Intelligent Transit Signal Priority (iTSP) Final Report

Sustainable Silicon Valley
City/ County Association of Governments (C/CAG) of San Mateo County
SamTrans
City of East Palo Alto
LYT

Intelligent Transit Signal Priority (iTSP) Final Report

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Prepared for:

City/County Association of Governments of San Mateo County
San Mateo County Transit District

Prepared by:

Sustainable Silicon Valley
155 San Lazaro
Sunnyvale, CA 94086
www.sustainablesv.org

LYT
3080 Olcott Street. Suite D125
Santa Clara, CA 95054
www.lyt.ai

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Executive Summary

Funded by City/ County Association of Governments (C/CAG) of San Mateo County, and managed by Sustainable Silicon Valley (SSV) and technology partner SinWaves, Inc. (doing business as LYT), the intelligent Transit Signal Priority (iTSP) pilot leverages a powerful coalition of project partners, including the City of East Palo Alto (EPA) and the San Mateo County Transit District (SamTrans). This partnership is committed to the shared goal of improving the on-time performance and travel time of buses within San Mateo County. EPA, a major traffic corridor in San Mateo County and also an Equity Priority Community, was chosen by the project team as an ideal location for this pilot.

Transit Signal Priority (TSP) is simply the idea of giving special treatment to transit vehicles at signalized intersections.[1] Traditional, hardware-based TSP systems, for the most part, require vehicle-detection hardware to be installed at every intersection. In addition, they use a priority scheme which relies on a pre-programed, static time of arrival, and do not provide accurate time of arrival data, real-time insights or mapping capabilities.

The objective of the iTSP pilot project is to demonstrate the feasibility of a cloud-based, Artificial Intelligence-powered transit signal priority system. SSV's technology partner LYT created and deployed an intelligent, cloud-based iTSP system named LYT.speed. This system combines asset management, automation and machine learning to provide services to an entire region. Unlike hardware-based TSP systems, LYT.speed leverages pre-existing equipment and utilizes cloud technology and Computer-Aided Dispatch / Automatic Vehicles Location (CAD/AVL). This removes the need for vehicle detection hardware at the intersections, because the vehicle location is known through the CAD/AVL system.

The location chosen for the iTSP pilot project is a highly-congested section of University Ave. in East Palo Alto (EPA) that is just over a half mile (0.65 miles) in length. EPA is one of the few low-income communities in Silicon Valley. According to the Metropolitan Transportation Commission (MTC), sections of EPA are designated as an Equity Priority Community. Among the demographic variables considered in this designation is the percentage of Zero-Vehicle Households, meaning those without access to a personal vehicle making reliable transit essential to the community's vitality.[2] These factors all contribute to making EPA the ideal location for this project.

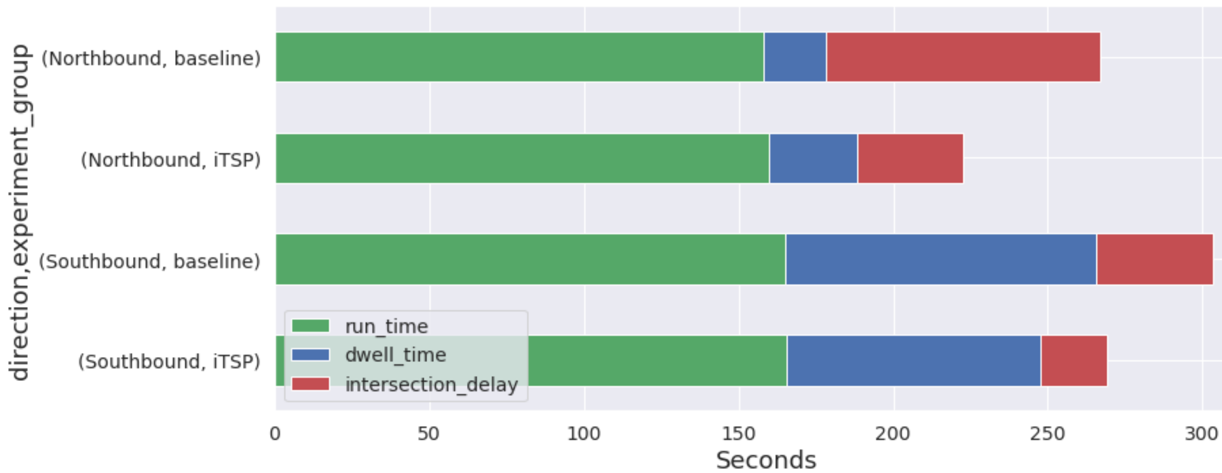
This six-month project involved four intersections and utilized a fleet of 40 SamTrans buses equipped with low-cost wireless GPS devices. The LYT software dynamically adjusts the phase and timing of traffic signals to provide sufficient green clearance time, improving transit throughput and reducing travel time along the route, while minimally impacting cross traffic.

Key metrics from the iTSP project include the following:

- iTSP reduced northbound *intersection delay* for buses by 45% (40 seconds) and southbound intersection delay by 19% (7 seconds) over the .65 mile length of the test location. The large difference between north and southbound results pre-exists in the baseline data prior to

[1] www.transit.dot.gov/research-innovation/signal-priority
[2] mtc.ca.gov/planning/transportation/access-equity-mobility/equity-priority-communities

implementation of iTSP, and is related to the prevalence of left hand turns on the northbound route. See chart below. (For further detail, please see the *Intersection Delay* section.)



Route 281, Comparison between Baseline Trip & iTSP Composition

- These reductions translate to 18% and 7% reductions in bus *travel time* for northbound and southbound respectively.

Findings and recommendations:

- The iTSP pilot project demonstrated that implementing LYT.speed had a statistically significant impact on improving the travel time of buses participating in the project.
- During this pilot, iTSP provided EPA with basic traffic signal operational insights that were not available to them previously. City staff were able to address other traffic signal operational issues using the online portal and historical data set.
- The project highlighted the value of high-frequency location data, and much of the month-over-month improvements were a direct result of having accurate bus route performance measurements.
- During the timespan of the pilot project, as the machine learning systems became more accurate and inclusive, the system performance improved month-over-month throughout the span of the project.
- The methodologies used for calculating TSP performance can be reused and leveraged for other transit projects.
- The lessons and experience from this project will inform a countywide TSP plan, which in turn can serve as a blueprint for future capital investments in San Mateo County.

With the return of in-person and hybrid options for work, school and services, communities are establishing new routines and habits around mobility. This presents a unique window of opportunity for enhancing transit options and systems. Transit is also a critical component in helping EPA and other Silicon Valley cities to meet their climate goals by reducing reliance on single occupancy vehicles (SOV). This pilot project highlights the potential for iTSP to improve communities' quality of life and access to employment, education and other services, all while simultaneously reducing carbon emissions.

Introduction

Objective of the iTSP Project

The objective of the intelligent Transit Signal Priority (iTSP) pilot is to demonstrate the feasibility of a cloud-based Artificial Intelligence-powered TSP system along University Avenue in East Palo Alto. The system uses traffic signal controllers via wireless cellular modems to dynamically adjust the phase and timing of traffic signals, providing sufficient green light clearance time while minimally impacting cross traffic. A sub-fleet of SamTrans buses serving the selected routes was equipped with low-cost wireless GPS devices that provide real time location-based information to the back-end system. Ultimately, this project demonstrated the efficacy, scalability and cost-effectiveness of such a system by reducing bus delays at intersections and providing more reliable service. The pilot ultimately proved that, at scale, the iTSP technology has the potential to improve on-time performance throughout the SamTrans bus network.

Project Budget, Stakeholders & Responsibilities

The iTSP pilot project budget is $236,700.

The iTSP pilot project engages and leverages a coalition of local and statewide partners, noted below, in addition to a description to their project roles:

- Sustainable Silicon Valley (SSV):
  SSV is the overall project manager, contracting with the project stakeholders through a series of contracts and MOUs.
- City/ County Association of Governments (C/CAG) of San Mateo County:
  C/CAG provides funding for the project.
- SamTrans:
  SamTrans provides the buses used in the Intelligent Transit Signal Priority (iTSP) project and advises which bus routes would be most suitable and which bus stop locations would be best.
- City of East Palo Alto (EPA):
  EPA is the owner/operator of the traffic signals along the section of University Ave which was chosen for iTSP project. EPA provided project members with access to necessary city equipment and documents.
- LYT (SinWaves Inc, doing business as LYT) with subcontractor support from Fourth Dimension and Bear Electric:
  LYT is the project technology partner which manages the communications and execution of system delivery and operation. LYT supports SSV in overall project management by addressing technical challenges associated with partnering agencies, asset integration and performance reporting. LYT also oversees subcontractor tasks as part of the project integration and technical support plan. Fourth Dimension, the traffic signal controller software vendor, provides onsite software upgrades and transit signal timing recommendations. Bear

Electrical provides certified technicians for the installation and removal of bus tracking equipment and in-cabinet cellular communication equipment.

