OCTA Orange County Transportation Authority

Harbor Boulevard Pilot Innovative Transit Signal Priority Study

Final Implementation Report

Strengthening Mobility and Revolutionizing Transportation (SMART) Grant Program

Stage 1 | FY2022

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1. Executive Summary

This Implementation Report documents the Stage 1 proof-of-concept deployment and evaluation of Transit Signal Priority (TSP) and advanced multimodal detection technologies along the Orange County Transportation Authority's (OCTA) Harbor Boulevard corridor. The project was funded through the U.S. Department of Transportation's (USDOT) Strengthening Mobility and Revolutionizing Transportation (SMART) Grant Program and focused on demonstrating how cloud-based, interoperable technologies can improve transit performance, enhance operational awareness, and support safer multimodal operations in a complex urban corridor.

Stage 1 deployment was limited in scale, consisting of nine signalized intersections within the City of Fullerton. Despite this limited footprint, the pilot generated meaningful performance data and operational insights that establish a clear baseline for evaluating benefits and informing future corridor-wide implementation. The evaluation leveraged data from OCTA transit systems, traffic signal controllers, arterial performance measures, and a Power BI dashboard to quantify transit delay, travel time, signal encounters, and intersection-level operational behavior.

The TSP component of the pilot demonstrated that real-time, cloud-based priority requests can be reliably generated and executed across multiple signal controller platforms without causing signal failures or unacceptable impacts to general traffic. Following TSP activation, average bus delay per signal was reduced by more than 30 percent, trip travel times decreased by approximately 7 to 8 percent, and buses encountered significantly fewer red-signal stops. These improvements translated into more reliable travel times for Routes 543 and 43, even within the constrained pilot area.

The project also showed that advanced multimodal detection technologies, including LiDAR, radar, and video-based systems, can support safety monitoring and operational insight at signalized intersections. The detection deployment demonstrated that modern sensor technologies, when paired with AI-based analytics, reliably identify and classify multimodal activity and unsafe conditions such as near-miss events, unsafe crossings, red-light violations, and wrong-way movements involving vehicles, pedestrians, and bicyclists. The detection evaluation confirmed the feasibility of generating intersection-level safety data that complements TSP performance monitoring and supports proactive operations.

Overall, the Stage 1 pilot confirms that next-generation TSP and detection technologies can deliver measurable transit performance benefits, enhance operational awareness, and support safer multimodal environments without degrading general traffic operations. The findings provide a strong technical foundation for advancing to Stage 2, where expanded deployment along the full Harbor Boulevard corridor can further evaluate corridor-wide impacts, refine priority and detection strategies, and support broader SMART statutory objectives related to congestion reduction, system reliability, and interoperability.

2. Introduction and Project Overview

The Harbor Boulevard Pilot Innovative Transit Signal Priority (TSP) Study is a Strengthening Mobility and Revolutionizing Transportation (SMART) Stage 1 grant project led by the Orange County Transportation Authority (OCTA), aimed at testing and evaluating cloud-based TSP and multimodal detection technologies along the Harbor Boulevard corridor. This pilot focuses on nine (9) signalized intersections within the City of Fullerton and will inform future corridor-wide deployment across a 12-mile segment that spans five (5) jurisdictions.

Project Description

Harbor Boulevard is a multimodal corridor in central Orange County, California, spanning the cities of Anaheim, Fountain Valley, Fullerton, Garden Grove, and Santa Ana. The Harbor Boulevard corridor was identified as needing high-quality transit. The full corridor covers approximately 12 miles of Harbor Boulevard, traversing Santa Ana, Fountain Valley, Garden Grove, Anaheim, and Fullerton, with nearly 60 signalized intersections that service OCTA’s Route 43 and 543 Rapid Bus, as shown in **Figure 1** (next page). This corridor connects major destinations including California State University at Fullerton, Santa Ana College, Disneyland, hospitals, and regional employment centers, and supports over 10,000 daily bus boardings.

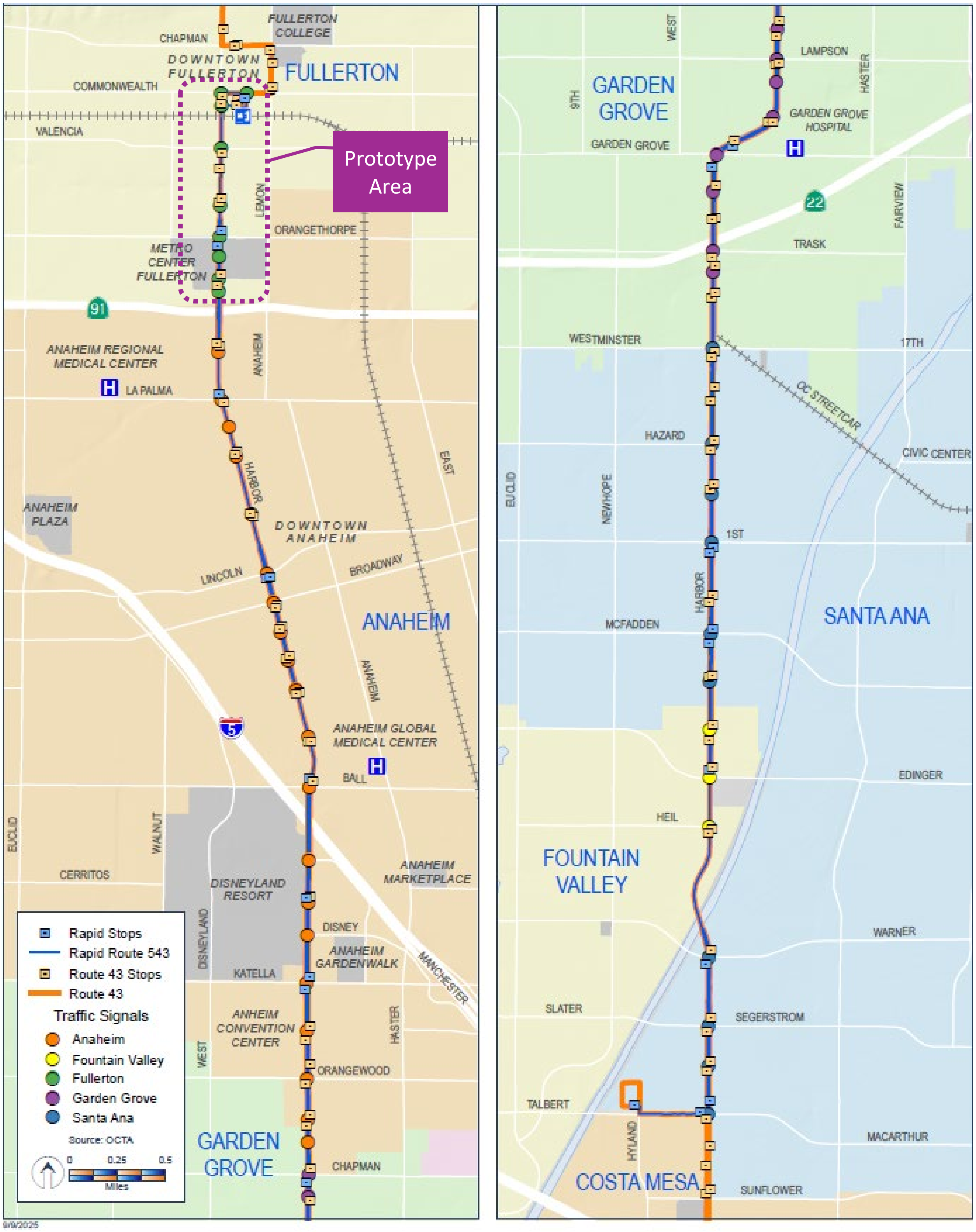
Real-World Issues and Challenges Addressed with At-Scale Implementation
The Harbor Boulevard corridor experienced the following challenges:

- Transit travel time variability due to high traffic volumes, frequent signal stops, and limited signal coordination.
- Safety improvements to vulnerable roadway users (VRUs) such as pedestrians and bicyclists, especially at wide, high-volume intersections.
- Limited real-time multimodal data to support integrated performance monitoring, operations, and planning.

