headways are 30 min. After about 9 p.m., headways increase to 60 min. At the time this project was initiated, UTA reported that the schedule reliability of Route 217 was about 86%, meaning that buses arrived at their designated time points less than 5 min late 86% of the time. Overall, UTA indicated that their bus system performed at a schedule reliability of about 94% at the time this project was initiated. Using TSP to improve the reliability of Route 217 was a key metric for this project.



a) Map of corridor b) Green time for main street phases with and without TSP

FIGURE 1 Redwood Road study corridor and signal controller programming for TSP

Connected Vehicle Communications Systems

UDOT acquired and installed DSRC road-side units (RSUs) at 25 of the 30 signalized intersections along Redwood Road. The five intersections not included in the DSRC deployment were two freeway interchanges, a cross-street with reversible lanes, a continuous-flow intersection, and a light-rail train crossing. The team determined that it was too complicated to intervene in the operation of these intersections with the TSP system.

In the early stages of the project, DSRC hardware was acquired from four different vendors so that the project could test and demonstrate interoperability of both hardware and software applications. The vendors included Savari, Arada (acquired by Lear in 2015), Cohda, and Lear. RSUs from all four vendors were installed along the Redwood Road corridor. Hardware compatibility turned out to be elusive due to the variations in the firmware systems and how standardized messages are handled by each vendor. None of the vendors managed the “signal request message” (SRM) and “signal status message” (SSM) (both of which are discussed in subsequent sections of this paper) in the same way, which required the software developers to find workarounds in the software. Each vendor handled message headers differently, in ways that were incompatible with other equipment. As described below, the application software does not operate on the RSU, it resides on a single-board Linux computer. Each brand of DSRC unit passes critical pieces of information off to the computer in different ways, and in some cases, will not pass certain data elements to the computer. These challenges, coupled with inadequate vendor support in some instances and a need to move the project forward in a timely manner, drove the decision to focus on one brand of DSRC unit. At the time of this study, the TSP system was only operational on this corridor at intersections where the Lear DSRC units were installed, generally south of 3500 South (*7*). Because of this constraint, this evaluation of the effectiveness of the TSP system on transit schedule reliability is confined to that portion of the corridor.

Similar to the roadside DSRC installations, all four brands of DSRC on-board units (OBUs) were tested on the transit vehicles. The OBUs are mounted in the bus communications cabinet, where they are powered and connected to the UTA communication system. In the operational TSP system, due to the same challenges described above for the RSUs, Lear OBUs were the only brand deployed on the buses during this study.

In addition to DSRC radios, small, single-board Linux computers were installed to process messages and run the TSP application software. BeagleBone Black industrial-grade Linux boards, with 1GHz CPU with 4GB of flash memory, were selected because of their processing capability and performance in harsh working environments. The board was placed in a protective case for installation. These boards were installed in each signal cabinet and bus where DSRC radios were installed.

Application Software

The TSP application software used on the Redwood Road project was based on the Multi-Modal Intelligent Traffic Signal System (MMITSS) application developed for the Connected Vehicle Pooled Fund Study by the University of Arizona, in conjunction with the University of California PATH Program (*8*). The MMITSS application utilizes V2I communication to consider and balance signal priority requests from vehicles approaching an intersection. Proof-of-concept versions of MMITSS have been deployed in Anthem, Arizona and Palo Alto, California. The use of MMITSS in the Utah deployment was focused on providing signal priority for individual transit buses which are behind schedule and met a minimum occupancy criteria, with the goal of helping those buses get back on schedule. A number of software modifications were made to the Arizona version of MMITSS to enable the “behind schedule” and “minimum occupancy” criteria, adapt it for operation with UDOT’s coordinated traffic signal system, and update it to meet more recent message standards. The modified version used on Redwood Road is referred to as MMITSS-Utah.

Other, more traditional, hardware and software approaches are available to provide transit signal priority, but the capability to use schedule and occupancy criteria were not common features in commercial systems at the time this project was initiated. Features were created in the MMITSS-Utah software to provide these capabilities. In addition, the DSRC-based MMITSS-Utah system created data streams which were useful in the analysis of TSP effectiveness.