- Caltrans:
  Caltrans is aware and supportive of the pilot but has no direct role. The signals utilized for the pilot are not maintained by Caltrans.

Project Location: East Palo Alto (EPA)

Silicon Valley is among the regions with the highest cost of living in the U.S; it is also a car-dependent region. The City of East Palo Alto (EPA) in San Mateo County is one of the few more affordable and low-income communities in Silicon Valley. EPA has a population of almost 30,000, a median income of $67,000, and a poverty rate of nearly 14% [3]. At the same time, housing expenses in San Mateo are 243% higher than the national average.[4]

Sections of EPA are designated as an Equity Priority Community, a framework which helps Metropolitan Transportation Commision (MTC) make decisions and investments to reduce disparities in access to transportation, housing and other community services.[5] Among the eight demographic variables considered in the designation of an Equity Priority Community is the percentage of Zero-Vehicle Households, meaning those without access to a personal vehicle.

According to the U.S. Census' American Community Survey, EPA residents currently own cars at a much lower rate than the county average (9% of households have no vehicle, as compared to 6% countywide). And yet residents are almost as likely to use a car to get to their places of employment rather than transit, due to the lack of viable alternatives. Per the data provided in the East Palo Alto General Plan 2035, "it is clear that East Palo Alto exhibits a larger than average transit dependent population, but poor east west transit connectivity and little bicycle and pedestrian infrastructure." [6]

Therefore, transit is essential for EPA residents to access education, work, food and social services, and the efficiency of the local transit system has a significant social impact on its communities. Transit is also critical to help EPA meet the established goals of a 20% reduction in Single Occupancy Commuting (percentage of trips to work made in a single occupancy vehicle).[7]

The Role of TSP in Improving Transit Service

From the perspective of a bus transit operator, inefficient routes that are a consequence of traffic congestion become increasingly more expensive to operate, as more vehicles are needed to maintain the same frequency of service. Slower bus speeds with more frequent stopping and starting also results in a poor rider experience, causing riders to opt for other modes of transport. Loss of riders, reduction in bus speed, and frequent periods of stop-and-go delay causes transit fare loss, increased

[3] datausa.io/profile/geo/east-palo-alto-ca/?compare=palo-alto-ca
[4] www.payscale.com/cost-of-living-calculator/California-San-Mateo
[5] mtc.ca.gov/planning/transportation/access-equity-mobility/equity-priority-communities
[6] www.cityofepa.org/sites/default/files/fileattachments/community_amp_economic_development/page/2731/epa_gp_chapter_6_transportation_final_201807271722051246.pdf
[7] idem

emissions, and increased spending for vehicle operations and maintenance. The overall efficiency of the local transit system has a greater direct social impact on communities with higher transit dependency and lower vehicle ownership on average.

One of the ways to counteract these inefficiencies is to implement Transit Signal Priority (TSP) for bus operations. The idea behind TSP is simply to give special treatment at traffic lights to transit vehicles, which generally have higher occupancy, thus increasing the per-person throughput of an intersection. However, implementation costs can be high and have not yet been optimized for larger scale deployments. Other challenges include the lack of data as to how the deployed system will affect overall traffic, as well as the fact that multiple jurisdictions are often involved, each with different traffic priorities.

In order for transit agencies to manage their fleet, they have typically implemented tracking devices on each of their vehicles which report their position to Computer-Aided Dispatch and Automatic Vehicle Location (CAD/AVL) software. With vehicle locations known in near real-time, software and networking can now be used to bridge the gap between transit vehicles and city signals to facilitate transit priority in a more reliable, sustainable and intelligent way. This project leverages these developments in order to give cities and transit operators a comprehensive, system-level overview of the transit network in real time, including detailed bus route information, accurate intersection bus arrival times, and a view of other traffic across the intersection and corridors — all while intelligently prioritizing buses.

Pilot Timeline, Location & Vehicles

The pilot contract with C/CAG was signed June 14, 2021, kicking off the installation and configuration of bus and traffic signal equipment throughout the months of July, August and September. At the end of September the pilot transitioned into the data collection phase. After collecting a month of bus location data, the iTSP system officially went live on November 1, 2021 and completed on February 28, 2022. The iTSP pilot delivered a cloud-based Artificial Intelligence-powered TSP system along University Avenue in East Palo Alto. The Transit Signal Priority (TSP) was deployed on a corridor consisting of four signalized intersections in East Palo Alto. This corridor is a subsection of SamTrans route 281 and includes the following intersections:

- University Ave. & Bay Rd.
- University Ave. & Runnymede St.
- University Ave. & Bell St.
- University Ave. & Donohoe St.

A sub-fleet of 40 SamTrans buses that serve the selected route was equipped with low-cost wireless GPS devices providing real time, location-based information to the LYT cloud platform.

Project Context

Previous TSP Deployments

In December of 2019, SamTrans commissioned the "El Camino Real Transit Signal Priority Project"[8] with the goal of helping reduce travel times for SamTrans buses on El Camino Real by extending green lights for buses running behind schedule. The scope of the project included 125 intersections along El Camino Real, and 152 SamTrans buses equipped with signal priority equipment. The project was completed in the Fall of 2021at a cost of $3,907,000 from federal and local funding.

Sensors were installed on the bus to send a radio signal to a sensor connected to the traffic light, which could hold the green light to allow the bus to pass through. The maximum time the system can extend a green light was no longer than 10 seconds at each intersection. Currently, the system is configured to request priority from the traffic signal whenever a vehicle is within range.

The goal of TSP was to improve SamTrans' on-time performance and provide more reliable service by reducing bus delays at intersections. Vehicles on cross streets experienced negligible impacts. Emergency vehicles always took priority over the signal request from the bus, and Caltrans had the ability to override the system if needed due to unusually heavy traffic.

SamTrans worked in coordination with Caltrans and the 12 cities along 26 miles of El Camino Real in San Mateo County to install the TSP equipment in traffic controller cabinets at intersections. Installations occurred during off-peak hours (10:00 am to 3:00 pm), with little disruption to vehicle, pedestrian and bike traffic. At the start of the project, there were no anticipated lane closures on El Camino Real or its cross streets associated with this project.

This type of TSP system operates on a concept known as check-in and check out. This is a simple detect and react method. A *check-in* is the act of the system detecting an approaching bus and then alerting the traffic signal controller that a bus is present for the direction of travel. The signal controller would then begin to run a pre-programmed priority plan that contains alternative signal timing settings. Once the bus crossed through the intersection, a *check-out* was placed by the system to notify the signal controller that the bus no longer needed priority.

The settings in the controller can vary by manufacturer and traffic signal agency, but in general a signal can be set up to provide an early green or an extension. Programming settings for an early green allows the controller to truncate or omit other directions of travel in order to provide early service to the bus. When early green service is used, the signal controller is programmed with a static time of arrival calculated from the detection point to the intersection stopbar. In order to derive this value, a traffic study must be performed. A green extension is a setting that allows a signal controller to extend past its pre-programmed max timing for a specific direction of travel. SamTrans's El Camino Real TSP deployment was set up to only provide green extensions.

[8]www.samtrans.com/Planning/Capital_Projects_and_Environmental_Planning/SignalPriority.html

Figure 1 demonstrates all of the functional components required of the El Camino Real Transit Signal Priority Project. Each bus receives a vehicle computer unit with a GPS and antenna to communicate wirelessly with another antenna at the traffic signal. The antenna reports information back to a special circuit board called a Priority Detector card. The Priority Detector card performs calculations to determine which direction of traffic needed to be prioritized. Using the bus's positional data, the Priority Detector card makes a determination as to whether the bus is in a Detection Zone (Figures 1 & 2). When a vehicle is found within a Detection Zone the Priority Detector card places a *check-in* request for priority for the duration of detection time. On El Camino Real, when a bus was in a detection zone, the traffic signal would only turn green for up to an additional ten seconds. The traffic signal would continue to add an additional ten seconds for every green light interval the bus was still in the detection zone until a *check-out* was received.