Though an in-depth analysis of TSP with older technologies was previously conducted on the Harbor Boulevard corridor, it was not deployed due to the required large capital improvement. In contrast, the OCTA proposed project through the SMART program requires less equipment and implements innovative solutions, while leveraging recent improvements local agencies have implemented using local funds. Therefore, a solid foundation is now in place to ensure successful TSP deployment and additional data insights with support from all five local agencies resulting in a more unified and streamlined approach to delivering this cross-jurisdiction improvement. Additionally, this project proposed to evaluate various signalized intersection detection solutions to collect appropriate data to properly evaluate the safety of bicycles and pedestrians traveling along and through the project corridor.

Ultimately, a successful evaluation in the prototype area as part of this SMART Stage 1 pilot project will result in a roadmap for the appropriate improvements required on the full Harbor Boulevard corridor to support cloud TSP and enhanced detection solutions for the appropriate insights required by transit and traffic operators to understand performance on this corridor.

Figure 1 – Project Stage 1 and At-Scale Implementation Geographic Area



Technologies Being Deployed

The pilot deployed an innovative TSP solution via the LYT cloud software platform and various multimodal detection technologies at a subset of intersections. These technologies fall under several DOT innovation categories:

- Smart Technology Traffic Signals: Adaptive, cloud-based TSP via the LYT platform to reduce bus delays and improve on-time performance.
- Intelligent Sensor-Based Infrastructure: Advanced detection systems such as Lidar, Radar, Fisheye Video, and Infrared, designed to identify and track VRUs like pedestrians and cyclists in real-time.
- Systems Integration: Integration with Automated Traffic Signal Performance Measures (ATSPMs), LYT, Iteris ClearGuide, and OCTA's General Transit Feed Specification (GTFS) and Swiftly systems to support data-driven operations and visualization dashboards.
- Connected Vehicles: The TSP system interfaces with vehicle location and priority request data from OCTA's GTFS and Swiftly connected buses, aligning with future Connected Vehicle applications.

The LYT Cloud based TSP solution implemented as part of this project was able to pull the bus location from Swiftly and compute an Estimated Time of Arrival (ETA) to the traffic signal controllers. The City of Fullerton operates the Q Free Advanced Traffic Controllers (ATC) and the remaining cities on the project corridor use various versions of the Econolite traffic controller technologies.

Goals and Desired Outcomes for At-Scale Implementation

The primary objective of Stage 2 at-scale implementation is to extend the reliability benefits of TSP across the entire Harbor Boulevard corridor while deploying advanced multimodal detection technologies to enhance safety for vulnerable roadway users (VRUs). Harbor Boulevard serves as a critical link connecting major destinations such as medical facilities, California State University, Fullerton, Disneyland, Santa Ana College, places of worship, and retail centers. By reducing the time buses spend waiting at red lights, the system can improve schedule adherence and potentially eliminate the need for an additional bus on certain routes, yielding significant operational cost savings. Furthermore, integrating detection technologies will strengthen protections for pedestrians and bicyclists, reduce crash risk at high-volume intersections, and foster a safer, more predictable travel environment for all corridor users.

The project presents the opportunity to address the six United States Department of Transportation's (USDOT's) strategic goals (safety, economic strength and global competitiveness, transformation, and organizational excellence) and all the SMART program's goals (safety and reliability, resiliency, partnerships, and integration), as summarized below.

- Reduce delay for transit buses, particularly on Route 543 and Route 43.
- Improve travel time reliability for the OCTA transit system, particularly for buses on Route 543 and Route 43.
- Enhance safety of transportation facilities and systems for pedestrians, bicyclists, and the broader traveling public through advanced multimodal detection and intersection analytics.
- Develop a scalable model for cloud-based TSP and sensor integration across corridors in Orange County.

- Improve access to jobs (Disney), health care, education (California State University at Fullerton, Santa Ana College), hospitals, and services by improving connectivity along this vital link in Orange County.
- Generate performance metrics (e.g., delay reduction, success rate of TSP calls, and other measures) via a unified dashboard and data architecture.
- Emphasize policies and processes that foster an innovative culture.

Impacted Communities

The Harbor Boulevard corridor serves a diverse and transit-dependent population, including low-income households, students, and essential workers. The corridor traverses multiple communities that would benefit greatly from a faster, more reliable service.

The project team worked closely with stakeholders including operations staff at OCTA and local agency staff to understand performance relevant to each stakeholder.

- The project directly improves mobility and safety in areas with limited access to private vehicles.
- Engagement occurred through stakeholder coordination with local cities and technical working groups.
- Future at-scale deployment would further reduce travel time penalties for all riders and prioritize safety enhancements in underserved zones.

As a successful pilot, OCTA will expand the technologies along the Harbor Boulevard corridor and on other OCTA routes throughout the county, thus extending these benefits to additional communities. In addition to the transit and roadway travelers within Orange County, a successful pilot will also strengthen partnerships with local agencies and community leaders to implement innovative technology solutions that not only focuses on the operation of the system but also provides performance insights for quicker and more informed planning and decision-making.

Scale of Deployment: Stage 1 vs. At-Scale

Stage 1 Pilot Scale:

- Deployment at nine signalized intersections within the City of Fullerton, covering approximately two miles of the Harbor Boulevard corridor.
- Implementation of cloud-based Transit Signal Priority in combination with multimodal detection technologies, including radar, LiDAR, infrared, and video-based systems.
- Evaluation of TSP performance and operational outcomes, including priority request success rates, reductions in transit delay, improvements in travel-time reliability, and detection-based safety insights.

At-Scale Implementation:

- Expansion to approximately 60 signalized intersections across a 12-mile segment of Harbor Boulevard, spanning multiple jurisdictions.
- Full corridor deployment of cloud-based TSP to support OCTA Routes 43 and 543.

- Installation of advanced multimodal detection systems at high-priority locations to support pedestrian and bicyclist safety.
- Scalable integration with local agency traffic signal systems and OCTA's data infrastructure to support coordinated operations, performance monitoring, and future enhancements.

Summary of Stage 1 Activities

There have been many milestones to date as a part of the OCTA SMART Grant. One of the outcomes OCTA is particularly proud of is the relationships built with fellow SMART Grant awardees and the USDOT Team. The knowledge transfer has resulted in exchanges across the country that have been extremely rewarding. The Project Team has also bolstered the relationships with regional traffic engineering partners including the cities of Anaheim, Fountain Valley, Fullerton, Garden Grove, and Santa Ana. Lastly, the OCTA project led to the successful award of a second SMART Grant for the City of Anaheim and staff look forward to partnering with them to implement an effective project.