Vehicle to Infrastructure Communication

Signal priority is facilitated in the MMITSS-Utah system by a series of messages passed between the traffic signal and the bus over the DSRC radios. These messages are defined by the Society of Automotive Engineers (SAE) in their J2735-2016 standard (*9*). The RSU broadcasts a “signal phase and timing” (SPaT) message that describes the current status of the signal light phases for each intersection movement, including whether priority requests have been made, and a map data message (MAP), which defines the geometry and configuration of the intersection, including the function of each lane (through or turning) and related features, such as crosswalks. In addition, the RSU broadcasts an SSM to report the status of active priority requests.

The OBU broadcasts a “basic safety message” (BSM). The intent of the BSM is to describe many aspects of a vehicle’s location, movement and activities, including things such as braking status and steering wheel turn angle. In this application, only portions of the BSM are sent, including the vehicle location (determined by the GPS on the OBU), speed and direction. The OBU also broadcasts an SRM to request signal priority, when the MMITSS-Utah application determines that a request is warranted, or to cancel that request when it is no longer needed.

BSM and SPaT messages are sent by the DSRC every one-tenth of a second. MAP, SRM and SSM messages are sent once per second.

Operation of the Application Software

In the MMITSS-Utah application, buses are allowed to request signal priority when they are behind their published schedule by at least 5 min and have an occupancy of at least 20%. The “five minute” schedule criteria is standard operating procedure in the UTA system. The “twenty percent” occupancy criteria, which corresponds to nine or more riders in the bus, was a selection made by the UDOT project team as a conservative approach to restrict the frequency of TSP service. Since it was unknown how granting TSP would impact other vehicles, UDOT decided to use this criteria to minimize the number of TSP calls. Some members of the project team disagreed with this choice because it ignores the fact that the interests of downstream riders should also be considered. Both of these criteria can be changed in the system, so an evaluation of broader traffic impacts can inform future operation. Figure 2 shows the percent of trips satisfying the occupancy criterion in the AM and PM peaks through the entire transit route. The grey area indicates the study corridor.

