Utah Transit Authority
Transit Signal Priority (TSP) Master Plan

UTA

Table of Contents

1 Executive Summary

In 2019 and 2020, the Utah Transit Authority (UTA) provided 20.3 and 12.1 million bus rides, respectively, providing a significant service to the Wasatch Front that helped move people, connect workers to employment opportunities, and enhance the overall quality of life of the region. As part of UTA's efforts to continuously improve its bus service, this Transit Signal Priority (TSP) Master Plan (Plan) seeks to align related agency efforts and guide new TSP initiatives. The Plan was developed collaboratively by UTA's Office of Innovative Mobility Solutions (IMS) and a working group of key stakeholders to plan for the evolution and expansion of TSP proactively.

The use of TSP among transit agencies in Utah is relatively new, however, these systems have been successfully deployed for quite some time by peer agencies across the U.S. Population growth along the Wasatch Front is accelerating the need for solutions like TSP to mitigate traffic congestion and maintain UTA's strong reputation for bus reliability and on-time operations. When transit vehicles are present, TSP modifies traffic signal timing by holding or extending a green signal for buses. There are several types of problems TSP can help solve by prioritizing buses. TSP can make bus service more reliable, reduce travel time, and cut operating costs through more efficient bus run scheduling. Ultimately, TSP can help to increase ridership. While UTA's bus reliability is typically measured at 90%, bus speeds have gradually declined along with ridership. Out of 142 reporting transit agencies, UTA has experienced the greatest decrease in bus speed (-24%) from 2010-2018. Meanwhile, during the same period, bus ridership fell by 10%.

TSP is one of many tools to improve transit service with faster speeds and better reliability. This Plan aligns with related UTA planning efforts such as UTA's **Bus Network Optimization Plan (BNOP)** project. Other non-TSP strategies can help, for example, dedicated bus lanes and strategies that reduce dwell time. There is a need to reimagine bus service, as TSP is most successful when it is supported and can support other service decisions that prioritize speed and reliability.

This Plan enables UTA to expand on its recent successes partnering with UDOT to pilot TSP to further demonstrate how TSP can contribute to a more efficient and reliable transit network. TSP technology trends were evaluated as the plan was developed, and the team found that connected vehicles and complimentary roadside infrastructure converge with traditional TSP uses, revealing new possibilities for safer and more efficient bus travel.

Therefore, the TSP Working Group has recommended in this Plan:

- Prioritizing strategic TSP investments on core routes and BRT services per UTA's **Five Year Service Plan**
- Focusing on shortening bus travel times, maintaining 90% reliability, and creating bus schedule efficiencies
- Leveraging Cellular Vehicle-to-Everything (C-V2X) technology as designed by UDOT/Panasonic for all future UTA TSP projects
- Collaborating with partners on
  - Local and regional coordination that crafts beneficial TSP solutions for all stakeholders;
  - Establishing budget needs, funding sources, and implementation plans;
  - Negotiating TSP conditions that ensure useful deployments;
  - Building support needed to maintain a state of good repair; and
  - Evaluating results, including measuring return on investment

In summary, the purpose of this plan is to provide a better customer experience, to improve operational efficiencies, and to prepare UTA to adopt and implement future Connected Vehicle (CV) technologies. UTA should expect incremental improvements as more TSP is implemented, bus schedules are optimized, complimentary enhancements to bus services come online, and TSP gradually becomes more and more effective. UTA believes that if the TSP system is effective for transit and is balanced, it benefits not just bus riders, but everyone who uses that road.

2 INTRODUCTION

This section presents the goals of the TSP Master Plan, background on why it has been developed, and clarification on the scope that it covers. Subsections also lay out the problem statement and needs, a list of existing TSP deployments, and context on the UDOT Connected Vehicle Ecosystem Project.

2.1 GOAL OF THE TSP MASTER PLAN

UTA should find it easier to achieve three primary goals through TSP:

- Improve the customer experience
  - Increase bus reliability
  - Decrease bus travel times
  - Incorporate TSP along with complementary bus service enhancements
- Improve operational efficiencies
  - Tighten bus run time schedules
  - Potential to reallocate fuel cost and hourly savings
  - Standardize on TSP equipment, plans and processes
  - Realize the full value out of the TSP system
- Prepare UTA to adopt and implement future connected vehicle technologies
  - Enhanced safety features and systems
  - Foundation for increasingly connected and automated vehicles

The core intent of this Plan is to improve UTA operations and enhance the customer experience by creating better bus services which are more competitive with auto travel times. The Plan is a proactive and strategic TSP approach. It should give UTA the ability to fast track high priority TSP projects. This Plan should tie to future TSP investments because it identifies where and how to spend, especially in the short term.

2.2 BACKGROUND

UTA's Innovative Mobility Solutions (IMS) team led the development of the Plan in close coordination with a comprehensive working group. The working group members included representatives from multiple departments within UTA, such as planning, information technology, and capital improvements, and relied on subject matter experts including bus operations and enterprise strategy. The working group actively coordinated with Utah Department of Transportation (UDOT) and Wasatch Front Regional Council (WFRC) and sought input from vendor and consultant teams.

2.2.1 Influence of Connected Vehicle Technologies

While this Plan is dedicated to exploring TSP, this is only one aspect of connected vehicle (CV) technology. Connected vehicle technologies lay the groundwork for a sustainable, efficient, safer, and a more innovative future. TSP, using CV technology, would not be a standalone project, but rather open the door to additional opportunities and a wider strategy towards innovation at UTA. More technical details on connected vehicle technology and the other applications it can enable can be found in Appendix 7.1.

These technologies enable buses, cars, roadway infrastructure, smart phones, and other devices to communicate quickly to share vital information. CV technologies enable vehicles to communicate with infrastructure (vehicle-to-infrastructure, or V2I), between vehicles (vehicle-to-vehicle, or V2V), and with other objects in the roadway (vehicle-to-everything, or V2X) when they are in close proximity to each other. Devices would be relying on direct, short-range communications between devices. Connected vehicles could dramatically reduce the number of fatalities and serious injuries caused by accidents on roads and highways. This Plan helps create a foundation for the future of connected vehicle technologies through TSP applications.

2.3 SCOPE

The scope of this Plan is fixed-route bus service which operates in mixed traffic. The Plan will concentrate on UTA's high-frequency Core Route Bus Network and on BRT service. These services have been determined to be the best candidates for consideration because they carry the highest volume of customers within UTA's fixed-route bus network and have the most operating hours. Therefore, benefits incurred through TSP's potential for improved bus travel time and reliability are anticipated to have the greatest impact.

This Plan represents UTA's best understanding of TSP technology at the time. The agency acknowledges that TSP solutions can be future-resilient but not future-proof. They must be nimble enough to shift as the technology, UTA's needs, and the needs of customers evolve. C-V2X was selected as the technology solution in part because it is expected to evolve with these trends as it is deployed across the country, providing the flexibility to make updates in the coming years.

2.4 PROBLEM STATEMENT & NEEDS

This Plan addresses needs that are consistent with UTA's Stewardship focus area. Without a TSP Master Plan, UTA will be unable to:

- Plan for TSP in a proactive, deliberate fashion;
- Effectively incorporate TSP as a method for improving service in the bus network;
- Respond quickly to partnership and funding opportunities as they become available;
- Implement TSP decisions based on sound framework;
- Develop a prioritized list of locations to implement TSP;
- Develop and obtain funding options based on priority and location;
- Ensure agency-wide alignment on implementation of TSP; and
- Confirm that UTA is making the most cost effective decisions when implementing TSP projects.

A Plan is necessary because UTA needs:

- To thoughtfully invest in TSP;
- To implement TSP where it will be most effective, most efficient for UTA to maintain, and with the best technology value; and
- To create a future-resilient solution that the whole agency can support.

2.5 EXISTING DEPLOYMENTS

UTA is already collaborating with MPOs, UDOT, and other partners to pursue TSP projects and will continue to make collaborative efforts. Current TSP projects and recent successes include:

- Route **217** (Redwood Road Connected Vehicle Project) – In partnership with UDOT. TSP was activated in 2017 with Dedicated Short Range Communication (DSRC) hardware on 10 UTA buses and at 30 intersections on Redwood Road, which serves Route 217. Data shows that after implementing TSP, on-time reliability increased by 4-6% with 19% less schedule variability.
- UVX / Route **830X** (Provo-Orem BRT) – In partnership with UDOT. TSP was activated in 2018 with DSRC hardware on all 25 UVX buses and at 47 intersections along UVX's 10.5-mile route.
- MAX Route **35M**/3500 South – *This TSP system is not currently active.* There are two separate TSP technologies on MAX at more than 30 intersections: an Opticom line-of-sight system and a puck transmitter system. UTA was recently awarded Congestion Mitigation and Air Quality Improvement (CMAQ) program funds to improve route amenities, including bus stop improvements, queue jumps, and updating outdated TSP systems.

TSP has been successfully deployed[1] at different transit agencies across the U.S. with measurable benefits, for example:

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

2.6 UDOT CONNECTED VEHICLE ECOSYSTEM PROJECT

UDOT has partnered with Panasonic to build a framework to handle future CV demand while providing benefits now. Going forward, the UDOT project will rely on C-V2X instead of DSRC technology for future TSP expansion.

UTA has been partnering with UDOT since 2017 to enhance the customer experience, improve operations, and safety of the transportation system by utilizing connected vehicle technologies and TSP. A schematic for the existing system that is utilized in Utah is shown in Appendix 7.6. Given that UDOT

[1] NATCO (National Association of City Transportation Officials)

owns 58% of the traffic signals in Utah, this strategic partnership has many benefits to UTA including UDOT's funding, installation, and management of the roadside infrastructure on UDOT corridors, and the ongoing value of collaboration to optimize the system.