Key Stage 1 activities include:

- Technology planning and selection, including evaluation of multimodal detection systems to determine that all four detection systems evaluated identified a range of unsafe conditions at signalized intersections.
- TSP activation and validation using the LYT platform at 9 intersections; results show over 30% reduction in average delay per signal.
- Development of a data dashboard architecture to integrate automated vehicle location (AVL), GTFS, signal phase and timing (SPaT), and traffic data.
- Coordination with partners such as OCTA, City of Fullerton, LYT, Iteris, Arcadis, and other stakeholders.
- Data collection and analysis of baseline and post-deployment performance, including TSP call frequency, average trip duration, and signal-level metrics.

Project activities engaged in Stage 1 are summarized below in **Table 1**.

Table 1: Stage 1 Project Activities

Month	Key Activities
Month 1-3 **Sep - Nov**	• Established a grant agreement with USDOT • Completed the evaluation and data management plans • Attended SMART Grant Kickoff Meetings at USDOT • Released Request for Proposal (RFP) for procurement of Project Team
Month 4-6 **Dec - Feb**	• Selected Project Team (Arcadis/LYT) for project delivery, including TSP and signal detection deployment and evaluation • Initiated coordination with vendors and stakeholders for data collection

Month	Key Activities
Month 7-9 **Mar - May**	- Stage 1 technical activities kicked off - Developed refined set of requirements for the sensor technologies
Month 10-12 **Jun - Aug**	- Completed meetings with OCTA bus operations staff - Completed meetings with City of Fullerton staff that triggered the installation of TSP technology at Stage 1 intersections - Addressed feasibility concerns from Project Team related to OCTA AVL system - Hosted USDOT staff for review of the corridor - Attended the TSP discussion and tour hosted by the Massachusetts Bay Transportation Authority (MBTA) and the SMART Grant Summit at Volpe Center - Data collection for "Before" corridor operations conditions
Month 13+ **Sep and beyond**	- Complete troubleshooting of technology for TSP operations - Implement and fine-tune TSP settings - Procurement of video detection, LIDAR, and radar for testing - Mounting of sensors at City intersections - Evaluation of TSP and sensors technology, Before/After study to determine performance - Stage 2 Concept Refinement

The deployment of TSP at the initial City of Fullerton intersections provided some early lessons learned, especially as the use of Cloud based technology is relatively new in the industry. Establishing a consistent connection to the City's traffic signal system took collaboration with multiple agencies and departments to understand the hardware and software minimum requirements. The implementation of the detectors centered on defining which would be the most feasible technology for the outcomes of improved actionable safety metrics. These installations will provide critical data to evaluate the system's performance under various conditions.

Public and Professional Visibility

The Stage 1 study was expected to have minimal media attention, especially as the technology solutions would only be implemented in a prototype area. However, close coordination with project stakeholders and community leaders was important to determine the success of Stage 2. OCTA hosted the following online site: https://octa.net/HarborTSP/

As TSP is new to Orange County and continuously evolving, OCTA staff has joined the Institute of Transportation Engineers' NTCIP 1211 TSP Working Group as a voting member along with City of Anaheim staff. OCTA's focus was to strengthen local technical staff's confidence and understanding of the technology so that all stakeholders agree before presenting it to the public. Once the project generated some data, representatives from OCTA began making presentations, as summarized below.

- The project has been presented to OCTA’s management and regional partner agencies.
- It has attracted attention from national and local practitioners, with planned inclusion in SMART grant reporting and multiple conference presentations including ITE, Western ITE and ITS California.
- Performance visuals and analytics (e.g., green light success rate, travel time savings, cross street impacts) have been used to communicate results to stakeholders and OCTA.
- A final report and best practices memo are planned to be shared publicly upon completion.

Deviations from Original Proposal

Overall, the project adhered to the original proposal, with only minor deviations noted:

- Detection system procurement took longer than anticipated due to the need for robust evaluation and vendor coordination.
- TSP activation was delayed and only fully deployed as of November 18, 2024, several months after baseline data collection began.
- The dashboard's data integration component required more time due to API access issues from vendors (e.g., LYT and Iteris).
- Minor scope adjustments were made to prioritize intersections with existing infrastructure to minimize construction during the pilot phase.

The deviations related to this project primarily related to schedule with some delays in the contracting and procurement processes. The collaboration with other SMART grantees has helped OCTA recognize that this is common for TSP and technology-focused projects. OCTA is taking a deliberate approach of testing safety sensors that can lead to updated standards and mainstream the use of advanced technology for improving safety.

3. Proof-of-Concept Findings

This section describes the proof-of-concept activities undertaken to demonstrate the functional viability of the Harbor Boulevard cloud-based TSP prototype and advanced detector implementation. The primary objective of this phase was to verify that transit vehicle location data, cloud-based analytics, traffic signal controllers, and detectors could be successfully integrated and operated within an active corridor environment. Data from the LYT platform and select Iteris ClearGuide analytics were used to observe existing bus and traffic operations and to confirm that the prototype could capture, process, and display the information required to support TSP operations.

The proof-of-concept focused on validating system connectivity, data availability, and basic performance monitoring rather than on full before-and-after operational impacts. Through monitoring OCTA Routes 543 and 43 at the pilot intersections, the project team confirmed that the prototype could associate bus delay with specific signalized intersections and provide a reliable operational baseline to support subsequent TSP activation and evaluation.

Discuss Findings on Performance of Proof-of-Concept as Discussed in Evaluation Plan

The OCTA consultant team: 1) Collected data on existing conditions for the corridor; 2) Developed key performance indicators to use as a part of the evaluation; and 3) Evaluated the TSP and detector technologies deployed as a part of Stage 1. The results of the evaluation follow.

For the Transit Signal Priority (TSP) component of the Stage 1 pilot, a comprehensive set of key performance indicators (KPIs) was established during project initiation to assess performance consistent with the SMART statutory areas of reducing congestion and delays, improving system reliability, and supporting safe, efficient multimodal operations. These KPIs focused primarily on transit vehicle operations, with supporting measures used to monitor impacts to mainline and cross-street traffic. Additional diagnostic metrics were applied by engineering staff to refine operations and validate system behavior but were not used to determine overall project success.

To ensure comparability and repeatability, performance was evaluated over a standardized 14-day analysis period that included both weekday and weekend conditions. Due to implementation sequencing and data availability constraints, the selected before and after periods were intentionally reversed from a traditional before–after framework; this approach was documented and applied consistently across all analyses. The results presented represent a static snapshot of performance during the evaluation window, with additional dynamic analysis available through the project dashboard.

As summarized in **Table 2**, the transit-focused KPIs demonstrate that implementation of TSP resulted in measurable reductions in transit delay and improved operational efficiency within the nine-intersection pilot area. Average delay per signal decreased by approximately 33 to 38 percent, with reductions of 3.5 to 3.7 seconds per signal in both northbound and southbound directions. The percentage of signals encountered by transit vehicles declined by 19 to 23 percent, and total trip travel times were reduced by approximately 7 to 8 percent, equating to 0.46 to 0.59 minutes per trip through the pilot segment. These results indicate that even a limited deployment produced statistically meaningful improvements in transit performance and suggest that broader corridor deployment would yield greater cumulative benefits.