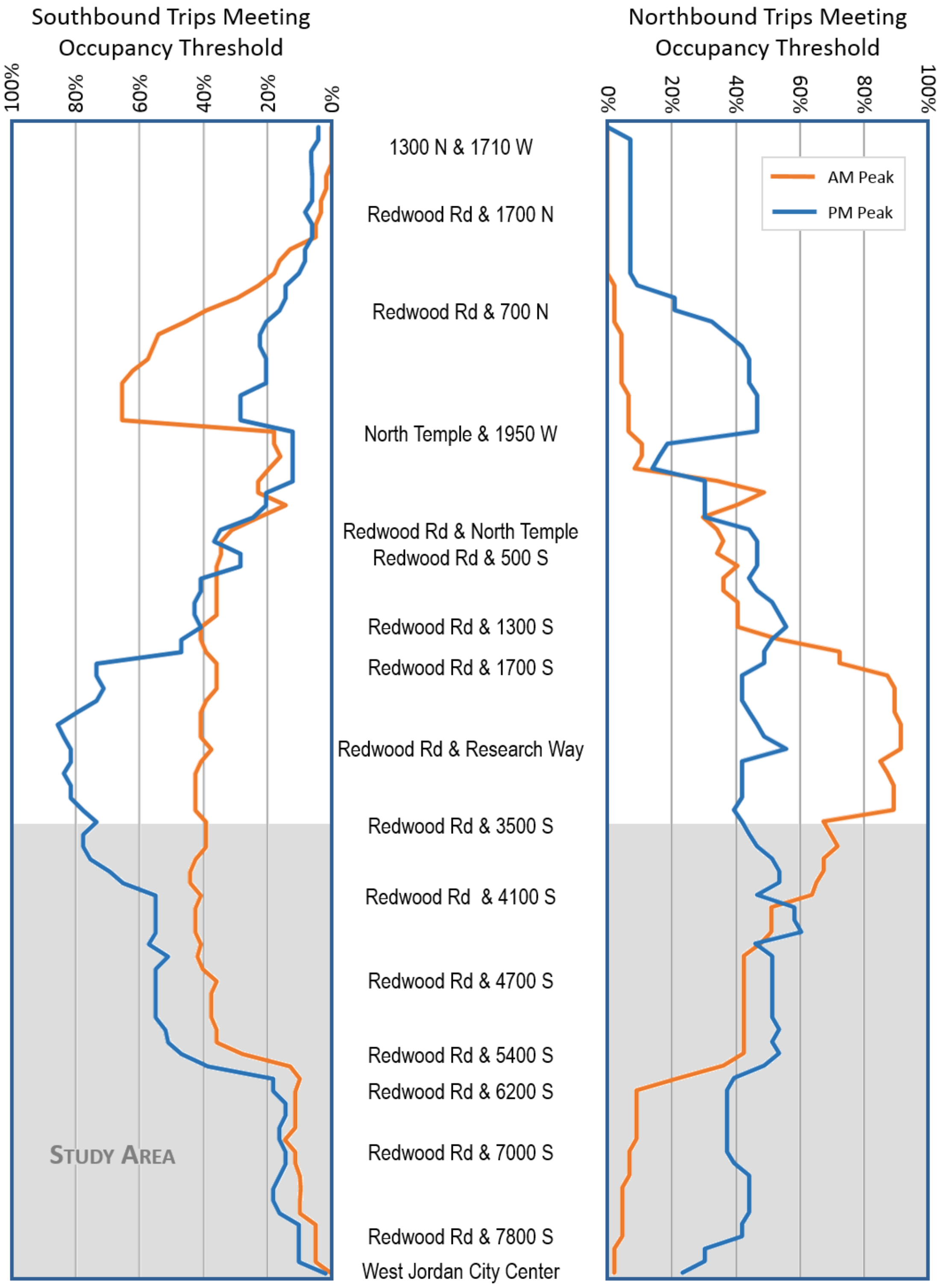


FIGURE 2 Percent of AM and PM trips meeting occupancy threshold

Buses are connected via cellular communication with the UTA operations software, Service Interface for Real-time Information (SIRI), and are tracked with GPS systems. As the bus passes designated "timepoints" along its planned route, usually major bus stops, the SIRI system determines if the bus is more than 5 min later than its published schedule, and, if it is, designates the bus as "late". Optical sensors in the doorways of the bus keep track of occupancy. The on-board MMITSS-Utah software connects to the on-board SIRI interface and queries whether the bus is "late" and meets the occupancy requirement of 20%. As the bus enters a geo-fenced limit around a signalized intersection, usually defined as 20 s ahead of the stop bar, or about 1000 ft, information in the MAP and BSM messages is used to determine which lane the bus is in and how far it is from the stop bar. If the "late" and occupancy criteria are met, the OBU then requests signal priority by sending an SRM message to the RSU. The Linux processor passes that message to the signal controller, and the controller logic determines whether the request can be served. The RSU sends a SSM back to the OBU indicating that the priority request is active. The controller does not report whether the request was served, so the MMITSS-Utah system does not know the result of its request. Once the bus passes through the intersection, the request is cancelled through another SRM message. The sequence of operation is shown in Figure 3.