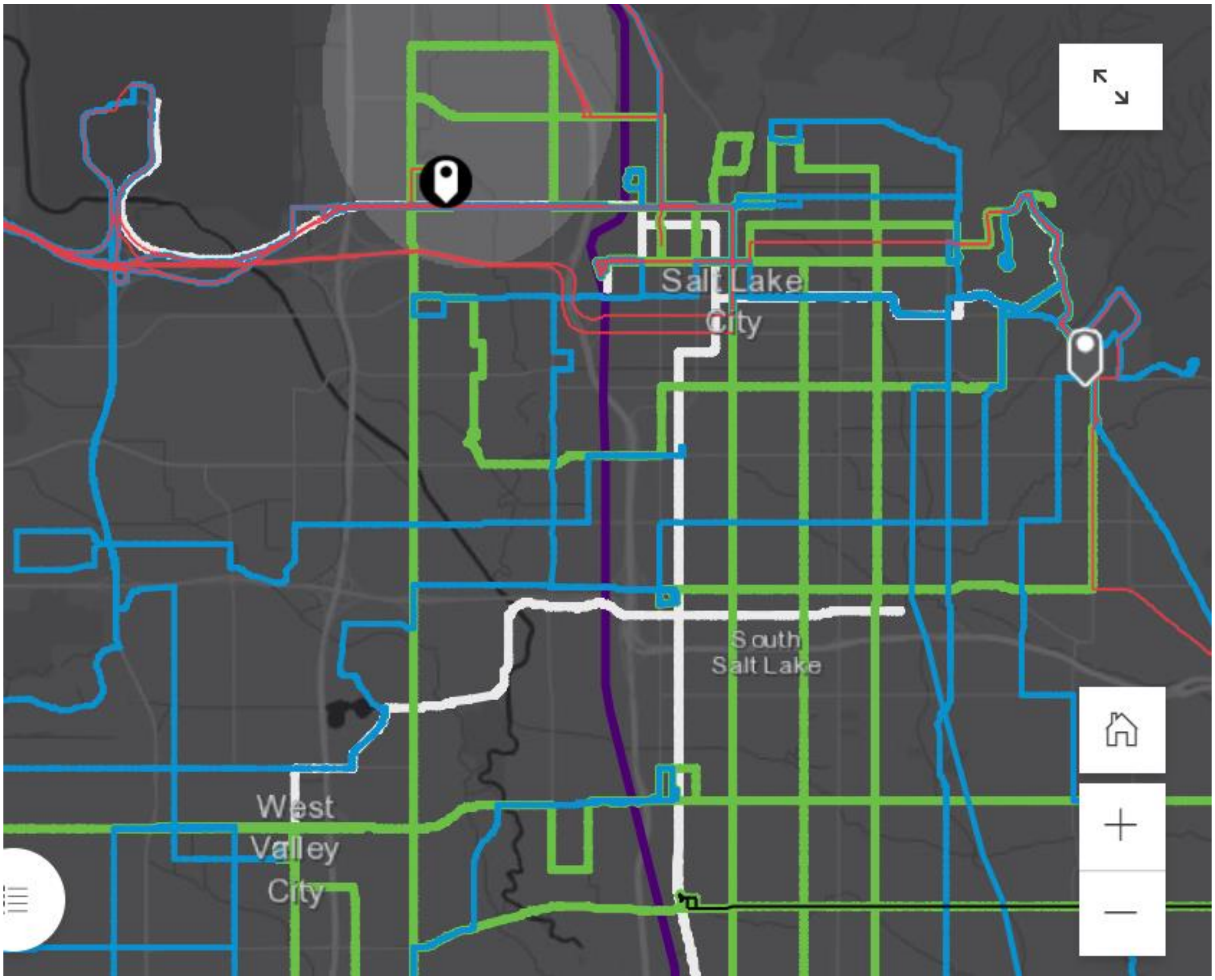
3 Improving Bus Speed and Reliability

This section presents the where, how, why, and when of proposed TSP implementation to improve bus speed and reliability.

3.1 Where: Core Routes & BRT

Creating a network of high frequency core routes with additional improvements to reduce travel time while maintaining reliability is part of the guiding framework of UTA's 2021-2025 Five-Year Service Plan. These core routes carry the highest levels of ridership in the UTA bus system. Improving speed while maintaining reliability is key to maintaining existing core route customers, while also attracting new riders to the system.

Figure 1: Five-Year Service Plan Map Section. Bus Route Color Legend: Core Routes, All Day Service, Peak Only Service.



This Plan recommends that **TSP should be implemented on core routes where TSP would be useful** – meaning where there's delay in the system that could be reduced through signal priority. While this Plan highlights short term opportunities for TSP using the best data available now, going forward UTA should attempt to incorporate additional data points (such as intersection-specific delays) that take time to gather. Further analysis is needed to determine where to best implement which tools, including TSP, across the bus network.

In alignment with UTA's Five Year Service Plan, bus routes with at least 15-minute frequency and all-day service are considered core routes. UTA has identified **19** Core Routes; 15 operate in Salt Lake County, 2 in Weber/Davis County, and 2 in Utah County (Table 1). Increasing the speed and reliability of these routes strongly supports the Five Year Service Plan. While BRT lines are not considered core routes, all new BRT projects will include some level of TSP.

*Table 1: Core Routes & **BRT***

Route	Name	WKD Pass/Hr.[2]	Daily Ridership[3]	County	OTP[4]	Avg. Bus MPH[5]	Speed as % of Road[6]
2	200 South	35	2,142	Salt Lake	91.1%	11.5	0.4
9	900 East	12	1,564	Salt Lake	92.4%	12.1	0.4
21	2100 South	29	2,332	Salt Lake	94.7%	14.9	0.5
33	3300 South	26	2,185	Salt Lake	88.3%	15.9	0.4
35	MAX-3500 South	19	1,772	Salt Lake	88.4%	17.5	0.5
39	3900 South	28	2,379	Salt Lake	93.6%	15.1	0.4
41	4100 South	22	521	Salt Lake	92.2%	17.3	0.4
45	4500 South	22	1,228	Salt Lake	94.0%	15.7	0.4
47	4700 South	22	1,597	Salt Lake	94.3%	16.0	0.4
54	5400 South	22	1,385	Salt Lake	89.6%	17.9	0.5
200	State Street North	30	3,412	Salt Lake	89.8%	12.7	0.4
205	500 East	27	2,372	Salt Lake	90.4%	13.1	0.4
209	900 East	26	3,064	Salt Lake	93.0%	14.6	0.4
217	Redwood Road	26	3,609	Salt Lake	93.9%	15.0	0.4
220	Highland Drive-1300 East	18	2,484	Salt Lake	85.7%	15.7	0.4
603	Weber State Univ.-McKay Dee	30	1,675	Weber	94.8%	14.7	0.4
612	Washington Blvd.	18	2,060	Weber	93.4%	14.4	0.4
830X	Utah Valley Express (UVX)	60	12,526	Utah	80.3%	17.6	0.5
850	State Street, Utah County	19	2,682	Utah	90.2%	19.2	0.5

All core routes operate at least some miles in UDOT's jurisdiction (see Appendices 7.8 and 7.9 for details). The percentage ranges from a low of 4% on Route 220 to a high of 79% on Route 850, averaging 43% of total core route miles. Moreover, 51% of all UTA bus pattern miles are on UDOT roads. This jurisdictional data can help UTA and UDOT slate individual core routes for TPS project phases.

3.2 How: TSP v. TSP Alternatives

TSP is one of many tools that transit agencies employ to improve speed and reliability for buses operating in mixed traffic conditions. As UTA Planning continues to develop Frequent Transit Priority projects, TSP and TSP alternatives should be evaluated for the best fit to address various route needs. Other useful bus friendly infrastructure options include the addition of left turn signals, dedicated bus lanes, and queue jumps. It's entirely possible that a bus route would be most improved by a queue jumps rather than TSP. That said, TSP and companion treatments like dedicated bus lanes can also complement each other for synergistic impact (i.e., 2 + 2 = 5)[7].

[2] A. Beim, 2019 Average
[3] J. Wadley, CSA, August 2020 Change Day (Daily Ridership = Weekday Boardings, Average)
[4] UTA Reliability Reporter at http://asp1/reliability, 2020 Average
[5] J. Wadley, August 2020 Change Day
[6] J. Wadley, August 2020 Change Day
[7] http://www.trb.org/Publications/Blurbs/180325.aspx

UTA should expect incremental improvements as more TSP is implemented, bus schedules are optimized, complementary enhancements to bus services come online, and TSP gradually becomes more and more effective. It is the role of Service and Operations Planning to suss out what type of problem exists and how best to resolve it, and it is the role of Strategic Planning to look out beyond the 5-year Service Plan horizon to position these projects for funding in the RTP. An assessment of tradeoffs between different technology options and agency focuses was conducted as part of the TSP Master Plan development process and is summarized in Appendix 7.3.

3.3 WHY: IMPROVING BUS SPEED AND RELIABILITY

The agency's expectation is that TSP can improve both speed and reliability. However, UTA has only been able to measure improvements in reliability so far. The reality could be that improving bus speeds takes a combination of TSP *plus* schedule adjustments *plus* other bus system improvements.

3.3.1 Benefits of Bus Speed and Reliability Improvements

First and foremost, speeding up buses and improving reliability through enhancements like TSP can improve the customer experience. In a national survey[8] transit riders highly value travel time and reliability. Reducing traffic signal delay through TSP can increase customer satisfaction as the bus quickly moves through intersections and riders realize travel time savings. It can also create more reliable bus-to-train connections, again reducing riders' total travel times. This can make the bus more attractive, leading to higher transit ridership.

Cost efficiency is another benefit. It can help fill a need for improved transit service without the time or cost of BRT or Light Rail. Moreover, reduced trip time can produce savings for UTA, which could be used to fund additional service.

An additional benefit is for other road users. Improving bus speeds can benefit other modes by mitigating vehicle congestion along the corridor. Taking a step back, the broader TSP traffic goal is to increase people throughput on roads. This perspective makes two assumptions about using TSP to improve traffic operations: [9]

- Transit is a normal part of traffic operations.
- TSP is a Transportation Systems Management & Operations (TSMO) strategy to improve the level of service for transit operations.

Increased transit ridership will naturally take some cars off the road and increase people throughput. As the level of service improves, bus travel times become more competitive with auto travel times, thereby building the potential to increase transit ridership and ultimately to increase people throughput. Because moving people is UTA's mission, note that this Plan is centered on increasing people throughput which is a different metric from vehicle throughput.

To summarize, UTA believes that bus speed and reliability improvements can benefit not just bus riders or just UTA, but everyone who uses that road. A more thorough cost-benefit analysis that considers various types of TSP improvements is provided in Appendix 7.2.

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[8] TransitCenter's WOB 2016 Nationwide survey

[9] FHWA, Transit Signal Priority ConOps for a Cooperative Driving Automation Environment. April 27, 2021.

3.3.2 Measuring Reliability

UTA uses an On Time Performance (OTP) percentage to measure reliability. On Time Performance has its challenges as a metric because it can be skewed by additional minutes built into the timetable. These "padded" minutes are designed to keep the bus on schedule when delays occur due to traffic congestion, high ridership, unfavorable signal timing, etc. While schedule padding can improve bus reliability and the OTP metric, too much padding can slow down travel times and can frustrate riders when the bus must hold for time to avoid running early. Ideally, it would be better to balance improving reliability along with shortening travel times. Recent ABBG[10] comparisons of OTP placed UTA among the top three reporting agencies. UTA is still tracking to 90% OTP while attempting to speed up customer travel time.