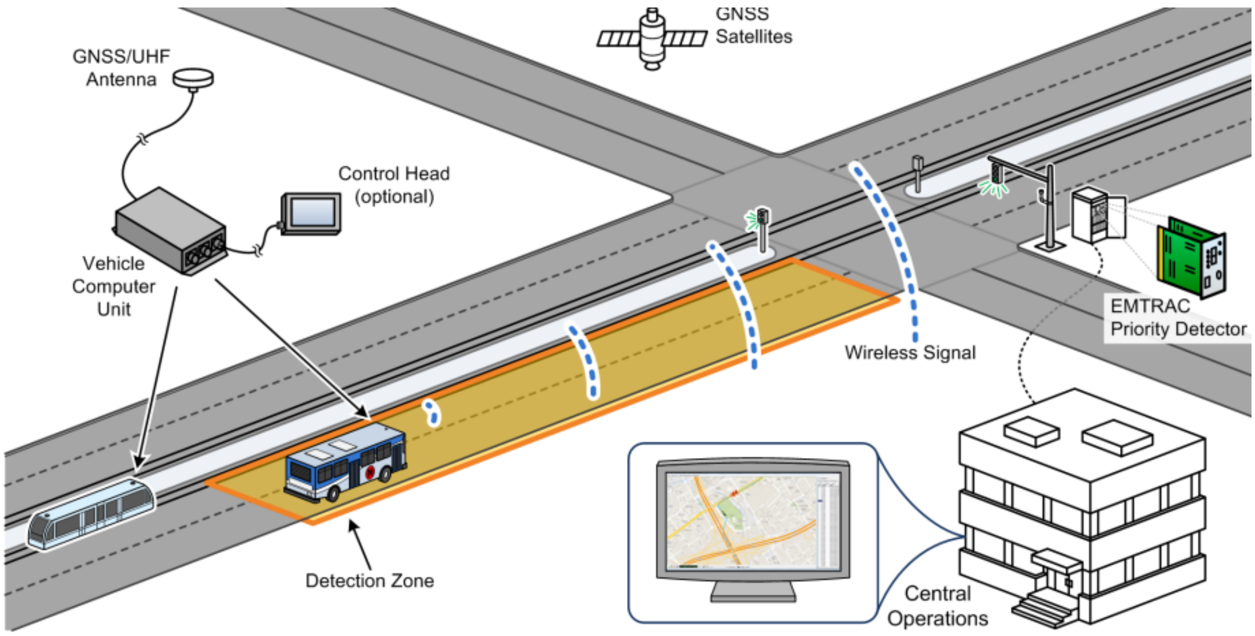


Figure 1: GPS Radio-based Transit Signal Priority[9]

[9] www.emtracsystems.com/wp-content/uploads/2021/01/EMTRAC-Transit.pdf

Figure 2: Detection Zones from a GPS Radio-based Transit Signal Priority Deployment[10]

[10] EMTRAC Detection Zones in the City of San Jose, Santa Clara Valley Transportation Authority

Intelligent TSP (iTSP) Technology

SSV's technology partner, LYT, created and deployed an Artificial Intelligence-powered, cloud-based Transit Signal Priority (iTSP) system named LYT.speed.

This system utilizes traffic signal controllers connected to a communications network to dynamically adjust the phase and timing of traffic signals. This system provides sufficient green clearance time while minimally impacting cross traffic, and combines asset management, automation and machine learning to produce a system capable of providing services to an entire region. What is unique about iTSP is the method by which priority requests are generated and transmitted to the signal, and its back-end user interfaces.

iTSP can be distinguished from other forms of TSP by the following two main factors:

1. Time of Arrival
   iTSP is a time-of-arrival-based system, unlike other systems which do not have the ability to change their programmed time of arrival info.

2. Observation Point
   Previous generation systems are set in ground / line of sight, whereas iTSP provides a bird's eye view which is more wholistic and interconnected.

Unlike hardware-based TSP systems, LYT.speed leverages pre-existing equipment and utilizes cloud technology and Computer-Aided Dispatch / Automatic Vehicles Location (CAD/AVL). This removes the need for vehicle detection hardware at the intersections, because the vehicle location is known through the CAD/AVL system.

This enables both priority calls from greater distances away from signals, and priority calls coordinated among a group of signals. LYT.speed processes live bus location information through machine learning models, and makes priority calls based on estimated times of arrival. Furthermore, the system provides real-time insights on which buses are currently receiving priority, along with daily reports of performance metrics.

LYT's method of placing priority calls to traffic signals is more sophisticated than previous TSP models and is not constrained to fixed point detection locations. Unlike the TSP system deployed along El Camino Real — which is dependent on a location-specific, single check-in with estimated time of arrival — the iTSP system uses a "vectorized" approach. In mathematics, a vector is an arrow representing a magnitude and a direction. In LYT's software, the arrow points in the direction of the traffic light and the magnitude is the travel time.

Once the LYT.speed system has been set up, traffic signals, bus routes and bus stops are all given a digital representation on this vector. This yields a digital geospatial map where software is then able to track bus progression along bus routes, and a system that can dynamically place transit calls regardless of its location. The system makes precise priority calls based on the expected time of arrival instead of a check-in and check-out notification. And due to the nature of the tracking algorithm, any significant changes to estimated time of arrival can be adjusted in real-time. For example, if a bus is predicted to skip a bus stop but does not, the system will detect the change and adjust the priority call accordingly.

The estimated time of arrival is derived from predictive machine learning models. When developing fast and efficient software for the real-time processing of data, machine learning can produce accurate results from historical data-driven models. LYT utilizes machine learning to analyze the large volume of bus location data and produce accurate models of bus route behavior. The result is an estimation of the time it will take the bus to reach the traffic signal which is based on many different factors. The developed models ultimately learn many different features of the bus route, such as daily and hourly traffic patterns, bus stop wait times, and skipped stops.

Figure 3 illustrates this process. In this figure, there are three different colored lines and two white circles. The green line indicates the path of travel for a bus traveling north on this route. The orange line represents the speed of a bus as it traverses this section of road. Each white circle indicates the location of a bus stop; in this example, there are two bus stops before the signalized intersection shown in the top right corner of the map. The purple line is the resulting vectorized time to arrival based on vehicle speed and bus stop wait time. Together they form the fundamental inputs and outputs of LYT's machine learning models.

Figure 3: LYT's Vectorized TSP Approach to North East Intersection

Pilot Project Implementation

This proof-of-concept pilot, presented by C/CAG, SSV, LYT, the City of East Palo Alto, and SamTrans, used a sub-fleet of the SamTrans buses to collect an initial five weeks of historic data (month of October, 2021). These data were then utilized for the first generation prediction models to determine accurate bus arrivals. Once the initial models were generated, the iTSP system was activated on November 1st, 2021 and operated until its decommission date of March 1st, 2021. LYT does not use the traditional method of geofencing GPS data points to determine whether a bus is inside a TSP activation zone. Instead, LYT uses true vehicle tracking methods, bus route progression and machine learning. This enables the iTSP system to account for changes in arrival time due to daily bus stop service times and traffic.

The sub-fleet of 40 SamTrans buses that serve the selected routes was equipped with low-cost wireless GPS devices providing real time location-based information to the back-end system. This was done because, at the time of the pilot, SamTrans' existing CAD/AVL system was not capable of updating its location at a rate fast enough for the iTSP platform (every 1 to 5 seconds). At the time the pilot was scoped, SamTrans' ping rate was every 60-90 seconds. After improvements to the on-board technology in late 2021/early 2022, the ping rate of the SamTrans fleet is now approximately every 25 seconds (June 2022).

The pilot system was deployed using a software interface (LYT/Maestro) which is only functional when connected to both intersections and wirelessly-connected buses. Given that the SamTrans fleet (with the exception of the El Camino project) is not yet fully connected via cellular, the pilot included the installation of temporary tracking devices — procured, installed and maintained by SSV — onboard a sub-fleet of SamTrans buses. In addition, Maestro required a very fast GPS refresh rate such as that offered by IOT supplier Particle, so the decision was made to source the trackers from Particle. At the end of the pilot, SSV and LYT managed the removal of all hardware from the SamTrans buses and City of East Palo Alto network.