Table 2: Transit Operations Key Performance Indicator Summary

Key Performance Indicator	Direction of Travel	Difference	% Change
Average Delay / Signal	Northbound	-3.47 secs	-37.5%
	Southbound	-3.66 secs	-32.9%
Percent Signals Encountered	Northbound	-7.74%	-23.1%
	Southbound	-6.89%	-18.6%
Trip Travel Time	Northbound	-0.46 mins	-7.5%
	Southbound	-0.59 mins	-8.5%

Supporting analyses of mainline and cross-street operations indicated that these transit benefits were achieved without material adverse impacts to general traffic. Changes to reliability metrics for non-transit traffic were small in magnitude, with variations generally within ±2 to 3 percent, and cross-street performance remained largely stable. Collectively, these findings demonstrate that the TSP deployment improved transit mobility while maintaining acceptable operating conditions for other roadway users, consistent with SMART statutory objectives related to congestion reduction and system reliability.

As part of the Stage 1 proof-of-concept evaluation, four multimodal detection technologies were deployed and assessed to understand their ability to support safety monitoring and operational insight at signalized intersections. The evaluated products included Ouster LiDAR, Derq's multi-sensor detection and analytics platform, Currux video-based detection, and Miovision video detection systems. Overall, all evaluated detection technologies demonstrated the capability to reliably identify a range of unsafe conditions occurring within the intersection environment. These conditions included vehicle-to-vehicle, vehicle-to-pedestrian, and vehicle-to-bicyclist near-miss events, unsafe pedestrian and bicyclist crossings, red-light violations, and wrong-way driving movements. The evaluation confirmed that these systems can provide meaningful, intersection-level safety data under real-world operating conditions.

The findings also highlighted the critical role of analytics in translating raw detection data into actionable safety information. For most unsafe conditions evaluated, including near-miss events and unsafe crossings, AI-based analytics embedded within each platform were required to accurately identify, classify, and record events based on object trajectories, proximity, and behavior. Detection hardware alone was generally sufficient to capture movement data, but without AI software layered on top of the detection systems, these safety-related events could not be reliably distinguished or documented. Red-light violations represented the primary exception, as these events can be directly identified through traffic signal controller input and output data without the need for advanced analytics.

The qualitative expectations for the established SMART grant performance measures were consistent with those outlined in the Evaluation Plan and are summarized in **Table 3** below, along with the corresponding evaluation findings.

Table 3: Qualitative Expectations from Evaluation Plan

Measure	Qualitative Expectation	Qualitative Evaluation Findings
Safety and Reliability	Reduce emergency response times	TSP and detection technologies are expected to support more predictable signal operations and improved traffic flow, which may contribute to improved emergency response conditions over time.
	Improve consistency of on-time arrivals on transit	Reliable transit signal priority is expected to improve schedule adherence by reducing signal delay and variability in travel time along routes 543 and 43.
	Capture speed, red light running, near misses, and turning movement counts	Advanced detection and analytics are expected to provide enhanced visibility into traffic behavior and potential safety conflicts at signalized intersections.
Resiliency	Each agency will have a consistent, standardized TSP technology across jurisdictional boundaries regardless of signal controller and system	A cloud-based TSP platform is expected to operate consistently across different controller types and agency systems, improving corridor-wide resiliency.
	Increased system insight with secure data sharing for proactive operations, including traffic signal and transit operations performance	Integrated systems are expected to improve access to operational data and system health information, supporting traffic and transit operations.
Partnerships	Increase local funding and projects focused on transit and multimodal safety	Demonstration of successful pilot outcomes is expected to support continued interagency collaboration and future investment.
Integration	Reduce infrastructure installed on fleet vehicles and on traffic signals with cloud-based technology for TSP	Cloud-based architecture is expected to reduce the need for extensive roadside and onboard hardware while maintaining functionality.

Note that the non-qualitative performance measures related to project costs, including both Stage 1 proof-of-concept costs and anticipated Stage 2 at-scale implementation costs, as well as lessons learned and recommendations, are addressed in subsequent sections of this report.

As outlined in the Evaluation Plan, Stage 1 of the Harbor Boulevard Innovative TSP Pilot Project focused on evaluating the performance of the proof-of-concept deployment within a prototype area consisting of nine signalized intersections. The evaluation assessed system accuracy, operational effectiveness, responsiveness, reliability, and scalability using a combination of field observations, system logs, operational testing, and stakeholder input. The findings summarized in **Table 4** reflect observed pilot performance relative to the established performance measures and targets identified in the Evaluation Plan. Collectively, these results demonstrated that the cloud-based TSP system functioned as intended under real-world conditions and provided valuable insight to inform potential corridor-wide implementation in subsequent project stages.

Table 4: Stage 1 Evaluation Findings

Evaluation Question	Performance Measure	Performance Measure Target	Observed Pilot Findings (Prototype Area – 9 Intersections)
How accurate is the arrival and departure of buses compared to the schedule?	Time of arrival/departure compared to estimated time on transit applications	No more than 5 minutes late to arrive	Observations confirmed that the system was accurate on arrival and departure estimates.
What is the operational effectiveness of the detection system at the signalized intersections?	Detection rate with high traffic volumes	99% of the detection rate under normal conditions	Field observations and controller log reviews confirmed that detection worked, correct phases were served, and lockout logic functioned during monitored periods.
How quickly is a priority request displayed in the Cloud system interface?	Time between request, confirmation, and display	3 seconds between detection and confirmation 2 seconds between confirmation and display	Operational testing and field validation confirmed that priority requests appeared in the cloud interface within target expectations.
How quickly could a priority request be sent to the traffic signal controller?	Time between priority request initiated and message received by the traffic signal controller recorded by the data logger	2 seconds between request and input shown in signal controller	Priority messages were observed in controller logs following request initiation within targe expectations.
How quickly could a security alert be sent to the TSP and/or signal systems?	Time between system security trigger to display on system	2 seconds between trigger to confirmation and system alert	System architecture supports rapid cloud-based alerting; however, formal security alert testing was not part of the initial field deployment phase.
How accurate is the location of the bus on the TSP system?	Accurate rate of bus location on system compared to field	95% of system bus location matching field under normal conditions within 400 feet	Comparison between field observations and cloud interface showed bus locations displayed consistently and within acceptable tolerance during monitored periods.

Evaluation Question	Performance Measure	Performance Measure Target	Observed Pilot Findings (Prototype Area – 9 Intersections)
How attractive is transit with the proposed project improvements as perceived by the riders?	Transit attractiveness evaluated through online survey results	Increased public perception and satisfaction with the project improvements	Rider feedback has not yet been conducted during this phase. Bus operators noted improvements and other drivers did not note any negative impacts on their commutes.
How long to get back into sync following a priority request?	Time in transition following priority service	2 cycles to transition back into sync following TSP	Monitoring confirmed that signals returned to coordinated operation within approximately one to two cycles following TSP events, with minimal disruption to general traffic.
How cost-effective is the proposed solution?	Cost of innovative solution compared to traditional improvements for TSP and ITS	A lower cost for the innovative solution compared to traditional approaches would suggest cost-effectiveness.	The cloud-based TSP solution leverages existing communications and minimizes new roadside infrastructure, indicating lower deployment and maintenance costs compared to traditional hardwired TSP systems.
Scalability and expandability of the proposed solutions for agency adoption throughout the County?	Adoption rate and agency approval or acceptance of the proposed technologies	Discussion with stakeholders indicating their acceptance of proposed technology solutions and the potential to include as standards for each agency	Stakeholder discussions indicate strong interest in scaling the solution. The pilot demonstrates interoperability across agencies and controller types, supporting expandability as a potential regional standard.