Table 2 provides a sample report of OTP rates relative to the 90% goal. This reliability metric is measured monthly for the entire system, for Bus and Rail modes, and by each service unit.

Table 2: Sample UTA OTP Data

On Time Performance, December 2019		
	Goal	Actual
System	**90.0%**	**90.7%**
Bus	90.0%	90.1%
Ogden	90.0%	92.4%
Salt Lake	90.0%	88.9%
Timpanogos	90.0%	86.3%
Special Services	90.0%	94.5%
Rail	90.0%	92.4%
FrontRunner	90.0%	88.4%
TRAX	90.0%	92.7%

3.3.3 Bus Speeds v. Auto Trip Times

Figure 2: Bus Scheduled Speed v. Road MPH, Aug 2020 for select BRT routes

Line	Road avg. mp	Bus avg. mph	bus speed as % of road	TSP
35	37.8	17.5	0.5	Y
217	35.4	15.0	0.4	Y
830X	32.6	**17.6**	0.5	Y
MIN	27.7	7.6		
MAX	62.2	40.6		

Posted speed limit could be used as a proxy for auto trip speed as shown in Figure 2. Planning compared actual bus speed to posted road speed limits as of August 2020. Planning observed that there was little difference between the actual and scheduled bus speed. The average for all UTA routes was 0.5, meaning bus speed was half of the speed limit. Surprisingly, current TSP routes 35, 217, and 830X bus speed as a percent of road MPH also averaged 0.5.

[10] American Bus Benchmarking Group

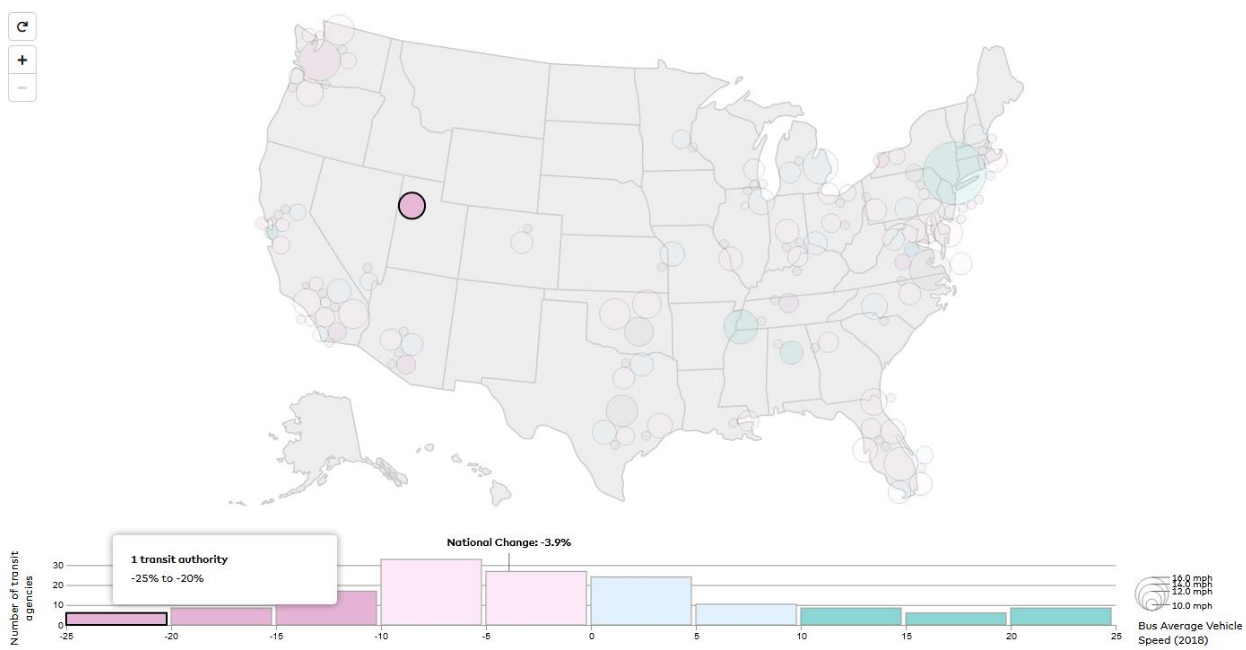
Even with signal priority, bus average speeds must always be lower than the speed limit because the bus must stop to board and alight customers. Total bus speed for the whole agency can change if service expands in slow traffic communities like downtown cores. In theory, TSP can help overcome both reasons for delay.

While roadway studies and customer choice decisions typically focus on travel time, both travel time and reliability are transit industry standard metrics. There is also a potential network effect, whereby a TSP system gains additional value as more people use it. By adding more TSP corridors UTA should expect a greater return on its investment and a high TSP benefit.

3.3.4 Speed Trends

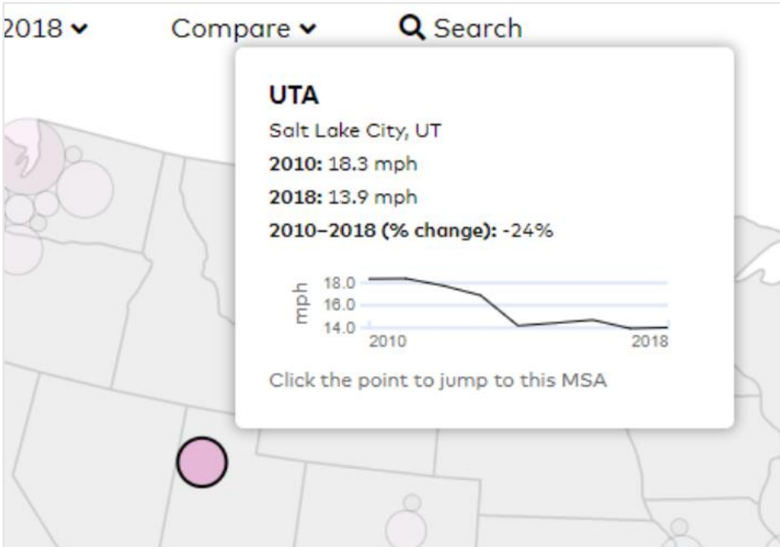
Nationally and at UTA, buses are moving more slowly over time. Out of 142 reporting agencies, UTA has experienced the greatest decrease in bus speed from 2010-2018. According to NTD data[11] provided through Transitcenter, from 2010 – 2018 UTA's average bus speed declined by -24%, from 18.3 to 13.9 MPH. Over the same timeframe the national change was -3.9%. Meanwhile, UTA bus ridership fell 10%.

Figure 3: UTA Bus Speed Trend



[11] https://insights.transitcenter.org/; February 3, 2021

Figure 4: Detail of UTA Bus Speed Trend



3.4 WHEN: RECOMMENDED PHASING

Given that there are many unknowns and technology innovations, the Plan offers two distinct phases, in line with the current TSP approach and funding presented in Appendix 7.5:

- **Short term** (2021 – 2025) – To align with UTA's Five-Year Service Plan, and to help advance currently funded TSP projects. Core route TSP projects scheduled in the short term are:
  - 3500 South, Salt Lake City (Routes 33, 35/35M)
  - Ogden-Weber BRT (Route 603)
  - State Street, Orem (Route 850)

  In addition to the core routes prioritized in the short term, Orem City and UDOT have presented a unique city-wide TSP opportunity on the following corridors that have some UTA bus service:
  - Geneva Road, Orem (Route 841)
  - 800 East, Orem (Route 862)

- **Long term** (2025 – 2035+) – To support the Regional Transportation Plans (RTPs), and to keep alignment with UTA's Five-Year Service Plan as it is updated. UTA also intends to reevaluate plans based on advancements in connected vehicle technologies.
  - It is important that TSP for core routes is prioritized and included in the suite of capital improvements for core routes listed in the RTPs. Accurate cost estimates for TSP implementation are also important to include in the RTPs. This will help make the case for support and funding of additional TSP along core routes. Funding sources may include UTA capital
  - Developing a defined roadmap for core routes, future TSP phases, and specific intersections is an important next step. These decisions can be assisted by collecting data including bus delay time by intersection, factoring in criteria such as partnerships by jurisdiction and Title VI areas, and by evaluating results from the above short term TSP projects.

4 PROPOSED TSP IMPLEMENTATION

This section lays out recommendations for strategic partners to respond to and move forward, including recommending C-V2X as the technology solution, providing a strategy to implement it across the fleet, proposing the conditions under which TSP is granted, and proposing an evaluation framework for further assessment after deployment. The proposed Plan encourages collaboration and ideas on how best to plan for and implement TSP. Strategic partners can assist UTA by providing feedback, continued collaboration on TSP, being aware of UTA's objectives, and weaving them into their plans. UTA believes that if the TSP system is effective for transit and is balanced, it benefits not just bus riders but everyone who uses that road.

4.1 RECOMMENDED TECHNOLOGY: C-V2X

Over several months the TSP working group explored various types of TSP systems. The group ultimately evaluated two preferred alternatives – a commercial GPS-based system by GTT Opticom and a cellular V2X as designed by UDOT/Panasonic. Estimated capital and operating costs were similar, and either system could deliver the core function of sending a signal request. Additional detailed calculations and tradeoffs are presented in Appendices 7.2 and 7.4. Ultimately the working group recommended the C-V2X solution from UDOT/Panasonic for the following reasons:

- Strategic agency alignment on one type of TSP system
- Opportunities for regional partnership and collaboration with UDOT
- Expected good faith negotiations with UDOT and other stakeholders on TSP Conditions
- Cost effectiveness through expense sharing on UDOT corridors
- Enhanced CV functionality has the potential to improve safety for all road users

4.2 RECOMMENDED TECHNOLOGY CHANGES BY BUS SERVICE UNIT

This section is focused on the short term recommendations to clarify the proposed hardware and technology support partnership changes by service unit through 2025. As the TSP system develops, individual TSP projects should develop detailed deployment plans that are coordinated with each service unit under a consistent approach for the agency. This includes considering the overall size and characteristics of the fleet, as shown in Appendix 7.7.