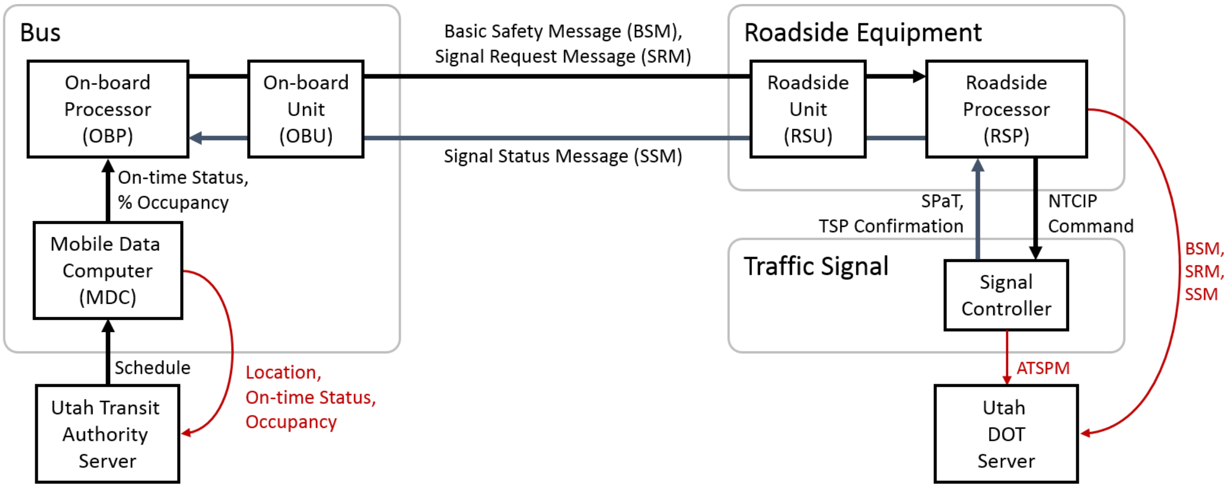


FIGURE 3 MMITSS-Utah operation diagram

The MMITSS-Utah system operates transparently to the bus driver. Messages are sent automatically, without any action by the driver, and no indication is given to the driver that the system is operating or that signal priority requests are requested or served. This was done because driver intervention is not needed and to avoid distracting the driver.

The data generated by this system is transmitted from the RSU over the UDOT fiber network and archived on servers in the UDOT Traffic Operations Center (TOC). This allows the data to be analyzed to identify operational problems in the MMITSS-Utah system (malfunctioning hardware, data errors, etc.) and to assess the performance of the system in meeting the schedule reliability goal.

The first test deployments of the MMITSS-Utah system occurred on Redwood Road in 2016, and demonstrations were held for several groups in late 2016 and early 2017. The system was put in operational mode in November 2017 at the intersections south of 3500 South and in four

UTA buses. System evaluation began with a data set covering a six-week period in February and March 2018. Using lessons learned from that analysis, a more complete data set was obtained for a four month period from April to July 2018. The analysis described in this paper is based on that longer data set.

MEASURING PERFORMANCE OF THE SYSTEM

Data Types and Sources

As stated earlier, the proposed goal of this TSP system was to improve the schedule reliability of UTA Route 217 from about 86% to 94%. Assessing the reliability required the use of various data sets from three distinct sources. The availability of these data sets, and their use in evaluating the effectiveness of a TSP system, is a unique feature of this project. These various data points are shown on Figure 4.