Overall, the Stage 1 proof-of-concept evaluation demonstrated that the cloud-based TSP system and associated detection technologies performed reliably within the prototype area and generally met or exceeded the qualitative expectations outlined in the Evaluation Plan. Field observations and operational testing confirmed that priority requests were processed accurately and efficiently, traffic signal operations returned to coordination with minimal disruption, and system performance was consistent. While some performance measures require additional data collection at a larger scale, the Stage 1 findings provide a strong technical foundation for advancing to Stage 2. The results support continued refinement of signal timing strategies, expanded sensor deployment, and broader corridor implementation to further evaluate system benefits and long-term scalability.

Proof-of-Concept Expectations

The Harbor Boulevard Innovative TSP proof-of-concept has met the original expectations outlined in the project proposal by successfully demonstrating the technical feasibility, operational effectiveness, and scalability of a cloud-based, next-generation TSP solution within a real-world corridor environment as well as successfully deploying detector solutions. The Stage 1 testing met the key goals outlined in the project proposal as follows:

1. **Confirmed feasibility of Transit Automatic Vehicle Location (AVL) data being used to estimate a time of arrival at Traffic Signal Controller**: Tests indicated that this approach is feasible in the existing OCTA system. Currently, a subset of buses has been modified to increase the frequency in which the bus location is being broadcasted, from 10 seconds to 5 seconds.

2. **Identified the most promising sensor technologies for cost-effective implementation of safety system**: Tests provided project stakeholders with detection solutions that can address the potential needs of each signalized intersection along the project corridor. This need was discussed with the five agencies operating the traffic signals along the corridor and is focused on the improved safety insights for bicycles and pedestrians at signalized intersections.

3. **Examined traffic signal timing settings that will be changed based on sensors**: Evaluation of the TSP and sensor solutions resulted in specific hardware and software upgrades on the project corridor to advance into Stage 2. TSP settings in the existing traffic controller have been examined with the City of Fullerton. Preliminary detection solutions and the recommended locations for these solutions confirmed the intersections have the appropriate infrastructure to operate each solution.

The pilot achieved its core goal of improving transit performance and reliability by enabling consistent, real-time priority requests at nine signalized intersections, resulting in substantial localized reductions in bus signal delay (over 30% delay reduction per signal) and improving travel-time reliability and reducing bus stopping frequency. In parallel, the deployment and evaluation of advanced multimodal detection technologies demonstrated the ability to reliably identify and classify a range of unsafe conditions at signalized intersections, including near-miss events, red-light violations, unsafe crossings, and wrong-way movements involving vehicles, pedestrians, and bicyclists. While direct safety outcomes such as reductions in traffic-related fatalities or injuries require longer-term evaluation, the project supports safety objectives by minimizing abrupt bus stops, reducing intersection delay, and validating advanced detection and priority logic that operate without causing signal failures or unsafe traffic disruptions. Additionally, by leveraging existing communications infrastructure and interoperable cloud systems, the pilot reduced traditional cost and institutional barriers associated with TSP deployment, demonstrating a replicable model that can be expanded across jurisdictions and corridors to improve transit service and regional mobility outcomes.

Stage 1 Demonstration of Statutory Benefits and Mobility Improvements

The Harbor Boulevard Innovative TSP Stage 1 project has demonstrated measurable progress in several statutory areas by deploying and validating advanced, cloud-based transportation technology within an active, multimodal corridor. With respect to reducing congestion and delays for the traveling public, the proof-of-concept confirmed that real-time transit signal priority could be reliably generated and executed at nine signalized intersections, resulting in substantial localized reductions in bus delay, exceeding 30 percent on average at pilot intersections, thereby improving travel-time reliability for transit riders and reducing stop-and-go conditions that contribute to general traffic delay. Regarding improving safety and system integration for all users, the project reduced bus stopping at intersections and maintained coordination for other roadway users, supporting safer and more predictable operations for pedestrians, bicyclists, and motorists. In addition, it validated the use of advanced multimodal detection technologies to support improved safety awareness and operational insight. The evaluated detection systems successfully identified unsafe conditions at signalized intersections, including near-miss events, red-light violations, unsafe crossings, and wrong-way movements involving vehicles, pedestrians, and bicyclists.

The project also advances access to jobs, education, and essential services and connectivity for all riders by improving the reliability of OCTA’s Route 543 and 43 services along Harbor Boulevard, a corridor that serves key employment centers, regional destinations, and communities with a high reliance on transit. By leveraging a cloud-based architecture and existing communications infrastructure, the Stage 1 deployment reduced traditional cost and institutional barriers associated with TSP, demonstrating a scalable model that can lower per-corridor deployment costs and support broader access improvements as the technology is expanded. The proof-of-concept further contributes to medium- and long-term economic competitiveness and system reliability by showing that next-generation TSP and detector technologies can be implemented without extensive new roadside infrastructure, while delivering consistent, repeatable operational benefits and improved reliability for existing transportation assets.

Finally, the Stage 1 project directly supports connectivity among vehicles, infrastructure, detection, and transportation systems by integrating real-time bus location data, cloud-based analytics, safety metrics, and traffic signal controllers into a unified operational environment. This connected framework enables transit and traffic agencies to share data, observe system performance, and make informed operational decisions, laying the foundation for expanded connected mobility applications and corridor-wide deployment in future project phases.

4. Anticipated Costs and Benefits of At-Scale Implementation

The anticipated costs and benefits of the at-scale implementation encompass several key components, including additional capital investments, ongoing operational expenses, and long-term maintenance requirements. Initial capital costs will be expedited based on prior technology acquisition, infrastructure modifications, and system integration. The operational expenses cover the day-to-day costs of running the technology, such as staffing, and user support. Finally, long-term maintenance costs involve routine upkeep, software updates, and potential repairs to ensure system reliability and longevity.

Anticipated Impacts of At-Scale Implementation

The anticipated impacts of at-scale implementation for each key goal area or "Measure" in **Table 3** is summarized below in **Table 5** based on experience from other similar projects.

Table 5: Potential Impacts of At-Scale Implementation

Goal Area	Anticipated Impacts	Description
Safety	Reduction in intersection-related accidents	• Implementation is expected to increase insights at the signalized intersections for better decision making that can lead to reduced crashes.
Reliability	Minimizing delay reduced travel time variability	• The cloud-based TSP technology has created more reliable transit service, decreasing delay at each intersection. • The OCTA bus operations team will also have more data for updating schedules.
Integration	Enhanced system integration across various traffic scenarios	• Building on the evaluation and planning conducted in Stage 1, Stage 2 will prioritize the fusion of expanded sensor technologies to optimize intersections for all road users. • In addition to integrating City and County systems, the Project will also incorporate various connected vehicle (CV) platforms, including in-vehicle V2X hardware. This integration will increase the system's ability to collect, analyze, and act on real-time data, thereby improving overall traffic management and safety.