Current TSP Technology Environment

Service Unit	BRT OBUs	Core Route OBUs	Roadside Units	Key Partners
Ogden	N/A	N/A	N/A	N/A
Salt Lake	Opticom	DSRC	Opticom / DSRC	Opticom / UDOT
Timpanogos	DSRC	N/A	Dual Units	UDOT

Recommended Future (2022 – 2025)

Service Unit	BRT BUs	Core Route OBUs	Roadside Units	Key Partners
Ogden	C-V2X	C-V2X	Dual Units	UDOT
Salt Lake	C-V2X	C-V2X	C-V2X[12]	UDOT
Timpanogos	C-V2X	C-V2X	Dual Units	UDOT

4.3 RECOMMENDED TSP CONDITIONS

The following recommended conditions for implementing TSP are based on best practices from throughout the country. These recommendations are intended to be a starting point, subject to localized (intersection-level) constraints and considerations, but should not be deviated from too much and should rather be considered minimum expectations. A successful TSP system requires tradeoffs and adjustments to other components of the transportation network, and continual evaluation will show whether the expected benefits are occurring or whether changes need to be made.

4.3.1 What UTA needs from a TSP technology solution

a. The ability to communicate with UTA's Mobile Data Computer (MDC) scheduling system and automatically send a priority request, as needed.
b. When UTA needs priority, it is granted. This means the ability to receive priority when activated, unless there is a higher level request (i.e. emergency vehicle preemption, pedestrian crossing).
c. A consistent solution that can be used on buses across UTA's service area, regardless of which entity has jurisdiction over the roadway.
d. The ability to set parameters at an intersection level for a specific signal.

4.3.2 When UTA would like to receive signal priority

a. UTA recommends operating under conditional priority and not in "always request" mode. Bus priority should be based on schedule adherence, or other reasons as UTA requires such as to maintain headway spacing.
b. When a bus is 1 minute late or more, then TSP is granted for 10-35 seconds.[13] Exceptions may apply if another bus was granted priority within 2 minutes.
c. When TSP is activated, it is generally granted regardless of signal cycle. Exceptions may apply to avoid excessive disruption to the programmed traffic cycles. UTA must consider that the financial investment may not be worth it if buses only get signal priority on every second or third cycle.
d. When TSP is deployed at intersections with near-side bus stops, the bus will request priority only after the bus has left the stop.

4.3.3 Support needed for TSP implementation

a. Clear lines of communication are in place that allows UTA to directly contact the TSP support vendor (e.g. Panasonic) or appropriate staff when there is an issue at any time (24x7).
b. Access to detailed data, as well as dashboards, that allow UTA to monitor TSP key performance indicators and transit system performance (how often buses are receiving priority, technical issues

[12] In Salt Lake County and the UVX BRT, UDOT's plan is to replace all DSRC RSU and OBU with C-V2X (or dual mode RSUs) in accordance with the FCC ruling.

[13] Based upon best practice as documented by Boston Region MPO, "The amount of time that a municipality can reallocate within a signal cycle plays an important role in the effectiveness of TSP."

that prevent correct TSP operation, the ability to calculate increased reliability and shorter travel times, etc.).

c. Standing review meetings.
d. A process for setting and updating TSP parameters across the service area. UTA is open to revisiting conditions that aren't workable. There needs to be a resolution process to adjust and to resolve conflicts as well as a dashboard or other method to continually measure performance.
e. Once implemented, UTA anticipates that the C-V2X TSP system will be maintained in a state of good repair.
f. UTA expects that the roadside unit signal equipment will be the responsibility of the signal owners (UDOT or municipalities) while on-board equipment support will be the shared responsibility of UTA and UDOT.

4.3.4 How UTA plans to implement TSP

a. To maximize the usefulness of TSP, expect UTA schedules to be optimized and tightened periodically over time to reduce customer travel times while maintaining bus reliability.
b. For ease of operations, the same type of OBU should be installed on all relevant transit buses. UTA understands that this rollout will take a few years to outfit the fleet. Completing OBU installations at a single bus service unit or garage is a helpful first step. Meanwhile, UTA can prioritize (not dedicate) TSP equipped buses to TSP enabled routes.
c. Focus implementation on UTA core routes as defined in UTA's Five Year Service Plan.
d. UTA may collaborate with stakeholders on TSP standards for different types of intersections. UTA expects the ability to improve bus service even at major intersections.
e. TSP conditions could be independent of mode, as some buses rival train ridership.
f. UTA anticipates the ability to integrate the C-V2X TSP system with other emerging solutions and systems for technology resilience.

4.4 RECOMMENDED EVALUATION FRAMEWORK

To properly evaluate the success of a TSP system, the three key components to measure are whether the technology is functioning properly, whether transit system performance is improving in terms of time savings and reliability, and whether the TSP technologies have impacted other users of the roadway.[14]

4.4.1 System Up Time and Reliability

Frequency, type, and result of TSP system calls. The TSP system software should log information about each request for priority, including the time of the request, the type of request (extended green, truncated red, etcetera), and whether the request was granted or denied. A priority request may be denied at a given condition because of TSP policy. These logs will help to confirm system up time.

When maintenance or other system issues occur, the incident should be logged and resolved quickly by the appropriate party. Response time should also be measured.

[14] https://www.transitwiki.org/TransitWiki/index.php/Transit_signal_priority_(TSP)#cite_ref-3

4.4.2 Transit System Performance & Financial Metrics

Overall travel time along the route. A successful TSP system can help reduce overall travel time along a route. [15] (Other non-TSP strategies can help further; for example, dedicated bus lanes and strategies that reduce dwell time.) According to the ITS TSP Handbook, experiences from prior deployments generally indicate bus travel time savings on the order of 15% (depending on the existing signal delay) with very minor impacts on the overall intersection operations.[16]

Transit reliability. A successful TSP system can help improve transit reliability for either scheduled or headway service. Improved schedule or headway adherence reduces transit vehicle bunching, which can reduce crowding. Passenger wait times are also reduced with more reliable service.

Transit vehicle signal delay. A successful TSP system will reduce transit vehicle signal delay, which can be measured by the average delay per transit vehicle, average queue length, or number of cycles required to clear the intersection.

Transit passenger signal delay. A successful TSP system will reduce total transit passenger signal delay, measured as the transit vehicle signal delay multiplied by the number of passengers on board.

Ridership. A successful TSP system can reduce delay, travel time, and schedule variability, increasing the attractiveness of transit usage. In some cases, the increased attractiveness of transit can lead to increased ridership.

Bus scheduling efficiency. A successful TSP system can enable faster movements through intersections and potentially reduce the number of vehicles needed to service a route at the same frequency (“cut a bus”).

Cost savings. A successful TSP system will reduce the amount of time vehicles spend idling at red lights, which will reduce fuel consumption.

Return on investment. For every dollar invested in TSP hardware and system operations, there should be a benefit measured as cost or time saved. For example, due to an annual operating cost savings of approximately $3.3 million in Los Angeles, the relative benefit-cost ratio for TSP associated with two bus rapid transit corridors was estimated to be more than 11:1 over 10 years.[17]

4.4.3 Other Users of the Roadway & Public Support Metrics

Cross-street traffic signal delay. A successful TSP system will not unduly disrupt existing traffic patterns. Most transit agencies report little to no impact on non-prioritized traffic. If TSP requests are causing excessive intersection delays, the number of allowable requests may need to be reduced. Conversely, if priority requests are not causing significant delays, then additional priority requests may be allowed.

Public response. Public support is important and helpful in measuring the success of TSP, and in ensuring its continued implementation can serve its communities as effectively as possible.

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[15] https://www.bostonmpo.org/data/html/studies/transit/TSP-Guidebook/TSP-Guidebook.html#_Toc532372789

[16] ITS America. (2005) Transit Signal Priority (TSP): A Planning and Implementation Handbook

[17] TCRP Report 118. 2007. P. 4-32

4.4.4 Ongoing Evaluation Process

It is important to engage the right UTA operations staff early to check that TSP data collection is useful. Without accurate and meaningful data, TSP could complicate schedule timing because it speeds up the bus and UTA planners can't determine where or how much time to cut out.

After evaluating the performance of TSP, UTA and the project stakeholders should make changes to improve the system design, if needed. UTA should also identify opportunities to make other adjustments based on TSP performance. For example, improved reliability and reduced travel time may result in less recovery time needed in the bus schedule. UTA planners should consider whether schedule adjustments or operating resource allocation can be modified because of TSP performance.

UTA's actual costs and estimated return on investment should be analyzed on an ongoing basis. Before-and-after comparisons of scheduled round-trip times with the projected time savings will indicate whether the savings would be sufficient to allow either a reduction in the number of buses or to increase service frequency with the same number of vehicles. Ultimately, any realized benefits from a TSP system can be used to continue to improve bus service.

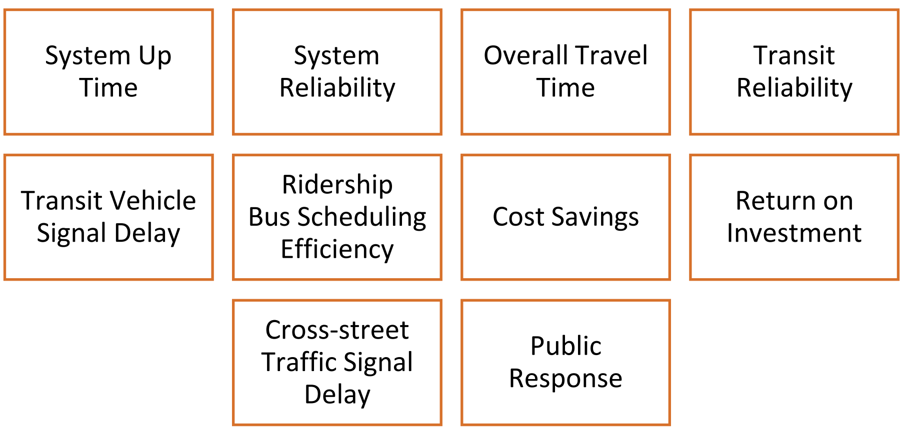

Figure 5: Evaluation Framework Elements

5 Next Steps

The intent of this Plan is to establish an initial, proactive, and strategic TSP approach. A lot of work remains to deliver on the promise of TSP. Recommended next steps are listed in this section.

- Communications & Planning
    - Fold this effort into UTA's broader community engagement plan. Ensure that UTA's TSP projects are community-informed.
    - Continue to collaborate with external stakeholders including UDOT, the Salt Lake County Traffic Management Subcommittee, WFRC, and MAG.
    - Develop a supplement to UDOT's existing Concept of Operations (ConOps). The purpose is to minimize risk as UTA begins to work more closely with UDOT to deploy C-V2X solutions throughout the Wasatch Front.