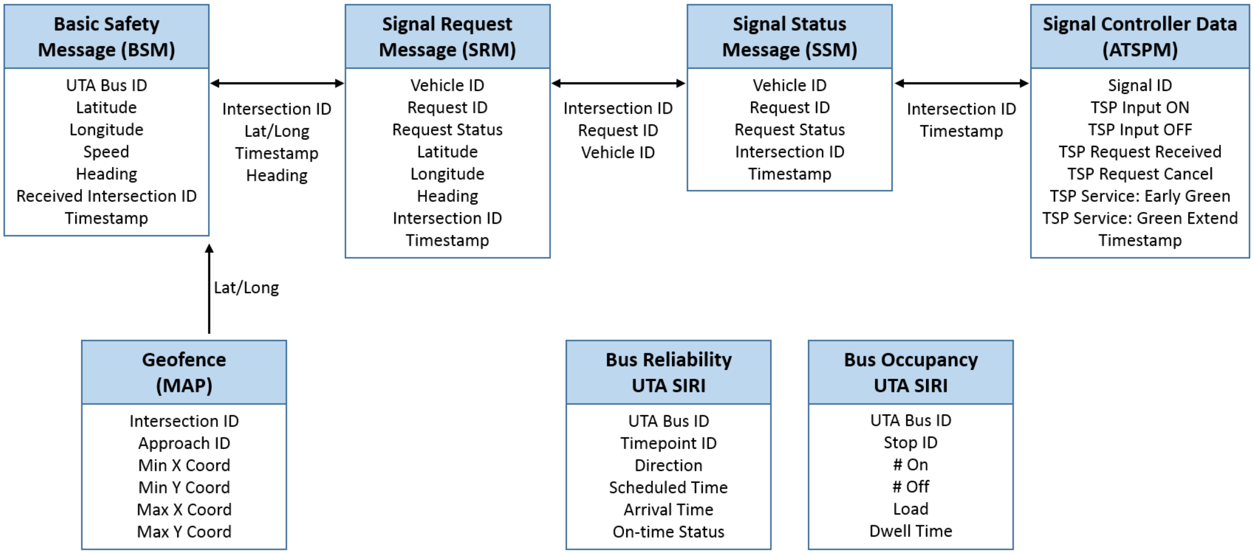


FIGURE 4 MMITSS-Utah database diagram

DSRC Data

Key performance evaluation data from the DSRC system is included in four of the messages sent between the RSU and the OBU. The BSM message includes the UTA Bus ID, location, direction and speed of the bus, and the timestamp of each message sent. The MAP file defines the "geofence" around a particular intersection, and includes the intersection ID and a series of coordinates defining the extents of each lane, or approach. When a signal priority request is made, the SRM message includes a random vehicle ID, the location of the vehicle at the time of the request, an ID of the intersection with which it is communicating, and a timestamp of the message. The SSM message confirms the vehicle ID making the request, the status of the request, and a timestamp of the message.

UTA SIRI Data

Two key data sets are obtained from the UTA system. The reliability database includes a record each time a given bus reaches a designated timepoint. At that timepoint, the system records the bus

ID, the timepoint ID, the travel direction, the bus's scheduled and actual arrival time at that timepoint, and the resulting on-time status. A separate database records the number of passengers that embark or disembark at each bus stop, the net number of people on the bus (the load), and the amount of time the bus dwells at that bus stop. The occupancy value is reset to zero at the beginning of each trip. These databases are stored on the bus and downloaded to the UTA server when the bus returns to the UTA operations and maintenance facility.

ATSPM Data

The ATSPM data generated by the signal controller every one-tenth of a second includes the signal ID number and timestamps for TSP request activations and cancellations, TSP by early green or green extension services, and start time of signal phase intervals (*10*).

Challenges with Data Correlation

While it seems straightforward to correlate these various data points from each of the three sources, matching data points proved to be complicated and cumbersome. There is not a common key between the three data sets or even all of the DSRC databases. To eliminate TSP requests from test vehicles or other anomalies, the bus ID, location, direction, and timestamp of the DSRC-enabled bus events generated from the BSM dataset were used to restrict data in the other DSRC and ATSPM databases. These data were manually compared to the UTA SIRI data and bus schedules to validate and verify the process.

The BSM data is broadcast very frequently (every one-tenth of a second) over DSRC. The nominal range of the signal is about 1000 feet, but the signal can often be received at much greater distances. In many instances, the BSM message was being received at multiple signals simultaneously even though the bus was approaching only one of the signals. Further, the frequent broadcast of the message resulted in multiple records for a single bus or request event. These issues were resolved by using a proximity filter based on the MAP of the intersection. Reduced databases were created by eliminating all records for each RSU outside of the extents of the geofence defined by the MAP file. The limit, time, and direction filters were then used to determine the first and last records for each bus event to determine the duration of the bus at each signal. These filtering exercises removed the noise and redundant data, and created an event used to correlate all the datasets.

RESULTS

TSP Requested and Served Analysis

A major step in understanding how the TSP system is operating is determining how often TSP is being served. Too many TSP services can have a detrimental impact on other road users. Too few TSP services might limit potential benefit to the transit system. In this analysis, the SRM database was used with the ATSPM database to trace TSP requests through the system.

To determine how often the bus requested TSP as it traveled the network, the BSM database was compared to the SRM database. The BSM database includes multiple records for each time the bus travels through a DSRC-equipped signal. These data were grouped to create a single record, or bus event, for each bus at each signal per bus trip. These records were aggregated to determine the total number of bus trips at each signal. SRM data was generated at each signal only when the bus is within the extents of the MAP file and when the bus is considered late. This data provides the number of TSP requests. Figure 5 shows the percentage of bus events at each signal where TSP was requested and served, with the southbound PM peak on the left side and the northbound AM peak on the right side. The height of the curve in Figure 5 represents the total TSP requests.