Due to communication challenges with the pre-existing traffic signal network, Caltrans recommends the use of direct communication to each traffic signal via a cellular network connection. To meet these requirements, LYT deployed its all-in-one cabinet solution, Maestro-LTE. Maestro-LTE is an ruggedized network appliance and computer used to securely connect traffic signals to LYT's cloud platform using its integrated cellular connectivity. With field technician support from Bear Electric, LYT orchestrated the installation and removal of each Maestro-LTE.

During the traffic signal integration process, it was found that the traffic control software used on the traffic signal controllers in the City of East Palo required a software update. This update was completed by software vendor Fourth Dimension, whose staff safely updated the traffic controller software and validated its operation. In November 2021, the southernmost intersection experienced operational issues. It was pulled from the field and underwent extensive testing to determine the cause. In the end, it was found that a controller replacement was necessary. The controller was replaced in January 2022, and iTSP was reactivated before the end of the month.

By October 1st, all required foundation systems were in place, enabling the collection of historical route performance information needed by the machine learning software in order to generate prediction models. After four weeks of data were collected, it was found that the machine learning models were good enough to begin initial system activations of transit signal priority. Throughout the remainder of the operational period, LYT's machine learning team made weekly checks of model accuracy and its impact on signal performance.

The following pages will explain in detail where the pilot took place, what equipment was used, how the system was set up, the timeline of events, and an in-depth analysis of the systems performance.

Pilot Location & Logistics

University Avenue, the main transportation corridor of East Palo Alto (EPA), carries an estimated volume of 25,000 vehicles on most segments, including the US 101 overpass, with even higher volumes, over 30,000 vehicles, on the segment just north of East Bayshore Road. On average, transit riders in EPA spend 25 more minutes commuting per day than the citywide average across all modes of transportation. University Avenue is a highly congested corridor, with riders commuting to work, services and activity centers, while sharing the road with cut-through traffic (that which neither originates nor ends in EPA).

SamTrans advised that Route 281 along University Avenue, a key connection for those traveling from Belle Haven and EPA to Stanford in Palo Alto (Figure 4), was the most suitable for the pilot, because it maintained frequent bus service for both directions of travel throughout the day. Average weekday ridership was 350 boardings on Feb 22, 2022 and 641 on Feb 19, 2019 (pre Covid) across the span of service 6 AM - 10 PM, at a frequency of 20 - 30 minutes.[11]

Feeding University Avenue is the Dumbarton Corridor, also heavily utilized by tech workers headed to and from the East Bay. For this pilot, the team focused on the heavily congested EPA intersections on University Ave. Figure 5 shows the area of traffic signals that took part in the study, overlaid with SamTrans Routes 280, 281, and 296.

[11] Source: SamTrans

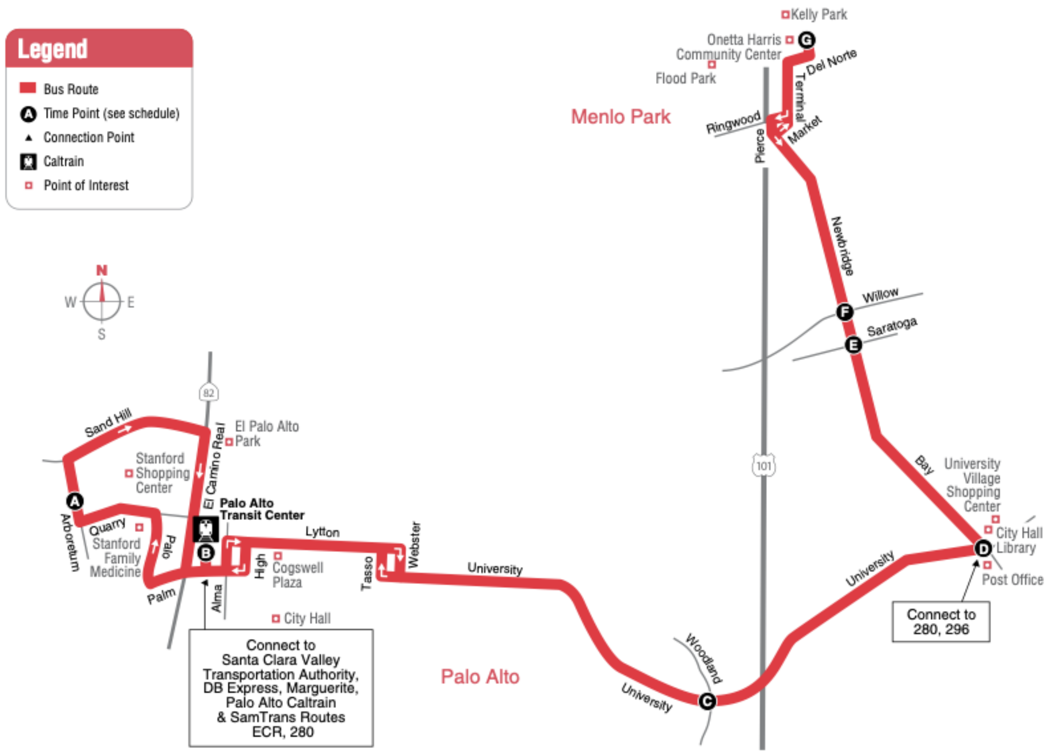


Figure 4: SamTrans Route 281 in East Palo Alto

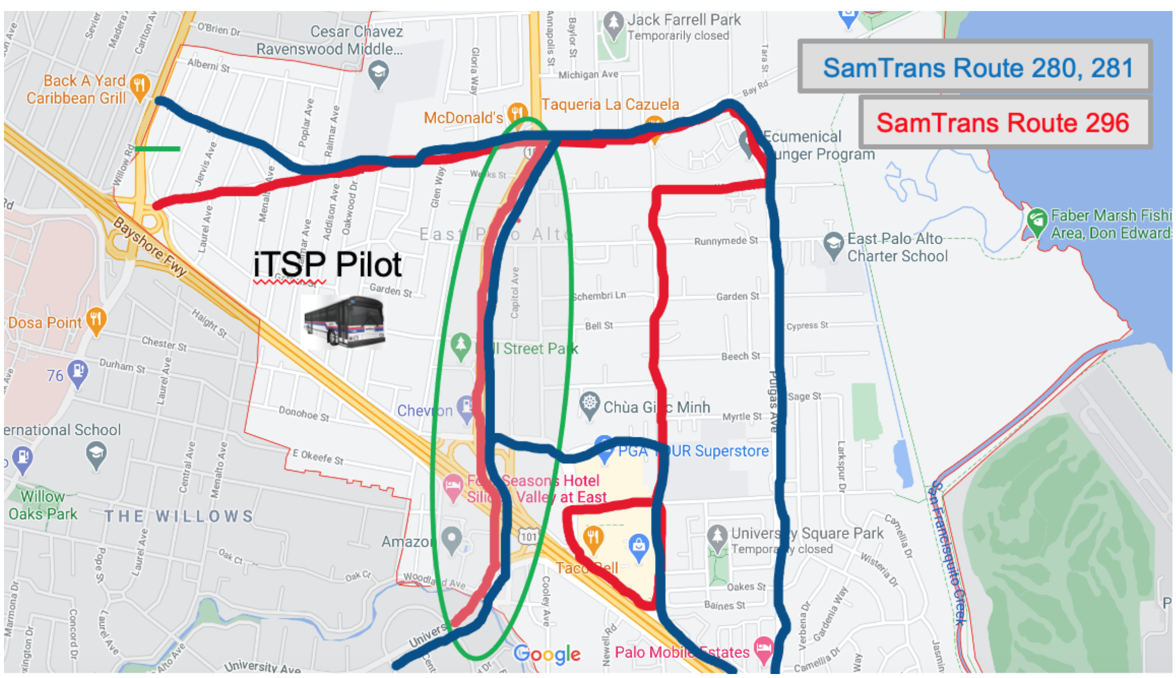


Figure 5: EPA Traffic Signals Overlayed with Routes 280, 281, and 296. The area enclosed by the green circle is the focus of the iTSP pilot and contains the 4 traffic signals controlled by the LYT system.