Anticipated Costs of At-Scale Implementation

The project corridor was inventoried and each agency in the At-Scale Implementation zone of the corridor was contacted to identify project needs for expanding the implementation. Approximately 95 percent of the project corridor utilizes existing fiber optics communication cable with modern Ethernet communications. Some of the communication equipment was identified as end-of-life, which will require upgrades. Some traffic controllers are older generation ATC type controllers that do not have the latest transit priority algorithms built into the software. These are recommended for upgrade as well. Some locations had existing equipment that can be maintained and utilized for the At-Scale deployment. The following **Table 6** shows the At-Scale deployment locations and the controller and communication upgrades recommended for the next phase of the project.

Table 6: At-Scale Recommended Upgrades for TSP

#	Agency	Primary Street	Cross Street	Traffic Signal Controller			Communication
				Existing	Firmware	Upgrade?	Upgrades
1	Fullerton	Commonwealth Ave	Pomona Ave	Q-Free	MaxTime	No	
2	Fullerton	Harbor Blvd	Commonwealth Ave	Q-Free	MaxTime	No	
3	Fullerton	Harbor Blvd	Santa Fe Ave	Q-Free	MaxTime	No	
4	Fullerton	Harbor Blvd	Valencia Dr	Q-Free	MaxTime	No	
5	Fullerton	Harbor Blvd	Southgate Ave / Costco Dwy	Q-Free	MaxTime	No	
6	Fullerton	Harbor Blvd	Orangethorpe Ave	Q-Free	MaxTime	No	
7	Fullerton	Harbor Blvd	Orangefair Mall Dwy	Q-Free	MaxTime	No	
8	Fullerton	Harbor Blvd	Orangefair Ave	Q-Free	MaxTime	No	
9	Fullerton	Harbor Blvd	Houston Ave	Q-Free	MaxTime	No	
10	Caltrans	Harbor Blvd	SR-91 WB Ramps				
11	Caltrans	Harbor Blvd	SR-91 EB Ramps				
12	Anaheim	Harbor Blvd	Romneya Dr	Econolite	ASC/3	Yes	Ethernet Switch
13	Anaheim	Harbor Blvd	La Palma Ave	Econolite	ASC/3	Yes	Ethernet Switch
14	Anaheim	Harbor Blvd	Ped Xing	Econolite	ASC/3	Yes	Ethernet Switch
15	Anaheim	Harbor Blvd	North St	Econolite	ASC/3	Yes	Ethernet Switch
16	Anaheim	Harbor Blvd	Sycamore St	Econolite	ASC/3	Yes	Ethernet Switch
17	Anaheim	Harbor Blvd	Lincoln Ave	Econolite	ASC/3	Yes	Ethernet Switch
18	Anaheim	Harbor Blvd	Broadway	Econolite	ASC/3	Yes	Ethernet Switch
19	Anaheim	Harbor Blvd	Santa Ana St	Siemens	SEPAC	Yes	Ethernet Switch
20	Anaheim	Harbor Blvd	Water St	Econolite	ASC/3	Yes	Ethernet Switch
21	Anaheim	Harbor Blvd	South St	Econolite	ASC/3	Yes	Ethernet Switch
22	Anaheim	Harbor Blvd	Vermont Ave	Econolite	ASC/3	Yes	Ethernet Switch
23	Anaheim	Harbor Blvd	Ball Rd	Econolite	ASC/3	Yes	
24	Caltrans	Harbor Blvd	I-5 NB Ramps				
25	Caltrans	Harbor Blvd	I-5 SB Ramps				
26	Anaheim	Harbor Blvd	Manchester Ave	Econolite	ASC/3	Yes	Ethernet Switch
27	Anaheim	Harbor Blvd	East Shuttle Area	Econolite	ASC/3	Yes	Ethernet Switch
28	Anaheim	Harbor Blvd	Disney Way	Econolite	ASC/3	Yes	Ethernet Switch
29	Anaheim	Harbor Blvd	Katella Ave	Econolite	ASC/3	Yes	
30	Anaheim	Harbor Blvd	Convention Way	Econolite	ASC/3	Yes	Ethernet Switch
31	Anaheim	Harbor Blvd	Orangewood Ave	Econolite	ASC/3	Yes	Ethernet Switch
32	Anaheim	Harbor Blvd	Wilken Way	Econolite	ASC/3	Yes	Ethernet Switch
33	Anaheim	Harbor Blvd	Hotels/ Shopping Center	Econolite	ASC/3	Yes	Ethernet Switch
34	Garden Grove	Harbor Blvd	Chapman Ave	Econolite	ASC/3	Yes	Ethernet Switch
35	Garden Grove	Harbor Blvd	Resort Way / Target Center	Econolite	ASC/3	Yes	Ethernet Switch
36	Garden Grove	Harbor Blvd	Twintree Ave	Econolite	ASC/3	Yes	Ethernet Switch

#	Agency	Primary Street	Cross Street	Traffic Signal Controller			Communication
				Existing	Firmware	Upgrade?	Upgrades
37	Garden Grove	Harbor Blvd	Lampson Ave	Econolite	ASC/3	Yes	Ethernet Switch
38	Garden Grove	Harbor Blvd	Great Wolf	Econolite	ASC/3	Yes	Ethernet Switch
39	Garden Grove	Harbor Blvd	Palm St	Econolite	ASC/3	Yes	Ethernet Switch
40	Garden Grove	Harbor Blvd	Garden Grove Blvd	Econolite	ASC/3	Yes	Ethernet Switch
41	Garden Grove	Harbor Blvd	Harbor Place Dwy	Econolite	ASC/3	Yes	Ethernet Switch
42	Caltrans	Harbor Blvd	SR-22 WB Ramps				
43	Garden Grove	Harbor Blvd	Trask Ave	Econolite	ASC/3	Yes	Ethernet Switch
44	Garden Grove	Harbor Blvd	Cardinal Cir	Econolite	ASC/3	Yes	Ethernet Switch
45	Santa Ana	Harbor Blvd	Westminster Ave	Econolite	ASC/3	Yes	Ethernet Switch
46	Santa Ana	Harbor Blvd	Hazard Ave	Econolite	ASC/3	Yes	Ethernet Switch
47	Santa Ana	Harbor Blvd	5th St	Econolite	ASC/3	Yes	Ethernet Switch
48	Santa Ana	Harbor Blvd	1st St	Econolite	EOS	No	
49	Santa Ana	Harbor Blvd	McFadden Ave	Cobalt	EOS	No	
50	Santa Ana	Harbor Blvd	Kent Ave	Econolite	ASC/3	Yes	Ethernet Switch
51	Fountain Valley	Harbor Blvd	Lilac Ave	Econolite	ASC/3	Yes	Ethernet Switch (on DSL extenders)
52	Fountain Valley	Harbor Blvd	Edinger Ave	Econolite	ASC/3	No	
53	Fountain Valley	Harbor Blvd	Heil Ave	Econolite	ASC/3	Yes	Ethernet Switch (on DSL extenders)
54	Santa Ana	Harbor Blvd	Warner Ave	Econolite	EOS	No	
55	Santa Ana	Harbor Blvd	Segerstrom Ave	Econolite	EOS	No	
56	Santa Ana	Harbor Blvd	Garry Ave	Econolite	ASC/3	Yes	Ethernet Switch
57	Santa Ana	Harbor Blvd	MacArthur Blvd	Econolite	EOS	No	
58	Santa Ana	MacArthur Blvd	Hyland Ave	Econolite	EOS	No	