The ATSPM data from the traffic signal controllers were used to determine how often TSP requests were served. The signal controller logs events when the TSP request is received and when extra time is provided to TSP-enabled phases. The events when extra time was provided were used to define when TSP was served. These events were matched to the bus events with the same time frame and direction. The percent of bus events with a TSP service is represented by gray areas in Figure 5. The red areas in Figure 5 represent the percent of requests that were not served.

One of the major reasons a TSP request will not be served is that the bus passes through the intersection without stopping during the green interval, causing the request to be cancelled before it is served. A low rate of TSP service often occurs at intersections with low-volume side streets, which tend to have more green time for the main street (see Figure 1(b)). For example, TSP is requested for about 35% of bus trips northbound in the AM Peak at both 4700 South and 4445 South. TSP is served for 33% of these requests at 4700 South where only 8% of the requests are served at 4445 South. As shown in Figure 1, the major street signal phase is allocated 33% of the green time at 4700 South, while the major street at 4445 South is programmed with 45% of the green time in the cycle length. The side street phases at 4445 South are often skipped and the signal will frequently rest in green for the main (north and south) movements for two or three cycles. Therefore, the bus has a greater chance of arriving on green at 4445 South than at 4700 South, which is reflected in the frequency of TSP service relative to requests.

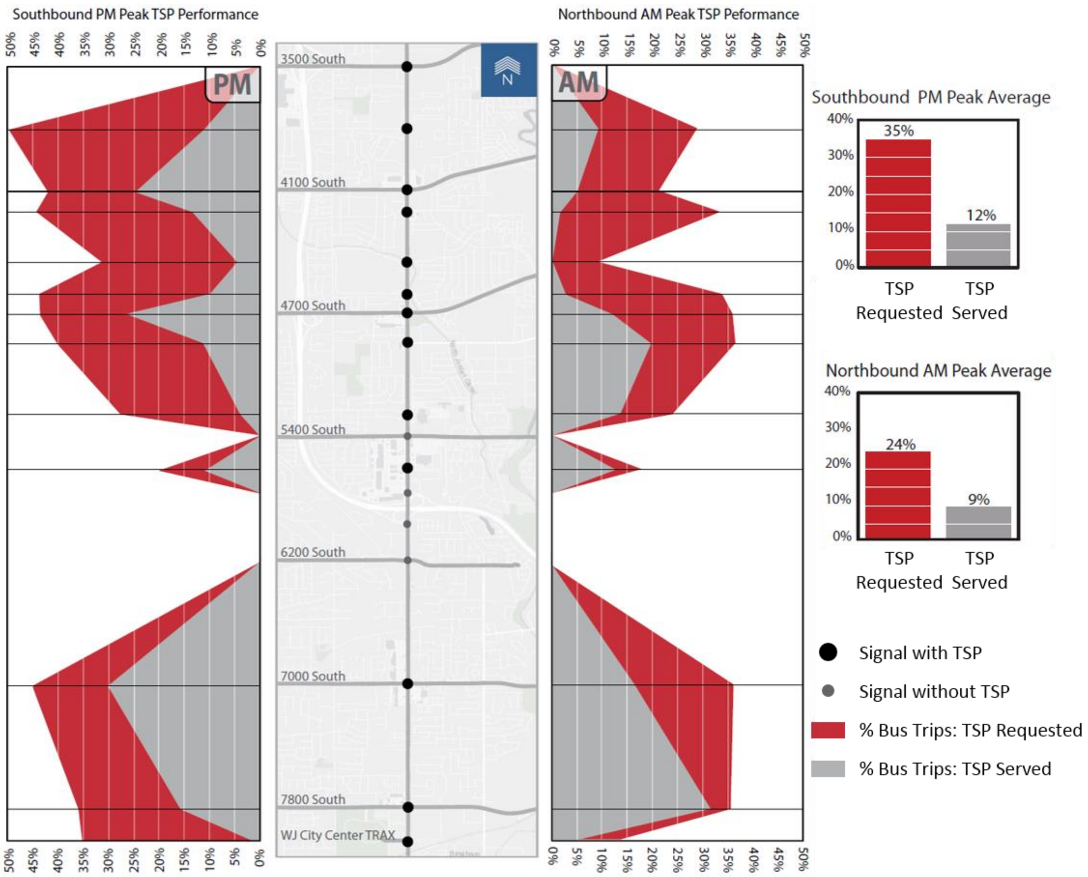


FIGURE 5 TSP requested and served analysis for peak period and direction

Bus Reliability Analysis

The most important metric evaluated is whether the TSP system actually improved the reliability of the bus system. This evaluation was completed solely from the data in UTA's reliability database. UTA's method for calculating reliability counts all on-time arrivals for each timepoint and divides them by the total arrivals for that timepoint. A bus is considered "on time" when it is less than five min behind its scheduled arrival time.