  - Prioritize cybersecurity. Identify and mitigate TSP-related cybersecurity liabilities and facilitate ongoing cybersecurity information exchange.
- Testing & Evaluation
  - In partnership with UDOT, evaluate intersection delay data by conducting the UTRAC project, "Identifying Transit Routes/Corridors with Greatest Potential to Benefit from TSP"
  - Design a simple before / after TSP evaluation process that can be consistently applied to multiple routes. This allows UTA to quantify results and learn if TSP is meeting our reliability and travel time objectives or not.
  - Develop test procedures that can verify if TSP is working properly before the bus leaves the yard.
  - The Recommended Evaluation Framework in Section 4.5 would benefit from additional details including identifying the evaluation team, useful data sources, and SMART objectives (Specific, Measurable, Achievable, Relevant, Timebound).
- Budgeting
  - Submit a 5-year capital budget request to equip all transit buses with OBUs. This 5-year request can be used to identify any budget gaps and research potential funding opportunities to close those gaps. Include costs for the Timpanogos Business Unit to complete OBU installs.
  - Build TSP OBU costs into all future relevant bus procurements.
  - Develop TSP budget estimates to support the Five-Year Service Plan and core routes, including equipment maintenance and operator training. Subsequent plans for TSP on core routes should be folded into UTA's regular capital budgeting process.
  - The ConOps supplement has not pinned down a funding source. Present this proposal and sponsorship opportunity at an upcoming Joint Projects Committee meeting.

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7 APPENDIX

The Appendix offers additional information that informed the Plan. The TSP Working Group developed this content as the group learned about TSP best practices and evaluated options. It is included as background material along with links to many other references.

7.1 STATE OF TECHNOLOGY

7.1.1 Types of TSP

- There are several different types of commercially available TSP solutions that use infrared strobe, optical detection, or inductive loop system, where infrastructure is installed at the deployment intersections to detect when a bus has arrived, or a radio, Wi-Fi, or Cellular enabled, GPS-position-based solution that determines the location of buses relative to the deployment intersections. These products have been used at various transit agencies across the country for many years. They are generally propriety solutions with hardware that must be installed on both the roadside and the eligible vehicle, and benefits are limited to TSP and other signal preempt/priority strategies rather than the broader benefits CV technology could enable.

    - A NACTO report from 2005 on the TSP state of the practice includes a list of 24 agencies that had already deployed TSP, including two with TSP deployments as early as 1985.[18] Many of the deployments were demonstration projects on just one or two routes. Approximately two thirds of the deployments used optical vehicle detection systems, while the other third used loop-based detection systems. Three agencies used other types of TSP such as GPS or radio frequency systems.
    - Recent examples of this type of TSP are in Chicago (see the evaluation report for the Regional Transit Signal Priority Implementation Program (RTSPIP), which also shows how the success of the system was assessed[19]) and Denver[20]

- A more traditional Commercial Off the Shelf (COTS) solution is GTT Opticom, which is already used for MAX BRT.[21] This is a line-of-sight system and a puck transmitter system. Emitter type Opticom can also work with existing automated vehicle location (AVL) systems to provide priority based on specific requirements, such as the schedule, time of day, or the number of passengers. With the Opticom automated schedule management (ASM) module for example, the Opticom system compares its satellite-based location to where it's supposed to be according to the schedule and then the ASM system turns transit signal priority on or off, depending on whether the bus needs help catching up. Alternatively, ASM can be used to manage headway by comparing the satellite-based locations of all buses on the route and then adjusting the transit signal priority of each accordingly (which is more useful for headway-based routes, rather than schedule-based routes).

[18] https://nacto.org/wp-content/uploads/2015/04/transit_signal_priority_handbook_smith.pdf
[19] https://preprod.rtams.org/sites/default/files/digital_documents/Evaluation%20Report%20for%20the%20Regional%20Transit%20Signal%20Priority%20Implementation%20Program%20%28RTSPIP%29.pdf
[20] https://www.rtd-denver.com/projects/transit-signal-priority
[21] https://www.gtt.com/

  - Has been deployed in Memphis, New York City, Highland, Indiana, and the East San Francisco Bay Area[22]

- **Dedicated Short-Range Communications (DSRC).** DSRC has been used to enable TSP applications as part of a connected vehicle environment developed by UDOT. This technology is in use today on UVX, Route 217 and several other UDOT corridors. Since October 1999, the Federal Communications Commission (FCC) has reserved a portion of the radio band for dedicated short-range communications (DSRC) between vehicles and infrastructure.

  New FCC regulations are likely to phase out the use of DSRC for TSP and allow the previously dedicated radio band to be split into a portion that is opened for commercial Wi-Fi use and a portion that is dedicated to cellular C-V2X technology instead of DSRC. This will require a transition period from DSRC to C-V2X between 2022 – 2024. UTA and UDOT will need to transition existing DSRC projects from DSRC to C-V2X during this time frame or as funding becomes available. Future DSRC deployments should be considered useful but temporary solutions due to FCC rule changes.

  - Examples include Multi-Modal Intelligent Traffic Signal System (MMITSS)[23] a pilot in Michigan[24]

- **C-V2X.** C-V2X technologies have the potential to provide the same safety and low latency communication benefits of DSRC applications yet are largely unproven at this time. Unlike DSRC, cellular deployments are capable of over-the-air updates, and this technology is expected to be widely available in U.S. production vehicles soon. In addition, in 2021 and for the first time in Utah, cellular TSP hardware will connect into the UTA bus electronics to provide valuable road safety and performance data, essentially enabling a public bus to act as a "probe" vehicle. UTA and UDOT have never deployed C-V2X before, so this pilot should provide substantial learnings on the current capabilities of this technology that has potential but has not been as vigorously tested as DSRC.

  Connecting into the vehicle's CAN (Controller Area Network) bus allows safety data to be pulled directly from UTA bus electronics to share data on environmental conditions, braking status, and more. On the downside, cellular C-V2X hardware is approximately four times as expensive than DSRC.

  C-V2X can communicate using direct V2X to a RSU or 4G LTE or 5G mobile cellular connectivity, depending on what is available. The principal difference between DSRC and C-V2X is the communications medium, and any other external interfaces to the roadside units (signal controllers, backhaul infrastructure, etc.) that were deployed for any DSRC pilots can be reused for C-V2X, and vice versa. Messages and applications remain the same as well.

  As the region moves toward a more widespread connected vehicle environment, the CV-based TSP solution allows a more sophisticated approach to TSP than traditional options due to the improved ability to detect all vehicles arriving at and departing from the intersection and to

[22] https://www.gtt.com/success-stories/
[23] https://www.its.dot.gov/research_archives/dma/bundle/mmitss_plan.htm
[24] https://www.danlawinc.com/bus-gets-green-light-priority-new-devices-tested-michigan/

adapt timing accordingly. In addition to supporting preemption and prioritization needs, CV can be used to provide signal phase and timing data, traveler information messages, or other critical safety information. It can also support two-way communications, wherein messages are both sent and received by the vehicle and infrastructure to update system needs and better inform the decision on what the best action to take is as the vehicle continues to approach the intersection that could provide TSP if needed (such as if the bus has already cleared the intersection and no longer needs signal priority).

- There have been limited deployments, but pilots are starting up, such as in Hawaii[25] and Georgia[26].

7.1.2 TSP System Components

TSP systems require four components: a detection system aboard transit vehicles; a priority request generator which can be aboard the vehicle or at a centralized management location; a strategy for prioritizing requests; and an overall TSP management system.[27] UTA's TSP components are:

1. Detection systems
    - On the vehicle – On Board Units (OBUs)
    - On the traffic signal – Road Side Units (RSUs)
2. Priority request generator – Mobile Data Computer (MDC)
3. Strategy for prioritizing requests – Set through partnerships with the owner/manager of the traffic signals and UTA. UTA uses a distributed request system where all priority decisions are made at the intersection level rather than at a central location like a traffic operations center.
4. Overall TSP management system – Set through partnerships with the owner/manager of the traffic signals and UTA
5. Communications network – Underlying infrastructure is required as a backbone to enable communications between the TSP system and the signal system at the intersection, as well as potentially between the transit vehicle and the TSP system or the intersection infrastructure, depending on the design of the system.

7.1.3 Building a Foundation for the Future with Connected Vehicles

While this Plan is dedicated to exploring TSP, TSP is only one aspect of connected vehicle (CV) technology. Connected vehicle technologies lay the groundwork for a sustainable, efficient, safer, and a more autonomous future. These technologies enable buses, cars, roads and other infrastructure, smartphones, and other devices to communicate with one another. Buses on route for example, would use short-range radio or cellular networks to communicate with other devices which share and receive important data regarding traffic conditions and safety related matters. The benefits of these technologies will enable bus drivers to receive notifications and alerts of dangerous situations, such as a pedestrian in an intersection or a vehicle about to run a red light. Connected vehicles could dramatically reduce the number of fatalities and serious injuries caused by accidents on roads and highways. This Plan should help build the foundation for CV through TSP.

[25] https://appinfoinc.com/applied-information-cv2x-hawaii/
[26] https://cdn.atlantaregional.org/wp-content/uploads/gdot-arc-tcc-12112020-1.pdf
[27] https://www.transitwiki.org/TransitWiki/index.php/Transit_signal_priority_(TSP)

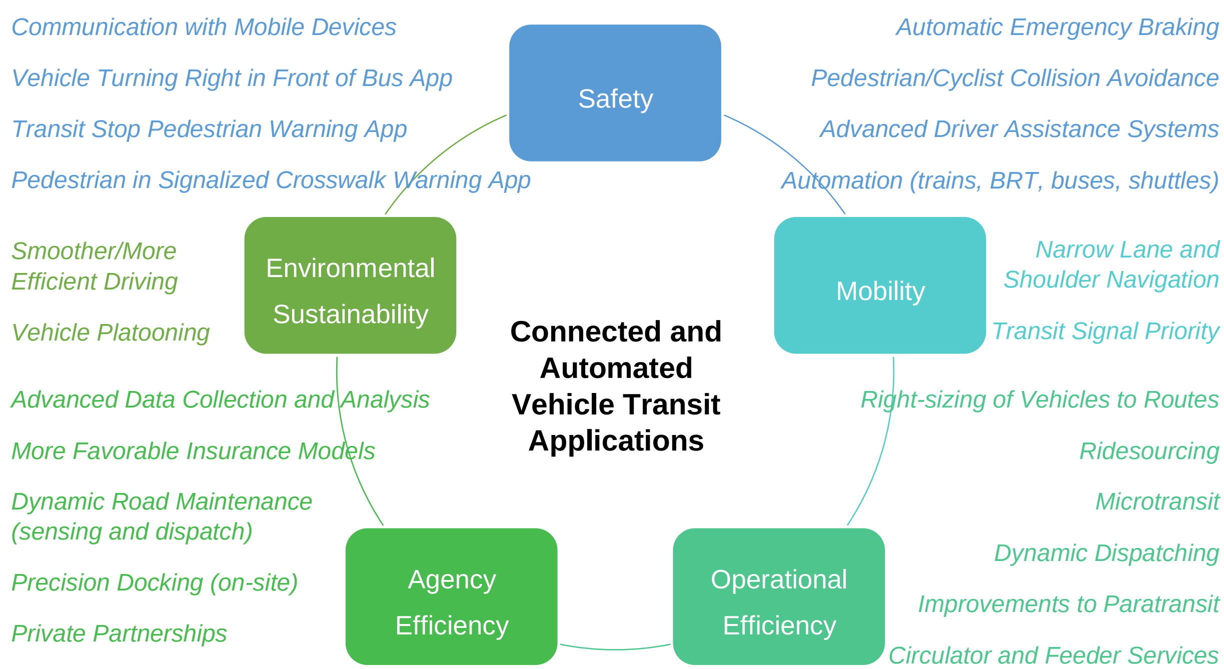
UTA recognizes that TSP and TSP-enabling CV technology is not evolving in a static environment, it's fluid and advancing quickly. We, members of the TSP working group, are aware that once this Plan is complete, some parts of it will already be outdated. This Plan anticipates building future technical transitions into the long term phase.