In addition to the traffic signal field upgrades, the evaluation had noted a need for system upgrades at the city's Traffic Management Center (TMC) to ensure cloud operation is possible and secure within the agency's network. The At-Scale deployment includes safety improvements through the deployment of detection systems and Artificial Intelligence (AI) analytics tools to identify safety issues. Locations were identified based on high pedestrian locations and a field review that evaluated heavy vehicular traffic along with a high volume of bicycle and pedestrian activity. These locations are listed below along with the recommended detection technology to deploy:

- Harbor Boulevard at La Palma Avenue – Install the Currux solution using the existing video detection system (VDS)
- Harbor Boulevard at Lincoln Avenue – Install the Currux solution using the existing VDS

- Harbor Boulevard at Ball Road – install the Currux solution using the existing VDS
- Harbor Boulevard at East Shuttle Area – Install the Derq solution and new VDS
- Harbor Boulevard at Katella Avenue – Install the Derq solution and new VDS
- Harbor Boulevard at Convention Way – Install two Lidar units
- Harbor Boulevard at Orangewood Avenue – Install the Derq solution using the existing VDS
- Harbor Boulevard at Chapman Avenue – Install the Derq solution using the existing VDS
- Harbor Boulevard at Garden Grove Boulevard – Install the Derq solution using the existing VDS
- Harbor Boulevard at Westminster Avenue – Install two Lidar units
- Harbor Boulevard at McFadden Avenue – Install the Derq solution using the existing VDS
- Harbor Boulevard at Edinger Avenue – Install two Lidar units
- Harbor Boulevard at Warner Avenue – Install the Derq solution using the existing VDS
- Harbor Boulevard at MacArthur Boulevard – Install the Derq solution using the existing VDS

The total cost for the upgrades is estimated at $1 million for procurement and installation of all the necessary traffic controller equipment, communication equipment, and detection system equipment. Included in the list of upgrades was a firewall for each implementation agency to ensure secure access from the cloud to the traffic control network can be provided through the City's Information Technology (IT) network security configuration. The costs detailed in **Table 7** reflect an estimate of the scale of Stage 2 deployment needs.

Table 7: Estimated Total Cost of At-Scale Implementation

Item	Estimated Total
Project Management Support	$300,000
Concept Evaluation and Design	$1,500,000
Research Team (local universities)	$800,000
Cyber Services	$400,000
Publication and Documentation	$500,000
Public Engagement	$600,000
TSP Cloud Based System (multi-year subscription)	$1,500,000
Signal Equipment and Detection Systems (based on evaluation)	$1,000,000
Supplemental Signal Infrastructure Upgrades	$700,000
Cellular Interconnect Upgrades (OCTA buses)	$200,000
Construction Management	$400,000
System Integration	$600,000
Performance Monitoring Data/Software (multi-year subscription)	$1,000,000
Signal Timing Configurations, Updates, and Testing	$500,000
Estimated At-Scale Implementation Costs:	**$10,000,000**

Potential Benefits

While the total estimated cost of the At-Scale Implementation is approximately $10 million, the projected benefits in terms of transit delay reduction, safety improvements, greater efficiency, and enhanced system integration are expected to significantly outweigh the initial and ongoing investments. The Pilot Phase demonstrated over 30% reduction in delay at key intersections, and with broader corridor coverage in Stage 2, even conservative estimates suggest a meaningful increase in route-level efficiency, fuel savings, and operational consistency for OCTA's high-ridership corridors.

For the At-Scale Implementation, there are several arterial crossing intersections that provide the largest benefit in delay reduction for the bus. However, during the peak periods, there is a significant amount of congestion in the southern portion of the corridor which will likely limit the amount of delay reduction achieved. The anticipated benefit to the bus through reduction in red-light delays is expected to be about 20%. With improved transit operation, it is expected that ridership will increase and the experience for the riders will be improved with a smoother ride experience due to less stops at the traffic signals.

5. Challenges and Lessons Learned

This project involved the procurement and configuration and installation of a Cloud TSP system at nine intersections along with Advanced Detection Systems installed at four intersections. The project's key challenges are summarized below.

Regulatory and Procurement

As one of the first grantees of this SMART grant, there was confusion and delays in securing the necessary regulatory requirements to proceed with the project procurement. The procurement process was also different from all other federally funded projects due to the funding agreement being executed directly with OCTA instead of through the state transportation department. The funding agreement for these projects helped reduce the amount of time the procurement would have traditionally taken for a federal project; therefore, this was a helpful lesson learned.

The other significant challenge was the lead time for the procuring detection systems, along with the time required for configuration and fine-tuning post-installation. Each detection system can be installed in a single day but requires a substantial amount of setup. Full configuration depended on vendor availability to send a technician to each location for on-site setup, followed by remote adjustments. This experience highlighted that system integration, rather than physical installation, is a key determinant of deployment success, and underscored the importance of early coordination and advance scheduling of vendor support at the time hardware is procured.

Technology and Cybersecurity

The Cloud TSP system was deployed in about four weeks at the onset of the project. However, to be fully operational, a piece of equipment that was installed at the City Traffic Management Center required internet access multiple communication ports, which enabled real-time data exchange between the Cloud system and the local traffic network. This type of operation required discussions with City IT to educate city staff on the necessary connectivity and the security implications.

This coordination took nearly five months of discussions and reviews of the City IT firewall appliance. The existing firewall had limited flexibility, which required alternative configurations and several rounds of discussions before a satisfactory solution could be reached. This delay emphasized the need for early IT engagement and proactive evaluation of network infrastructure. This was a critical lesson learned, and for at-scale implementation it will be addressed early in deployment through planned upgrades of each agency's firewall to next-generation security and performance standards.

Data Governance

The preparation of a Data Management Plan was a helpful reminder of what data may be expected of the project; however, with any pilot project, there was limited understanding of how the data was gathered, stored, and shared by each of the vendors. The consultant team had several meetings and discussions with various data vendors, including LYT, to ingest the various data available into a Power BI dashboard. The amount of data available allowed room for various representations of the data; however, a deeper dive may be required with research partners to understand the integration of the various data.