There are six traffic signals contained within the green circle. This original pilot planned to integrate with five of the six signals, because the sixth signal is under Caltrans maintenance and operation. When integration began with the five signal controllers, it was found that the signal at Woodland Ave and University Ave was controlled by an older traffic controller model (170 Controller) which is not compatible with the LYT system. Efforts were made by the project stakeholders to update the signal within the pilot time period. Ultimately, EPA's contracted signal technicians were unable to perform the upgrade on time. The result is that LYT deployed TSP on four signalized intersections along University Ave. in East Palo Alto (Figure 6). This corridor is a subsection (3,433 feet or 0.65 miles) of SamTrans route 281 and includes the following intersections:

- University Ave. & Bay Rd. - Northernmost intersection
- University Ave. & Runnymede St.
- University Ave. & Bell St.
- University Ave. & Donohoe St. - Southernmost intersection

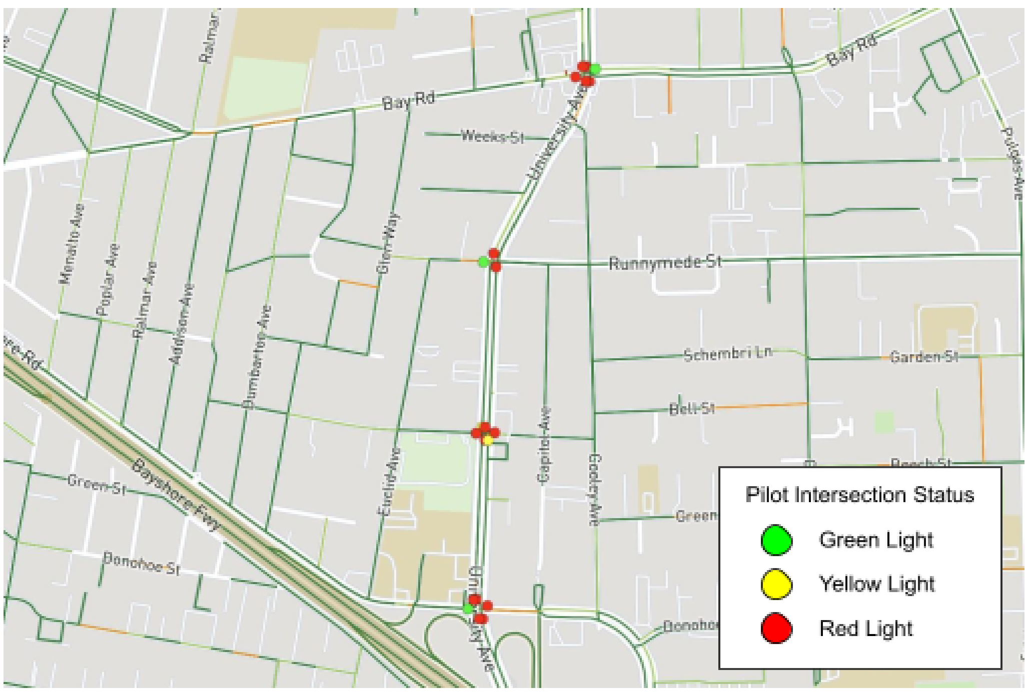


Figure 6: East Palo Alto Transit Signal Priority Traffic Signals Along University Ave.

Project Prerequisites

A iTSP (LYT.speed) deployment requires the following systems to be already available.

Transit Agency Data Requirements:

A. Transit vehicle must have a global positioning system (GPS) device onboard capable of reporting the following information every 1 to 5 seconds:
   1. Latitude in degrees
   2. Longitude in degrees
   3. Direction of travel
   4. Vehicle speed
   5. Number of satellites in view
   6. Time of measurement

B. Transit vehicle must have a unique identification number.

C. Transit vehicle must report location information with a unique ID with a frequency of less than five seconds and no more than one second.

D. Transit agency must be able to direct their transit vehicle location information from their Automatic Vehicle Location (AVL) system to the vendor's cloud server:
   1. Vendor must accept data from network connections that use UDP or HTTP requests.
   2. Vendor must accept transit vehicle location data in an XML or JSON format.

E. Transit agency must provide the vendor in a csv, excel, or JSON file structure the location of bus stops and the route numbers that service them.

F. Transit agency must provide the vendor bus route maps and schedules.

City Agency Data Requirements:

A. The iTSP system must be a centralized system with its physical equipment located within the city traffic management center.

B. The iTSP equipment must be able to connect to the iTSP remote server using AES 256-bit encrypted TCP communication through the city firewall.

C. The iTSP equipment must not require a public IP and will conform to city network security requirements.

D. City equipment must be 2070 type traffic controllers running firmware by Fourth Dimension.

E. City must have traffic controllers using NTCIP and the vendor's proprietary transit signal priority network messages.

F. City IT department must implement vendor networking settings and configurations required for a safe and secure connection.

G. City must provide vendor with each traffic signal's IP address and port number.

Required Equipment

For this pilot there was a need to place temporary equipment on SamTrans buses and within traffic signal control cabinets in the City of East Palo. As described in the previous section on system prerequisites, the iTSP system requires access to a stream of high-frequency bus positioning data. Since the buses in SamTrans fleet are currently not capable of providing bus positioning information at a rate of every one to five seconds, the project team equipped a sub-fleet of SamTrans vehicles with a temporary vehicle tracking system from supplier Particle.io. Based on the actual number of SamTrans buses dispatched along the pilot routes, SSV purchased 40 GPS tracking units (at a cost of approximately $8,000) which provided a temporary tracking/location capability for the pilot. An example of the device is shown in Figure 7.

Figure 7: Temporary Vehicle Tracking Device “Particle Tracker One”

Bear Electric performed the installation of the tracking devices. The wiring schematic is included as Appendix A.

The participating traffic signals in the City of East Palo are not connected to a city communication network. In order to communicate with the four traffic signals located on University Ave., four Maesto-LTEs (a small, secure cellular network appliance and computer, Figure 8) were supplied by LYT. These units function as a computer that resides at the network "edge" and serve as the protective link between city traffic signals and the LYT platform. They contain software that enables secure communication over the cellular network between the LYT cloud platform and city traffic signal. They are designed to securely manage the information exchange between traffic lights and LYT’s cloud platform.

Figure 8: Maestro-LTE

System Setup

The temporary vehicle tracking devices attached to the SamTrans sub-fleet were configured to send location updates to the LYT cloud platform at once every second, and the software collected and processed transit bus location updates in real-time. After approximately five weeks of transit bus location information had been saved, LYT began training machine learning models capable of predicting the buses arrival time to the piloted traffic signals.

The City of East Palo Alto (EPA) provided LYT with traffic signal phase diagrams according to the National Electrical Manufacturers Association (NEMA) standard. With this information, LYT was able to implement secure communication between traffic signals, Maestro-LTE, and the cloud platform.