7.1.4 Influence of Connected Vehicle Technologies

Connected vehicle (CV) technologies enable various types of vehicles, roadway infrastructure, mobile devices, and other objects to communicate quickly to share vital information. CV technologies enable vehicles to communicate with infrastructure (vehicle-to-infrastructure, or V2I), between vehicles (vehicle-to-vehicle, or V2V), and with other objects in the roadway (vehicle-to-everything, or V2X).

Beyond TSP, V2I applications for transit could also be used to enable smoother vehicle operations, via more efficient acceleration and braking when approaching signalized intersections knowing what the signal phase will be, which could have positive environmental (reduced fuel usage) and maintenance (reduced wear-and-tear) impacts. V2I could also enable enhanced data collection and real-time information sharing. This includes information currently provided to passengers, such as real-time location and stop arrival times, as well as additional information that could be gained, such as the location and characteristics of roadway damage, traffic backups, and road closures.

Figure 6: Potential Benefits and Applications of CAV for Transit (source: WSP)



In addition, a common V2V application is the Vehicle Turning Right in Front of Bus application, which enhances the safety of a transit vehicle leaving a stop as another vehicle is trying to pass it and turn right, but it depends on connectivity with vehicles outside the transit vehicle fleet (which may not be available in the short term). While automakers could be motivated to pursue CV for driver safety and have made many claims, little CV technology has materialized in today's consumer auto market. Instead, CV is being implemented now in commercial and government fleets. With hundreds of buses and a 12 year replacement cycle, it is important for UTA to leverage this technology as it evolves.

7.1.5 Industry Scan & Literature Review

While studying the state of technology, the Project Team scanned the transit industry for relevant TSP projects and reviewed literature including:

- NACTO Transit Street Design Guide section on Active Transit Signal Priority[28]
- Washtenaw BRT study that has a cost comparison between GPS/AVL, CV, and C2C in a location that is also deploy CV[29]
- Transit Signal Priority with Connected Vehicle Technology[30]
- ITS JPO – Transit Signal Priority Fact Sheet[31]
- Transit Priority Treatments in Oregon[32]

Potential benefits and specific use cases of TSP derived from the literature review include:

- Reduced travel time by transit – enable faster movements through intersections and potential reduce the number of vehicles needed to service a route at the same frequency
    - BRT is the prime use case to leverage this benefit, as other features of BRT already remove or mitigate many of the other factors (congestion, fare collection, etc.) that add to travel time.
- Increase reliability of travel time by transit – enable more consistent movements through intersections, allowing more accurate schedules to be developed, reducing incidents of bus bunching, and enabling passengers to plan more efficient transfers (especially for trips that include transfers)
    - Intersections with long signal cycles, particularly when the movement the bus is traveling on is not favored relative to cross traffic.
    - Streets with long distances between signals, where the only/main cause of unreliability is the signal.
    - At intersections where bus routes turn, TSP can extend turn phase time or reservice a turn phase to provide a clear turn lane and additional phase time for slow maneuvers for buses and especially for articulated buses (see 850X).
    - This can also be used to develop schedules with less padding (and break times for drivers can still be included in the schedule at terminals, where it doesn't impact passengers).
- TSP could be deployed in conjunction with emergency vehicle preemption, snow plow signal priority, and other connected vehicle applications like red light violation warnings, eco-traffic signal timings, and pedestrian in signalize crosswalk warnings to further enhance the safety and mobility benefits to the transportation network.
- Beyond transit operational benefits, there could be traffic safety benefits as well: https://journals.sagepub.com/doi/10.1177/0361198118770168

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[28] https://nacto.org/publication/transit-street-design-guide/intersections/signals-operations/active-transit-signal-priority/
[29] https://www.theride.org/media/278/download?inline
[30] https://nacto.org/wp-content/uploads/2016/04/1-4_Park-Hu-Transit-Signal-Priority-with-Connected-Vehicle-Technology_2014.pdf
[31] https://www.pcb.its.dot.gov/factSheets/tsp/tsp_overview.aspx#page=tech
[32] https://www.oregon.gov/ODOT/Planning/Documents/Mosaic-Transit-Priority-Treatments.pdf; http://bertini.eng.usf.edu/papers/PR128.pdf

7.2 COST BENEFIT ANALYSIS

There is little debate about the general cost benefit of TSP systems as measured by operational efficiencies and time saved. For example, due to an annual operating cost savings of approximately $3.3 million in Los Angeles, the relative benefit-cost ratio for TSP associated with two bus rapid transit corridors was estimated to be more than 11:1 over 10 years.[33]

This section provides an assessment of the present technology alternatives that enable TSP, to compare the costs and benefits of each option. This benefit-cost analysis is presented in Table 33, which also includes other noteworthy information for each alternative such as whether there are existing deployments in Utah or what the expected lifespan of the technology deployment would be.

The costs of each alternative consider both the upfront hardware, software, and installation costs, as well as ongoing operations and maintenance costs to maintain a state of good repair. These are total costs of an entire deployment, but it is worth noting that the net cost to UTA could be lower if partners are interested in cost sharing, or if existing or new grant funding could be leveraged.

Benefits cover the capabilities of each alternative and the value these capabilities provide. All alternatives have the benefits of decreasing trip times, thereby improving passenger throughput, and increasing the reliability and schedule adherence of existing bus routes.

Table 3: Cost Benefit Analysis

Technology	*Estimated Cost*	*Cost Benefit Analysis*	*Other Information*
C-V2X: Data Ecosystem project, Panasonic and UDOT *Other vendors include Qualcomm and Applied Information*[34]	Hardware estimate is $4,150 per OBU. If a contractor installs it's $2,400 each ($6,550 total). If UTA installs installation costs are $800 each ($4,950 total). RSU costs are $6,000 for the unit and $1,500 to install ($7,500 total). O&M cost is estimated at $86,840 per year across the TSP system.	**Pros**: Supports CV applications for enhanced safety and smart data transmission. LTE is backed by the communications industry making it future-resilient. UDOT partnership and cost sharing greatly reduces UTA's net expense on UDOT roads. From a TSP perspective, CV technologies provide better insight into real-time traffic information, more accurate arrival time prediction, and can enable advanced TSP logic conditions. **Cons**: No financial or tech support on non-UDOT roads. Does not currently support municipal EMS systems. Rollout takes longer due to partnering and customization. Technology has only been deployed at a few locations across the country to date and will probably require significant testing and troubleshooting in the short	Expected lifespan of new equipment is **7-10** years. Possible issue with 5.9 GHz interference and spectrum loss. UDOT is already in the process of deploying this technology locally.

[33] TCRP Report 118. 2007. P. 4-32

[34] https://appinfoinc.com/applied-information-cv2x-hawaii/; https://hidot.hawaii.gov/highways/files/2020/08/V2X-Enabled-TCS-Innovations-Proposal-Econolite-Systems-redacted.pdf
This deployment is part of a $6.85 million ATCMTD grant program to deploy C-V2X technology including TSP.

		term. UTA may have less control over signal parameters.	
DSRC: *USDOT Pilots*	Hardware estimate is $1,400 per OBU + $800 for installation (**$2,200** total). O&M cost is estimated at $X.[35]	**Pros:** DSRC is the type of TSP technology in use today on UVX, Route 217 and several other UDOT corridors demonstrating its effectiveness. It has also been deployed in many other states for over a decade. Any V2X technologies have the added benefit of two-way communication – bus can notify when it is approaching the intersection, as well as when it has cleared the intersection. **Cons:** Does not support CV applications nor municipal EMS systems. Future DSRC deployments should be considered useful but temporary solutions due to FCC rule changes. No financial or tech support on non-UDOT roads. Currently no way for UTA to monitor directly (UDOT can).	Expected lifespan of new equipment is **1-3** years. Unless regulations change, DSRC components will need to be phased out in 2022 - 2024. FCC may be required to provide "transition" compensation. Dependent on contractors to maintain equipment. Possible issue with 5.9 GHz interference and spectrum loss.
Location-Based COTS (GPS/CAD/AVL)	Commercial GPS-based solutions such as Opticom/GTT, Clever Devices, Siemens, or Bosch. Vehicle hardware estimate is $3,300 per OBU. Installation costs are $500 ($3,800 total). RSU costs are $6,200 for the unit and $1,350 to install ($7,550 total). One-time software costs are $173 per intersection. O&M cost is estimated at $85,990 per year across the TSP system.	**Pros**: Simple, proven technology with many existing deployments to learn from. UTA has direct experience operating and maintaining the current Opticom/GTT system on 3500 South. Functioning as an independent system, UTA may have more control to consistently get priority or change parameters. More leverage with direct vendor support. **Cons**: Does not support CV applications nor municipal EMS systems.	Expected lifespan of new, upgraded equipment is **7-10+** years. Analog systems can run for decades. Maintenance and operation are easier with newer, digital systems that provide transparent online monitoring. This is more traditional TSP option and has been widely deployed for applications across the country for decades. Therefore, it is unlikely to be competitive for grant funding.
Loop Detectors	Vehicle hardware estimate is $100. Intersection costs can up to $30,000. Other costs $X. O&M cost is estimated at $X.	**Pros:** Bus transponders aren't even necessary since the loop detector can detect the bus, but they would potentially enable more logic to be added to the system. **Cons:** Currently very expensive per intersection.	Expected lifespan is **10-20** years (or they may need to be replaced when a road is resurfaced). TRAX uses loop detectors. Very traditional system.