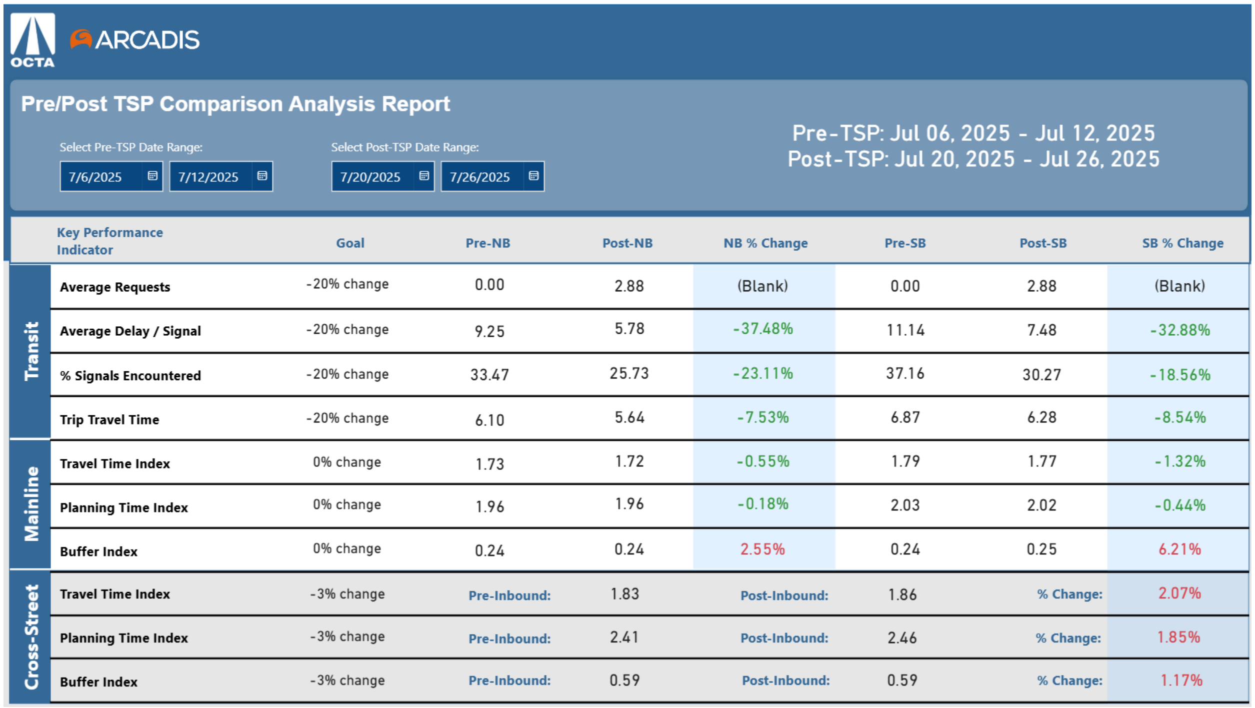
6. Deployment Readiness

There are three critical areas that are required to be ready for At-Scale deployment. This includes IT support with Firewall configuration, traffic controller equipment upgrades for the latest priority algorithms, and the transit priority allowable timing parameters for each agency. These discussions began with each agency during the pilot deployment based on the lessons learned. Thus, all agencies are aware of the firewall and security requirements for cloud system access from the traffic controller network.

During the field review for the entire project corridor, some hardware upgrades were identified. These upgrades are essential to maximize the benefits that can be obtained from the TSP system. The upgrades include replacing end-of-life communication devices with new hardware that will be supported by the manufacturer as well as traffic controller upgrades to benefit from the latest advanced transit priority algorithms. All agencies have been contacted and are in support of these upgrades and the At-Scale implementation and all the changes to the traffic controllers for priority operation that go along with the system installation including the detection systems.

The entire project corridor is ready for the expansion, which includes the institutional buy-in and agreement for the expansion as well as acceptance of the necessary upgrades to maximize the benefits to the bus while minimizing impacts on traffic. Each agency understands signal timing will be dynamically adjusted to benefit the bus while reducing some green time for the vehicles. Using the Arcadis dashboard, **Figure 2**, there is an understanding that the impact to traffic can be monitored, and adjustments made to minimize any impacts to traffic. The image below displays one of the screens from the dashboard that can be used to monitor this impact.

Figure 2 – Sample Pre/Post TSP Comparison Analysis in Power BI



Pre/Post TSP Comparison Analysis Report

Select Pre-TSP Date Range: 7/6/2025 7/12/2025

Select Post-TSP Date Range: 7/20/2025 7/26/2025

Pre-TSP: Jul 06, 2025 - Jul 12, 2025
Post-TSP: Jul 20, 2025 - Jul 26, 2025

	Key Performance Indicator	Goal	Pre-NB	Post-NB	NB % Change	Pre-SB	Post-SB	SB % Change
Transit	Average Requests	-20% change	0.00	2.88	(Blank)	0.00	2.88	(Blank)
	Average Delay / Signal	-20% change	9.25	5.78	-37.48%	11.14	7.48	-32.88%
	% Signals Encountered	-20% change	33.47	25.73	-23.11%	37.16	30.27	-18.56%
	Trip Travel Time	-20% change	6.10	5.64	-7.53%	6.87	6.28	-8.54%
Mainline	Travel Time Index	0% change	1.73	1.72	-0.55%	1.79	1.77	-1.32%
	Planning Time Index	0% change	1.96	1.96	-0.18%	2.03	2.02	-0.44%
	Buffer Index	0% change	0.24	0.24	2.55%	0.24	0.25	6.21%
Cross-Street	Travel Time Index	-3% change	Pre-Inbound:	1.83	Post-Inbound:	1.86	% Change:	2.07%
	Planning Time Index	-3% change	Pre-Inbound:	2.41	Post-Inbound:	2.46	% Change:	1.85%
	Buffer Index	-3% change	Pre-Inbound:	0.59	Post-Inbound:	0.59	% Change:	1.17%

7. Wrap-Up

The Harbor Boulevard TSP Pilot successfully demonstrated the effectiveness of the proposed solutions, with equipment configuration and system performance meeting and in several key areas exceeding initial expectations. Notably, improvements in bus operations outpaced projections, validating the potential of cloud-based TSP to enhance transit reliability. The project also deepened our understanding of how to balance transit benefits with general traffic operations and provided OCTA and partner cities with new tools to actively monitor and manage that relationship moving forward.

Technically, the solution performed as intended, requiring no major changes to the original design. The system delivered the anticipated service levels, and the deployment confirmed that the core technology is sound and scalable. One enhancement for future implementations would be ensuring earlier and broader access to the full range of data collected and processed by the system. This would allow for faster diagnostics, easier performance validation, and more efficient system optimization.

A key takeaway from the pilot was the importance of engaging agency IT teams early in the process to align on cybersecurity, firewall, and network integration requirements. While collaboration with City IT began in the second month, the time needed to resolve firewall-related configurations was longer than expected. Still, this experience strengthened interdepartmental relationships and will inform more streamlined approaches in future deployments. With focused and upfront collaboration, the same issues could likely be resolved in weeks rather than months.

Another key takeaway is narrowing down the operational requirements of each agency to understand the detection needs at their signalized intersections, which may be limited by physical or budget constraints. With the main focus being the TSP solution and delays in securing all detection solutions, the goal for the detection evaluations was more qualitative rather than on quantitative performance measures. All solutions evaluated showed that they can generate high-level insights; however, more detailed scenario analyses were not conducted in this phase and may be revisited later given the importance to each stakeholder on the project.

Overall, the pilot not only delivered clear operational benefits but also helped shape a practical blueprint for scaling the system across the corridor. The experience and lessons gained through this project place OCTA and its partners in a strong position to accelerate deployment in Stage 2 with a clearer understanding of both the technical and institutional pathways to success.