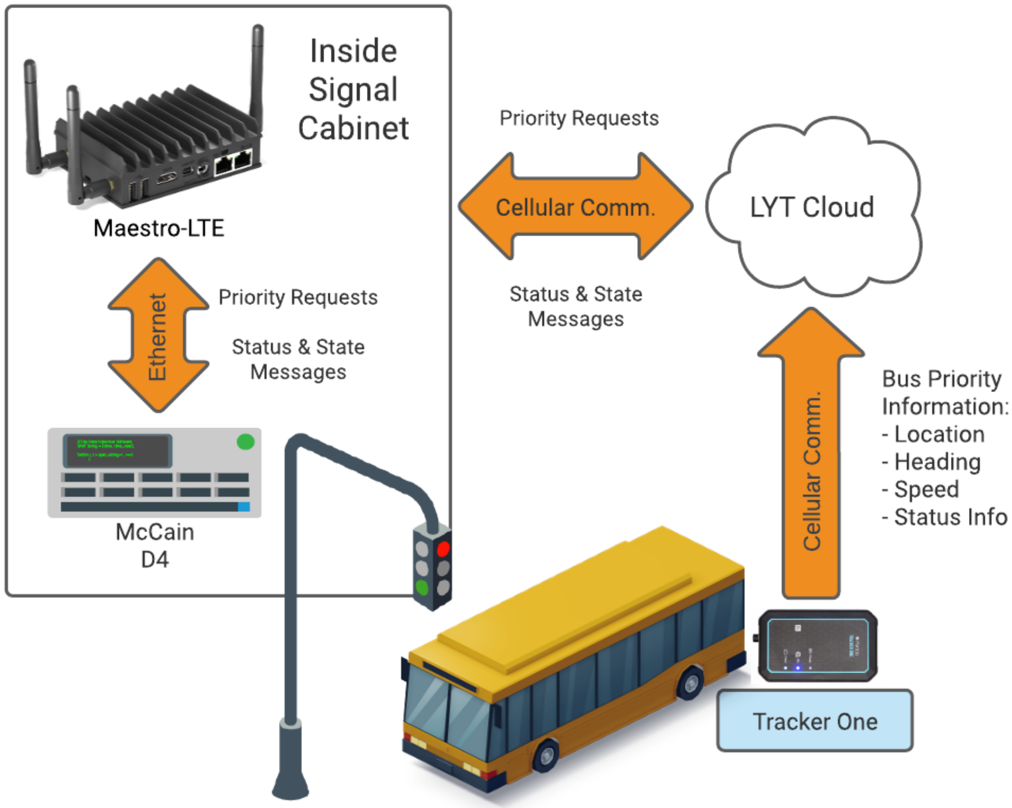


Figure 9: LYT.speed Network Architecture Diagram

System Software, Data Collection & Monitoring

The LYT system includes a web portal for EPA, C/CAG and SamTrans staff to login and view how the transit system is performing at each of the piloted traffic signals. Features include:

- Secure login with additional One Time Password (OTP) at each login.
- Viewing the entire city, multiple cities, a particular signal or a particular transit vehicle.
- Troubleshooting issues in real time at the intersection level with signal performance metrics.
- Reviewing charts of daily priority calls and their impact on transit performance.

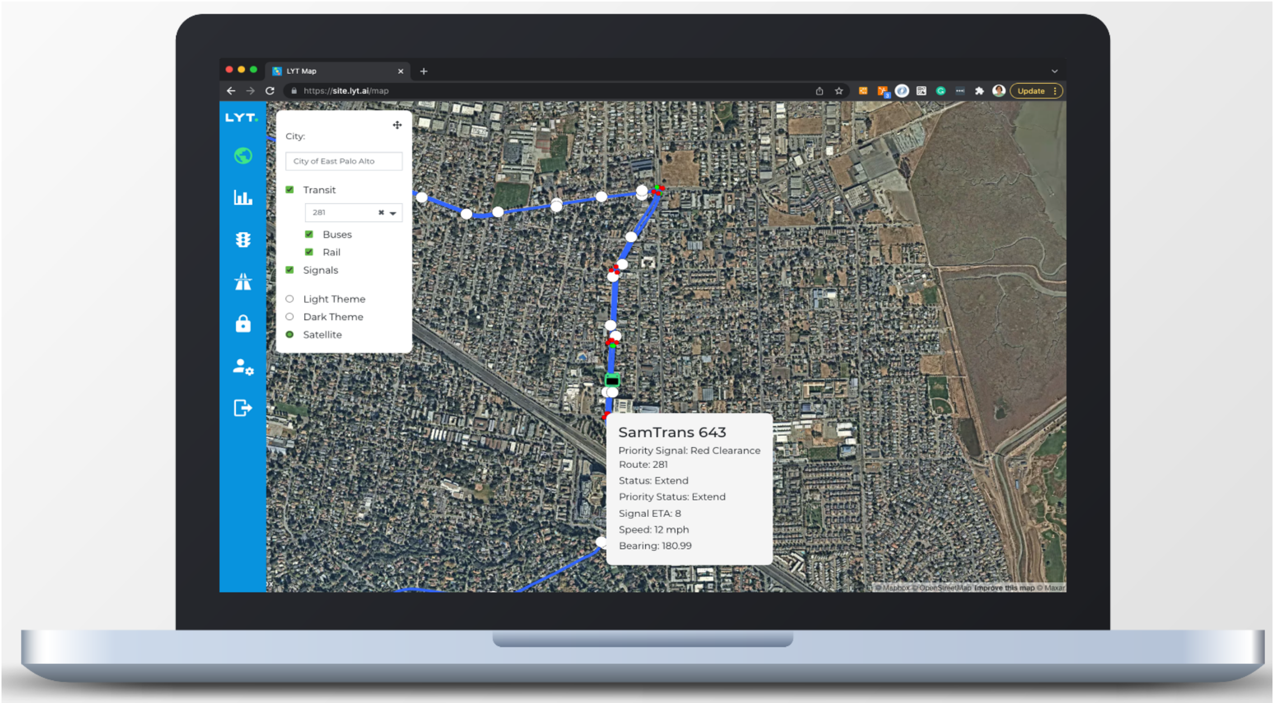


Figure 10: LYT's Live Map

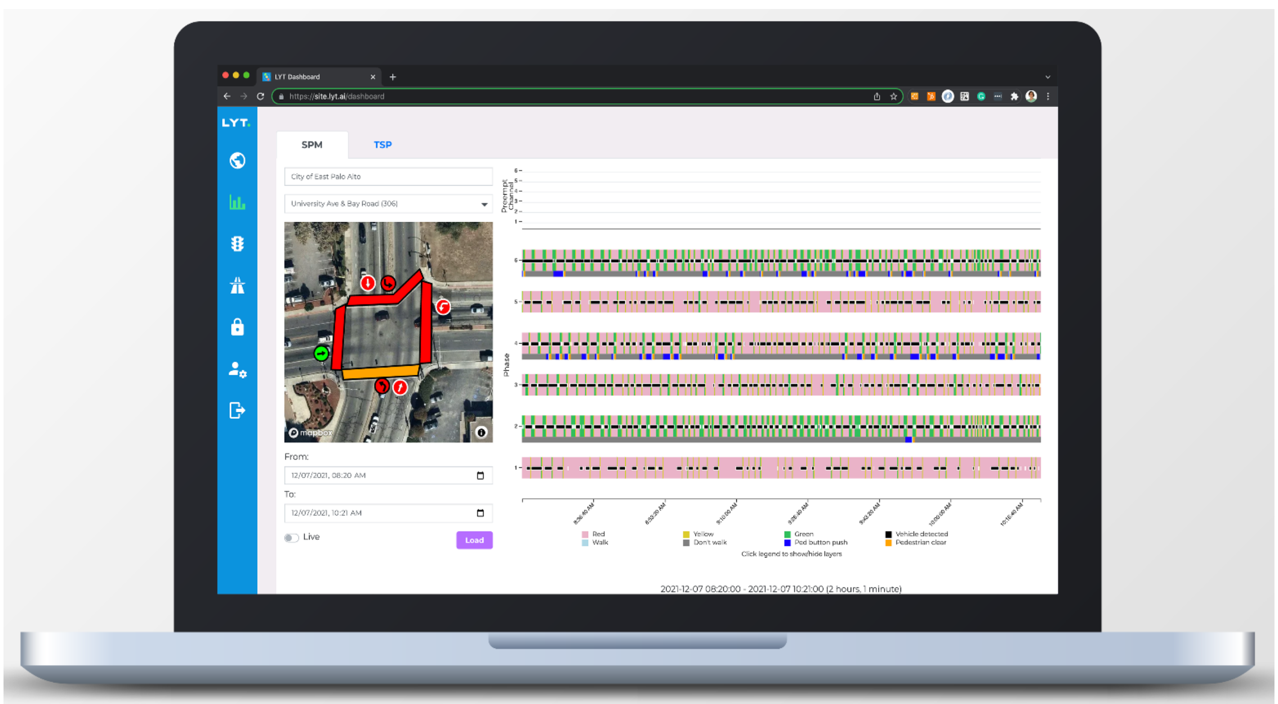


Figure 11: LYT's Signal Performance Records

The Results of the Pilot

The following charts and tables cover bus trips observed from 10/1/2021 to 2/28/2022. iTSP was deployed on 11/1/21 for all intersections except Donohoe, which was fully operationalized on 1/28/22. The period of time before iTSP was operational will be referred to as the baseline period.

Key Performance Metrics & Results

The tables and charts below demonstrate the positive effect of iTSP across several key metrics. In general, TSP aims to increase the reliability of bus arrival times by reducing delays caused by red lights. The following metrics quantify these delays as well as other facets of bus travel time which this project optimizes via iTSP:

- **Dwell time**: The amount of time buses are stopped at scheduled bus stops.
- **Green light success rate**: The probability of a bus clearing a signaled intersection without stopping at a red light.
- **Intersection delay:** The amount of time buses are stopped at red lights.
- **Run time:** Total bus time within the pilot corridors minus time servicing bus stops and stopping at intersections.
- **Travel time** and **travel speed**: Indicators of how fast the bus is able to move through a segment (excluding dwell time).