Additional information on the range of capital and operating costs for different TSP detection systems can be found in TCRP Report 118: Bus Rapid Transit Practitioner's Guide, Exhibit 4-38.[36]

[35] https://www.theride.org/media/278/download?inline

[36] https://www.trb.org/Publications/Blurbs/158960.aspx

7.3 Tradeoff Evaluation & Recommendations

Tradeoff	Considerations	Recommendation
TSP or not TSP	While TSP falls under Connected Vehicle applications, over the last 10 years CV has attracted more transit industry attention as the newer technology. Proven TSP benefits are still relevant, even if the vendor market and support for deployed products is thin. Should UTA still invest in TSP or focus instead on emerging CV applications?	Implement TSP now while still exploring new CV opportunities
Local project flexibility v. regional / agency standards	Individual BRT projects can access new capital funds. Project managers may study unique TSP solutions, but a lack of interoperability increases the complexity and overall cost of the TSP network. The largest supplier and promoter of CV and TSP technology in the region is UDOT. Currently UTA has 3 bus service units and 2 of them are deploying C-V2X with UDOT in some fashion. Should UTA be flexible enough to support multiple types of CV and TSP solutions?	Set agency standards
Fleet v. BRT focus	The Salt Lake Service Unit has the most (78%) Core Routes making a whole fleet TSP investment worthwhile in Salt Lake County. Ogden and Timpanogos Service Units have fewer core routes, making TSP investments most useful on BRT. Note that the Timpanogos Service Unit has short term plans to equip 66% of its general fleet with TSP. Should UTA support different TSP approaches depending on the Service Unit?	Target 100% of fleet for ease of running any bus on Core Routes
Any bus v. prioritized bus	This question pertains to the general bus fleet and not routes that already have a dedicated bus type (i.e. Ski, BRT). Note that the tradeoff is for a prioritized bus (not dedicated bus) because it is a not efficient for a service unit to dedicate buses to a specific route due to difficulty of scheduling, maintenance, and spare ratios. Is it worth prioritizing buses to save on TSP costs, or should the entire fleet be outfitted to leverage the 'any bus, anywhere' philosophy?	Any bus; start with coverage of all buses within a fleet type (i.e. 40' Gillig)
Commercial Off the Shelf (COTS) v. CV technology	CV technology can support other applications for enhanced safety and smart data transmission. It can also support enhanced TSP capabilities, such as insight into real-time traffic	CV technology

	information, more accurate arrival time prediction, and more advanced TSP logic conditions. However, COTS solutions have been more widely deployed and validated, and will likely require less maintenance and attention than emerging CV technologies.	
Toggle v. intelligent	Intelligent TSP systems are fully automated and more consistent. It's a challenge to decrease variability with a toggle system because each operator has their own driving style and tendency to use the manual toggle switch. However, Emergency Response vehicles use only toggle-based systems.	Select an intelligent system
Corridors v. spot improvements	Focusing on spot improvements, for example downtown intersections. For how many seconds are buses delayed by traffic signals? It is also worth considering that TSP operations are most effective at signalized intersections with moderate-to-heavy traffic conditions. Areas with lighter traffic provide less of an advantage to buses, areas with heavier traffic experience more impacts on cross street performance, including high cross street delay and increased delay recovery cycles.[37]	Decision framework and more precise data is needed
UDOT roads v. all roads	UDOT has been successful and planning for and securing funds to install RSUs on various corridors. These corridors don't always line up with transit needs. Should UTA leverage UDOT's TSP corridors or focus attention on our most useful transit roads?	Concentrate on Core Routes and BRT projects
Equity v. expediency	UTA's equity analysis can measure bus travel times by neighborhood. Buses carry a higher percentage of transit dependent and low income riders compared to rail[38], so any bus service improvement has a greater impact on equity. Moreover, Title VI requires that UTA rotates the fleet. Should UTA strive to provide better bus service sooner regardless of neighborhood?	Consider equity when planning and phasing projects

[37] https://nacto.org/publication/transit-street-design-guide/intersections/signals-operations/active-transit-signal-priority/

[38] UTA 2019 On-Board Survey

7.4 Specific TSP Cost Scenario for 3500 South

DRAFT 3500 South TSP Scenario									
Capital Cost Estimate	Roadside Unit	RSU Install	Onboard Unit	OBU Installation	Software Setup	Total Project Capital Est.	Cost offset: Amount	Cost offset: Source / Grant	Net Capital Cost Est.
C-V2X as supported by UDOT/Panasonic	$6,000	$1,500	$4,150	$2,400	$0	$421,700	$421,700	UDOT / CMAQ	$0
Commercial GPS-based system (Pinetop)	$6,200	$1,350	$3,300	$500	$173	$392,990	$300,000	UTA / CMAQ	$92,990
Operations Cost Estimate	Est. Annual O&M	Year 1	Year 2	Year 3	Year 4	Year 5	Cost offset: Amount	Cost offset: Source / Grant	Operations Est. Years 1-5
C-V2X as supported by UDOT/Panasonic	$85,840	$85,840	$87,557	$89,308	$91,094	$92,916	$0	N/A	$446,715
Commercial GPS-based system (Pinetop)	$85,990	$85,990	$87,710	$89,464	$91,253	$93,078	$0	N/A	$447,495
Est. 5-Year Total Cost									**Total Est.**
C-V2X as supported by UDOT/Panasonic									$446,715
Commercial GPS-based system (Pinetop)									$540,485
Inputs									
Capital									
Intersections	44								
Buses	14								
Operations									
UTA FTE per year (spread across projects	$75,000								
Other O&M per year	$10,000								
Software Maint. Fee (COTS only)	$990								
Security cert. for OBUs (UDOT only)	$60								
Inflation	2%								
Assumptions									
Exisiting traffic signal controllers can optimize multiple TSP messages through heirachy									
C-V2X: RSUs can be funded by UDOT for this project									
Support costs are similar for both TSP types									
1 UTA FTE is required, allocated across all TSP projects									
All intersections will have TSP (next tab)									

7.5 Current TSP Approach and Funding

UDOT is the recipient of a 2018 USDOT Advanced Transportation and Congestion Management Deployment (ATCMTD) Grant which provides significant funding for CV applications and TSP expansion in Utah. Unless otherwise mentioned, upcoming 2021 projects are receiving funds from UDOT's ATCMTD award. UDOT has a total of 60 OBUs on hand – 30 DSRC and 30 cellular C-V2X. These 60 units may be spread across a limited number of buses and corridor-based projects to maximize TSP benefits for UTA riders and Operations. UTA may consider funding for additional buses in the future.

When deploying transit-related TSP projects, UDOT relies on UTA to help prioritize adding Roadside Units (RSUs) to corridors which most benefit transit. UTA Planning and Operations staff prioritizes BRT routes, Core Routes, and routes in a Frequent Transit Network in alignment with the UTA's Five-Year Service Plan and Regional Transportation Plans. On-time performance data has been the primary metric for selecting bus routes for TSP projects.

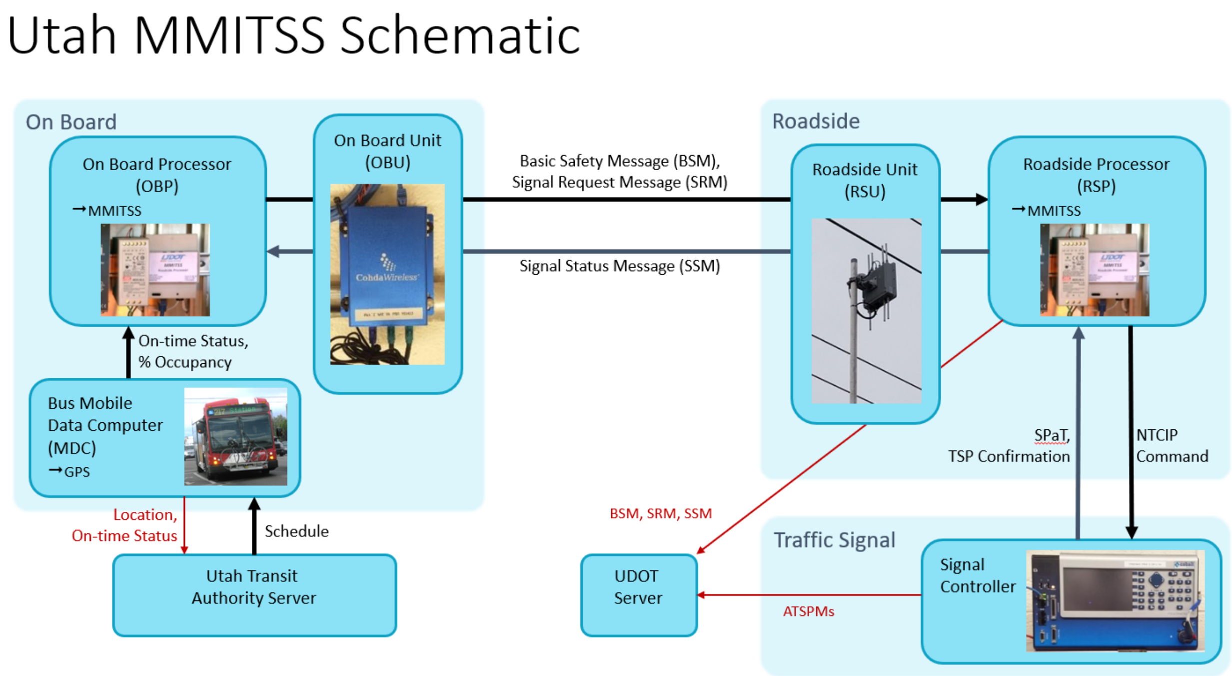
For operational efficiency, UTA does not generally equip TSP on buses for a specific route. UTA relies on an "any bus, anywhere" practice for the most efficient fleet management and scheduling, and ideally all buses that could benefit from TSP would be equipped with TSP hardware. At this time, UTA cannot realize the full benefit of the growing TSP roadside network because only a fraction of buses has TSP hardware onboard. It is much easier to realize TSP benefits on BRT when these routes have a dedicated bus fleet.

Maintenance for DSRC On Board Units (OBUs) is shared by UTA and a UDOT contractor company Narwhal. Currently UTA maintains the connections to the DSRC onboard unit because it connects to the

Bus Mobile Data Computer (MDC) system. UDOT is supporting the OBUs on the buses. If the onboard modem breaks, then UTA calls Narwhal to repair or replace it.