The analysis compared the average reliability of equipped and non-equipped buses on the corridor during the four-month study period. The available sample size was 85 equipped bus trips for northbound buses in the AM peak and 829 non-equipped buses. In the PM peak, southbound direction, there were 170 equipped bus trips and 1081 non-equipped bus trips.

As shown in Figure 6, northbound buses begin their route from a transit center located at the southernmost end of the study corridor (about 8040 South). The bus inherently begins its travel on time (high reliability). Northbound DSRC-equipped buses traveling between 6 and 9 a.m. on weekdays reached the timepoint at 3500 South less than five min late 98% of the time. Buses without DSRC arrive at this timepoint on time only 85% of the trips. As the buses continue north, beyond the end of the graph in Figure 6, the DSRC-equipped buses maintained this advantage and arrived at the end of the route with an average reliability of 98%, compared with 96% reliability for non-equipped buses.

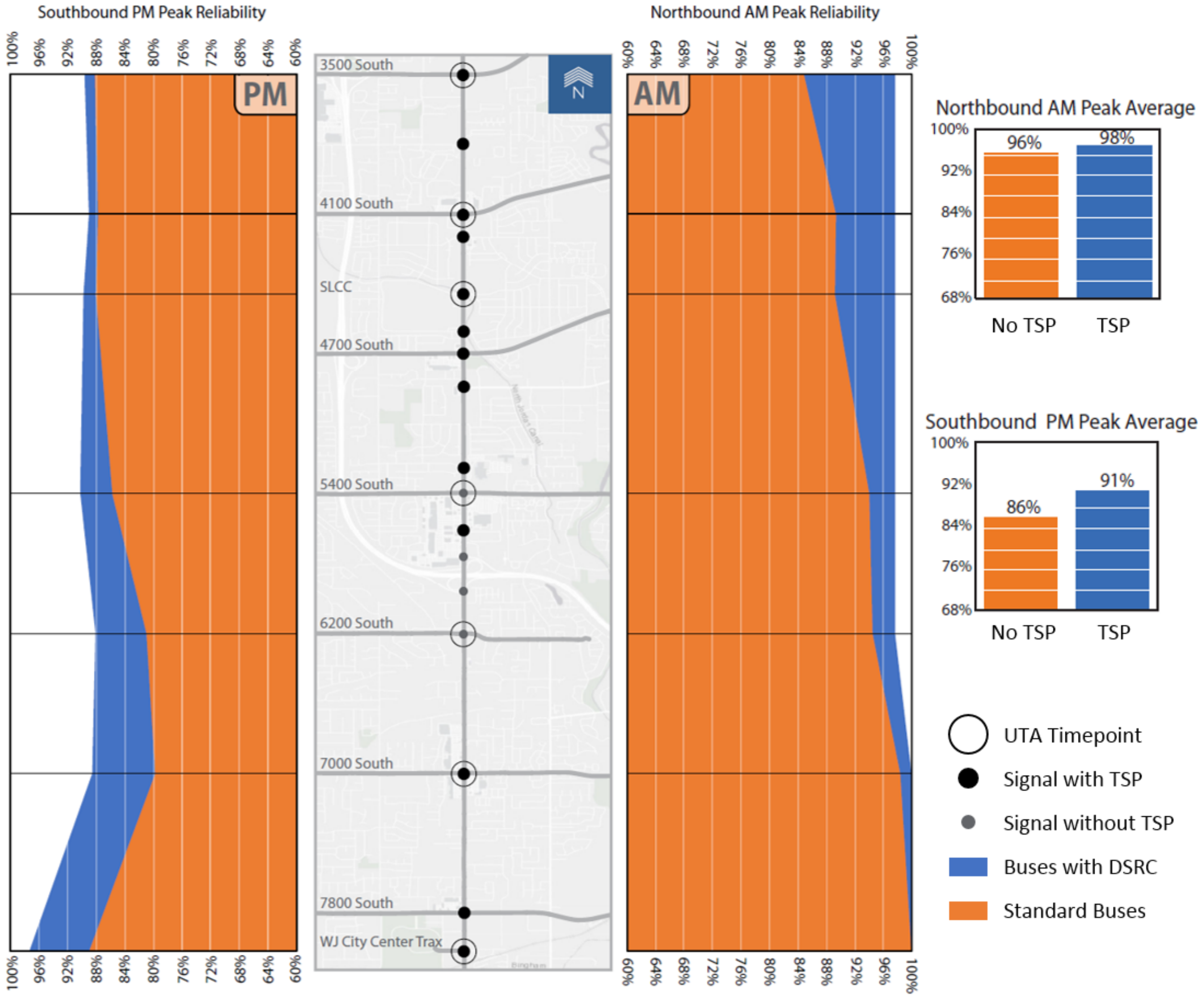


FIGURE 6 Transit reliability results for peak period and direction

Southbound buses also begin their route from an “on-time” starting point, but that starting point is 10 mi (about 40 min) north of the north end of the route included in the study (3500 South). On average, non-equipped, southbound buses arrive at 3500 South on time in the PM peak 88% of the time, as shown in Figure 6. Equipped buses arrive on time 90% of the time. There are a few signals with operating TSP north of the study area, which may have given equipped buses an advantage. The presence of TSP at 3500 South may also explain some of the difference as the timepoint for 3500 South is on the far side of the signal after the bus may have received priority.

Congestion for southbound traffic in the study area between 3 and 6 p.m. routinely occurs at 3500 South, 4100 South and 4700 South. Equipped buses experience an advantage through this section and arrive at West Jordan City Center on time 97% of trips while non-equipped bus trips are on time 89% of the time. The average reliability along the route is 91% for equipped buses and 86% for non-equipped buses.

CONCLUSION

An analysis of the data from the buses on Redwood Road indicates that buses allowed to request signal priority when behind schedule have improved schedule adherence compared with those buses that do not have this capability. The extent of the improved performance varies by time of day and direction.