Baseline Data

In order to understand the effect of iTSP, it is necessary to establish the baseline performance. The chart below (Figure 12) shows how trips in the baseline period break down between dwell time, intersection delay and run time.

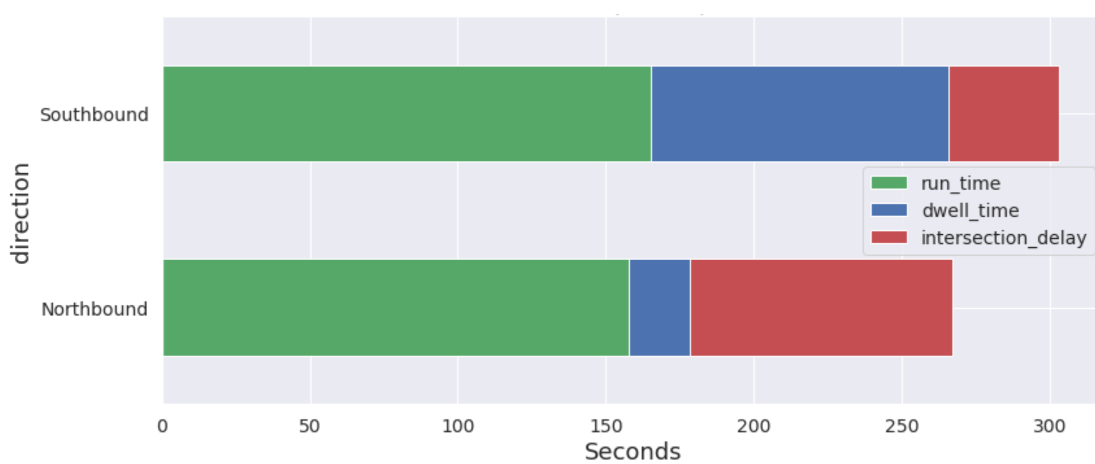


Figure 12: Route 281, Baseline Trip Composition

A key takeaway from this chart is that buses in the baseline period experience roughly ~2.38 times more intersection delay in the northbound direction than southbound.

The following box and whisker chart further breaks down intersection delay by direction and intersection, to identify the bottlenecks in the corridor. The center line of each rectangle (box) represents the middle 50%, or 50th percentile of the data set. The rectangle itself contains 50% of the data set with the remaining 48% shown in the lines (whiskers). The little dots above and below the whiskers are outliers and they represent the final 2% of the data set. From whisker to whisker, 98% of the dataset is represented. The greater the distance from end to end, the higher the variation.

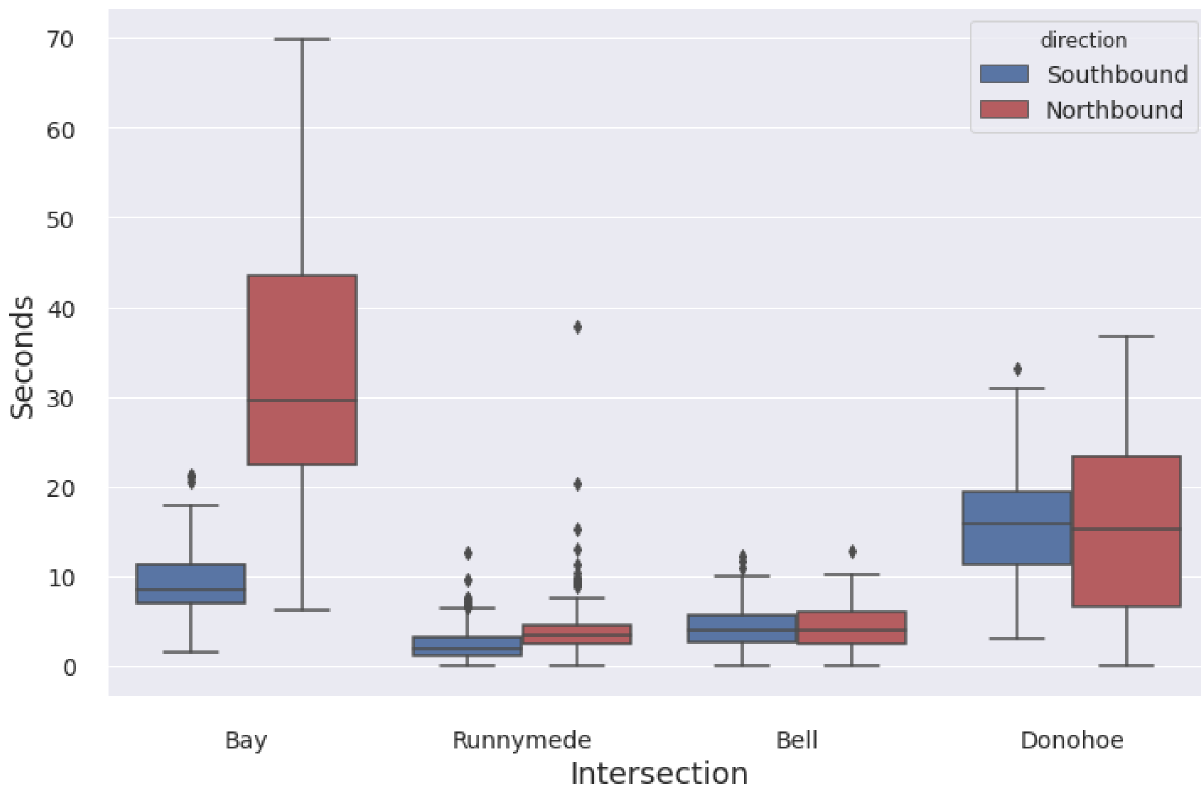


Figure 13: Route 281, Baseline Intersection Delay (In Seconds) by Direction and Intersection

In the northbound direction, Bay Rd. is the biggest bottleneck (bus makes a left turn) followed by Donohoe St.. For the southbound direction, Donohoe St. is the largest contributor of intersection delay, followed by Bay Rd., Runnymede St., and Bell St. each of which typically add only a few seconds of intersection delay in either direction.

Intersection Delay

The metric that TSP has the most control over is intersection delay. The baseline data indicate that the northbound direction suffers from more than twice the intersection delay as southbound. Northbound delay is much larger than southbound delay because route 281 goes to the west at Bay Rd. Buses making a left turn on to Bay from University experience far more signal delay then at any other intersection. After the implementation of TSP, northbound intersection delay is reduced by roughly 45% and brought in line with southbound's baseline. Southbound, with a relatively lower amount of baseline intersection delay, still benefits from a 19% reduction, due to TSP.

	Northbound	**Southbound**
Baseline	88.46s	37.43s
iTSP	48.46s	30.31s
Absolute Reduction	40.00s	7.12s
Relative Reduction	**45.22%**	**19.02%**

Table 1: Intersection Delay Before and After iTSP

Inspecting the individual intersections in Figure 14, it is clear that those identified as the biggest bottlenecks (Bay Rd., Donohoe St.) are indeed where the largest intersection delay reductions are observed.

In the proceeding box and whisker plots, the purple boxes represent the distribution of intersection delay values from the baseline period, whereas the green boxes indicate intersection delays from the period in which iTSP was operational.