7.6 Utah MMITSS Schematic, Existing DSRC TSP System

Image credit: UDOT



7.7 UTA Bus Fleet Counts

By Type and Garage, K. Doane

Estimated Peak Pullout (in service) Comparison

December 2019 (Pre-Covid)

	OG	TP	CN	MB	RS	
40' Bus	53	30	78	121		282
MCI	18	8		24		50
Flex					32	32
Ski	11	2		32		45
Trolley	4					4
BRT		26				26
	86	66	78	177	32	**439**

November 2020

	OG	TP	CN	MB	RS	
40' Bus	48	33	62	110		253
MCI	6	6		9		21
Flex					26	26
Ski	11	2		32		45
Trolley	4					4
BRT		11				11
	69	52	62	151	26	**360**

5-Year Service Plan

	OG	TP	CN	MB	RS	
40' Bus	52	37	94	99		282
MCI	11	15	4	13		43
Flex					21	21
Ski	11	2		32		45
Trolley	4					4
BRT	6	16				22
	84	70	98	144	21	**417**

Estimates represent number of buses in active revenue service; does not include spare ratios.
Peak pullout of 417 buses in the 5-Year Service plan is lower than December 2019 (pre-Covid) but higher than November 2020
Bus types for each route can be adjusted in the "Bus Assumptions" tab.
5YSP Pullout estimated at the route level and does not include blocking or signout efficiencies. Likely a slight overestimate.
Flex includes contracted routes (Tooele, Ogden).
Ski is not assumed to change in the 5YSP

7.8 Length and Percentage of UTA Route Patterns on UDOT Roads, Core Routes & BRT Only

By J. Wadley. ***Color scale:*** *Shading increases as route miles on UDOT roads increase*

Route	Name	Core Route / BRT	Pattern Miles	UDOT Road Miles	% UDOT
2	200 SOUTH	Yes	5.5	0.7	12.6%
200	STATE STREET NORTH	Yes	12.2	8.8	72.1%
205	500 EAST	Yes	10.9	0.8	7.1%
209	900 EAST	Yes	17.1	2.9	16.7%
21	2100 SOUTH / 2100 EAST	Yes	9.8	3.9	39.5%
217	REDWOOD ROAD	Yes	18.5	13.6	73.6%
220	HIGHLAND DRIVE / 1300 EAST	Yes	18.4	0.7	3.7%
33	3300 SOUTH	Yes	7.7	5.9	75.7%
35	3500 SOUTH	Yes	19.4	13.7	70.3%
39	3900 SOUTH	Yes	13.5	1.5	11.1%
41	4100 SOUTH	Yes	5.0	0.7	14.5%
45	4500 SOUTH	Yes	9.3	4.0	42.9%
47	4700 SOUTH	Yes	13.5	5.0	37.1%
54	5400 SOUTH	Yes	10.8	6.6	61.4%
603	WEBER STATE UNIVERSITY / MCKAY DEE	Yes	8.1	4.4	55.1%
612	WASHINGTON BLVD	Yes	33.1	19.9	60.1%
830X	UTAH VALLEY EXPRESS	Yes	16.7	9.2	55.4%
850	STATE STREET	Yes	27.1	21.3	78.6%
9	900 SOUTH	Yes	12.6	2.9	23.4%

7.9 Length and Percentage of UTA Route Patterns on UDOT Roads

By J. Wadley

Route	Name	Core Route / BRT	Pattern Miles	UDOT Road Miles	% UDOT
17	1700 SOUTH	No	9.7	2.9	29.6%
2	200 SOUTH	Yes	5.5	0.7	12.6%
200	STATE STREET NORTH	Yes	12.2	8.8	72.1%
201	STATE STREET SOUTH	No	12.7	8.6	67.6%
205	500 EAST	Yes	10.9	0.8	7.1%
209	900 EAST	Yes	17.1	2.9	16.7%
21	2100 SOUTH / 2100 EAST	Yes	9.8	3.9	39.5%
213	1300 EAST / 1100 EAST	No	19.6	3.5	18.0%
217	REDWOOD ROAD	Yes	18.5	13.6	73.6%
218	SOUTH JORDAN	No	9.2	5.5	60.2%
220	HIGHLAND DRIVE / 1300 EAST	Yes	18.4	0.7	3.7%
223	2300 EAST/ HOLLADAY BLVD	No	18.6	3.4	18.0%
227	2700 WEST	No	6.9	0.0	0.0%
240	4000 WEST/ DIXIE VALLEY	No	14.4	2.5	17.0%
248	4800 WEST	No	17.1	1.2	7.3%
3	3RD AVENUE	No	10.4	1.7	16.3%
33	3300 SOUTH	Yes	7.7	5.9	75.7%
35	3500 SOUTH	Yes	19.4	13.7	70.3%
39	3900 SOUTH	Yes	13.5	1.5	11.1%
4	400 SOUTH	No	17.2	12.4	71.9%

41	4100 SOUTH	Yes	5.0	0.7	14.5%
45	4500 SOUTH	Yes	9.3	4.0	42.9%
451	TOOELE FAST BUS	No	63.8	59.8	93.7%
454	GRANTSVILLE/SALT LAKE	No	68.6	51.4	74.8%
455	U OF U/DAVIS COUNTY/WSU	No	66.7	45.7	68.6%
47	4700 SOUTH	Yes	13.5	5.0	37.1%
470	OGDEN - SALT LAKE INTERCITY	No	48.8	36.6	75.0%
473	SLC - OGDEN HWY 89 EXPRESS	No	74.2	66.7	89.9%
509	900 W SHUTTLE	No	15.3	2.3	14.7%
513	INDUSTRIAL BUSINESS PARK SHUTTLE	No	21.6	1.5	6.8%
519	FAIRPARK	No	9.1	0.4	4.9%
520	ROSE PARK	No	9.1	0.4	4.9%
54	5400 SOUTH	Yes	10.8	6.6	61.4%
551	INTERNATIONAL CENTER	No	14.1	3.9	27.3%
6	6TH AVENUE	No	8.3	1.1	13.9%
601	OGDEN TROLLEY	No	2.1	0.6	30.5%
603	WEBER STATE UNIVERSITY / MCKAY DEE	Yes	8.1	4.4	55.1%
604	WEST OGDEN	No	16.4	11.5	69.8%
606	ENABLE INDUTRIES	No	7.3	5.0	68.6%
612	WASHINGTON BLVD	Yes	33.1	19.9	60.1%
613	WEBER INDUSTRIAL PARK	No	10.9	5.1	46.9%
62	6200 SOUTH	No	12.6	0.3	2.0%
625	ATC / HARRISON BLVD / WSU	No	17.7	11.4	64.1%
626	WEST ROY / CLFD STAT	No	12.1	11.0	90.6%
627	CLFD STATION / DATC	No	16.0	6.2	38.9%
628	MIDTOWN TROLLEY	No	8.5	4.3	49.8%
630	BRIGHAM CITY/ OGDEN COMMUTER	No	27.7	25.4	92.0%
640	LAYTON HILLS MALL / WSU OGDEN CAMP	No	24.7	12.1	49.0%
645	MONROE BLVD	No	22.5	8.8	39.0%
650	OGDEN FRONTRUNNER / WSU FAST BUS	No	6.7	3.9	58.0%
667	LAGOON / STATION PARK SHUTTLE	No	5.6	2.0	36.1%
701	Blue Line	No	19.3	0.0	0.0%
703	Red Line	No	23.7	3.0	12.6%
704	Green Line	No	15.0	0.0	0.0%
72	7200 SOUTH	No	6.2	0.3	5.2%
720	S-Line	No	2.1	0.0	0.0%
750	FrontRunner	No	82.0	0.0	0.0%
805	SANTAQUIN/PAYSON/SF/PROVO STN/UVU	No	55.7	53.9	96.7%
806	EAGLE MTN/SARATOGA SPR/LEHI STN/UVU	No	47.2	39.1	82.9%
807	NORTH COUNTY/LEHI STATION/UVU	No	24.5	14.1	57.6%
821	SOUTH COUNTY/PROVO STATION	No	25.2	16.7	66.2%
822	SOUTH UTAH COUNTY BYU/UVU LIMITED	No	31.1	21.0	67.6%
830X	UTAH VALLEY EXPRESS	Yes	16.7	9.2	55.4%
831	PROVO GRANDVIEW	No	14.1	4.2	29.8%
833	AIRPORT/PROVO STATION	No	6.8	3.1	45.5%
834	OREM CITY/RIVERWOODS/ PROVO STATION	No	11.3	3.7	32.7%
841	UVU - OREM STATION	No	3.1	0.8	24.8%
850	STATE STREET	Yes	27.1	21.3	78.6%
862	OREM EAST/WEST	No	17.1	2.7	15.5%
864	LEHI STATION/XACTWARE	No	6.7	0.0	0.0%
871	TECH CORRIDOR RAIL CONNECTOR	No	21.5	16.5	76.9%
9	900 SOUTH	Yes	12.6	2.9	23.4%
902	PC-SLC CONNECT	No	47.2	38.9	82.4%
919	FAIRPARK (WEST HS)	No	9.2	0.6	6.7%
920	ROSE PARK (WEST HS)	No	9.2	0.6	6.7%
953	MDVLFTUN/SNOWBIRD/ALTA	No	25.1	15.5	61.7%

999	Bus Shuttle	No	1.9	0.0	0.0%
F11	11TH AVENUE FLEX	No	5.3	0.7	13.1%
F202	BINGHAM JCTN FLEX	No	5.5	0.0	0.0%
F232	3200 WEST FLEX	No	8.4	0.0	0.0%
F400	TOOELE FLEX	No	8.1	2.8	34.8%
F402	TOOELE CITY CIRCULATOR	No	7.1	1.4	19.6%
F453	TOOELE SLC FLEX	No	51.1	43.7	85.5%
F514	JORDAN GATEWAY FLEX	No	8.4	0.0	0.0%
F522	2200 WEST FLEX SHUTTLE	No	4.4	0.0	0.0%
F525	MIDVALE FLEX	No	5.8	0.4	7.6%
F556	5600 WEST FLEX	No	8.3	5.1	61.8%
F570	7000 SOUTH FLEX	No	9.3	2.9	31.6%
F578	7800 SOUTH FLEX	No	8.2	2.1	25.3%
F590	9000 SOUTH FLEX	No	7.0	4.7	67.2%
F605	SOUTH DAVIS FLEX	No	8.3	3.1	37.0%
F618	OGDEN BDO FLEX	No	11.6	4.3	36.9%
F620	WEST HAVEN FLEX	No	10.0	6.0	60.5%
F638	THE BRIGHAM CITY Flex	No	7.6	2.7	35.2%
F94	SANDY FLEX	No	9.1	4.5	49.0%
			1684.6	864.8	51.3%

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