Buses traveling in both directions experienced improved reliability when they were given priority at the traffic signals. These improvements were made with only an average of 35% of the requests for TSP being served. The need for TSP service decreases as the available green time for the approaches increases allowing for the buses to pass through the intersection with normal operations.

Improved schedule adherence provides value to both the transit system rider and the operator. Although difficult to quantify and monetize, riders benefit from a system that consistently meets its published schedule and have an increased tendency to use such a system. Transit operators constantly seek to improve reliability as part of their effort to attract riders, and benefit from improvements yielded by TSP systems and other methods.

Analysis of performance along this corridor is continuing. The next phase of the evaluation will include studying the impact of granting TSP on other traffic on the corridor. Specifically, the three data sets will be used to study the impact on green time of TSP phases during the TSP call cycle, and evaluate the impact on split failures for non-TSP phases during the TSP call cycle relative to their performance just before the TSP call. In addition, a study is underway to investigate the impact of changing the criteria for lateness to intervals shorter than five min.

Traffic signal engineers need to find a balance between the frequency of TSP service to benefit transit operations and the potential negative impact on other vehicles. This decision process is influenced by local policies and priorities, and informed by good data. The tools developed in this, and subsequent, analysis can be used to optimize TSP settings to balance the benefit to transit reliability against the impacts to the rest of the transportation network.

The MMITSS-Utah TSP system described here is currently being installed on another corridor. A new bus rapid transit (BRT) system being constructed in the cities of Provo and Orem, Utah, will include this system. The BRT will have exclusive, center-running lanes in a large portion of its corridor and will have 6-min headways in peak periods. The signal system will be closely monitored to insure that crucial headways are maintained while signal operations are not impaired for the remaining traffic flow.

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The Standing Committee on Intelligent Transportation Systems (AHB15) peer-reviewed this paper (19–03456).