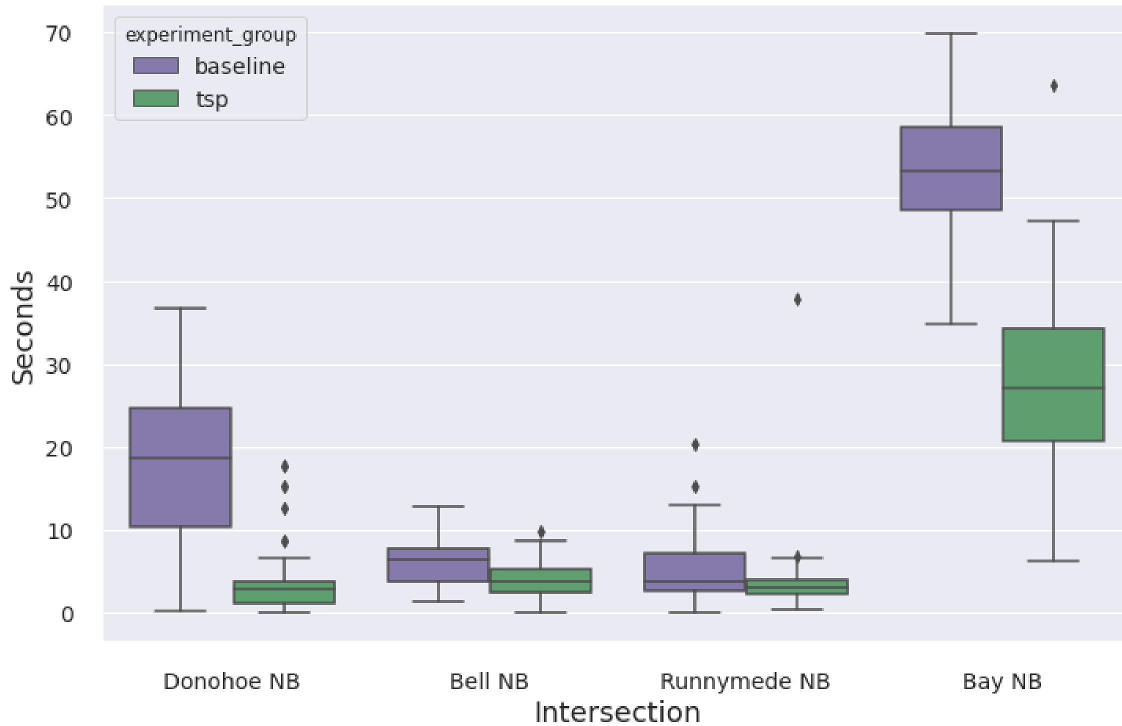


Figure 14: Route 281, Before and After iTSP, Northbound, Intersection Delay

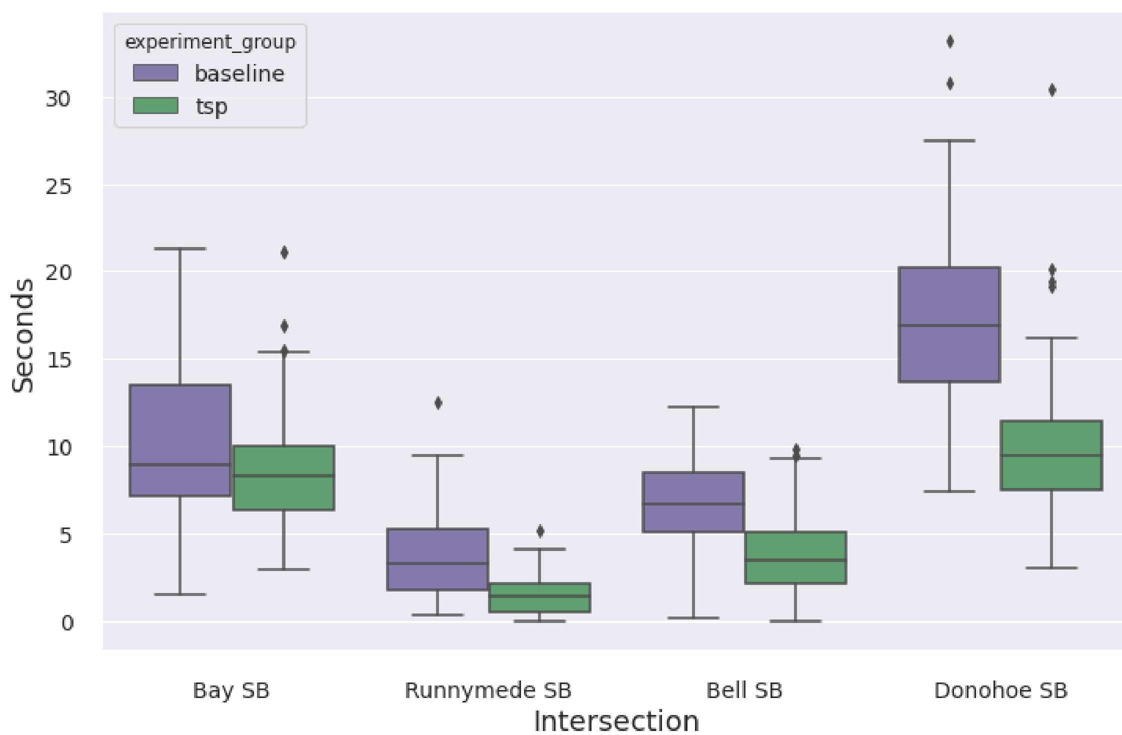


Figure 15: Route 281, Before and After iTSP, Southbound, Intersection Delay

Travel Time

Reductions in intersection delay are reflected in reduced travel times. Since intersection delay is a component of travel time, travel time falls by a similar absolute amount as intersection delay. In relative terms, travel time is reduced by ~18% for northbound trips and ~7% for southbound.

	Northbound	Southbound
Baseline	246.33s	209.39s
iTSP	202.43s	195.36s
Absolute Reduction (s)	43.9s	14.03s
Relative Reduction	**17.82%**	**6.70%**

Table 2: Route 281, Before and After iTSP, Travel Time

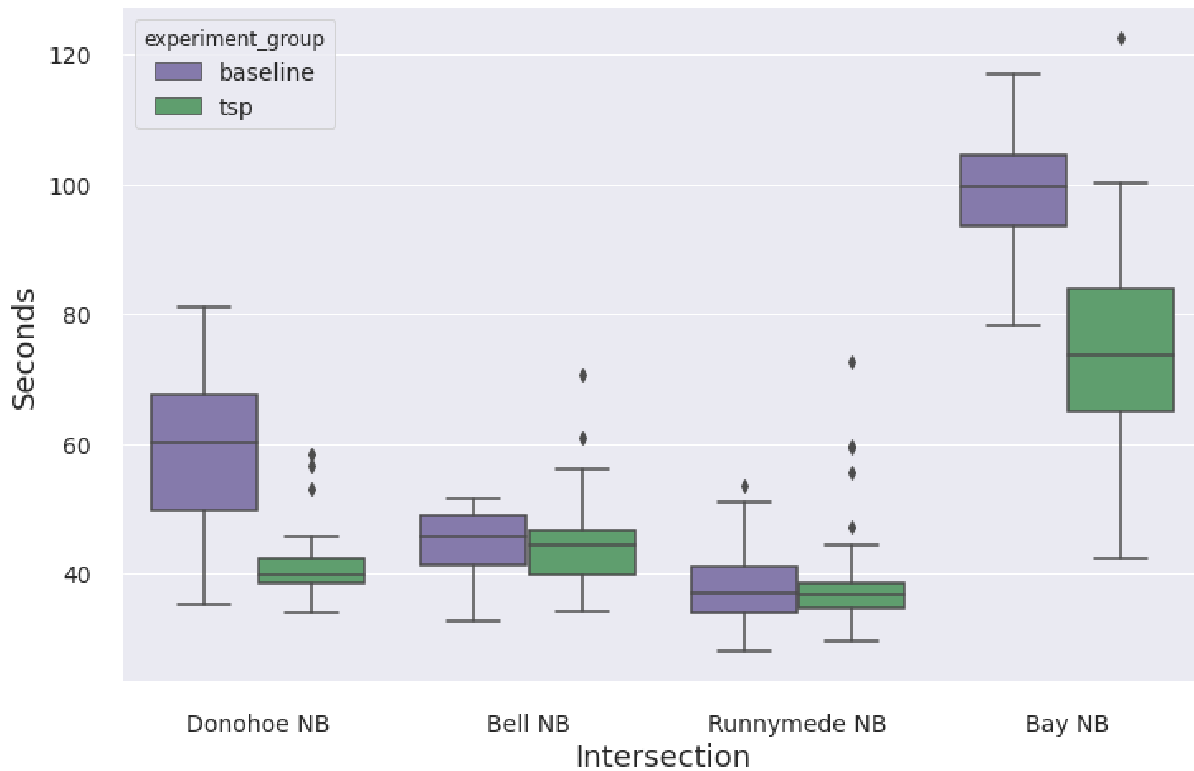


Figure 16: Route 281, Before and After iTSP, Northbound, Travel Times

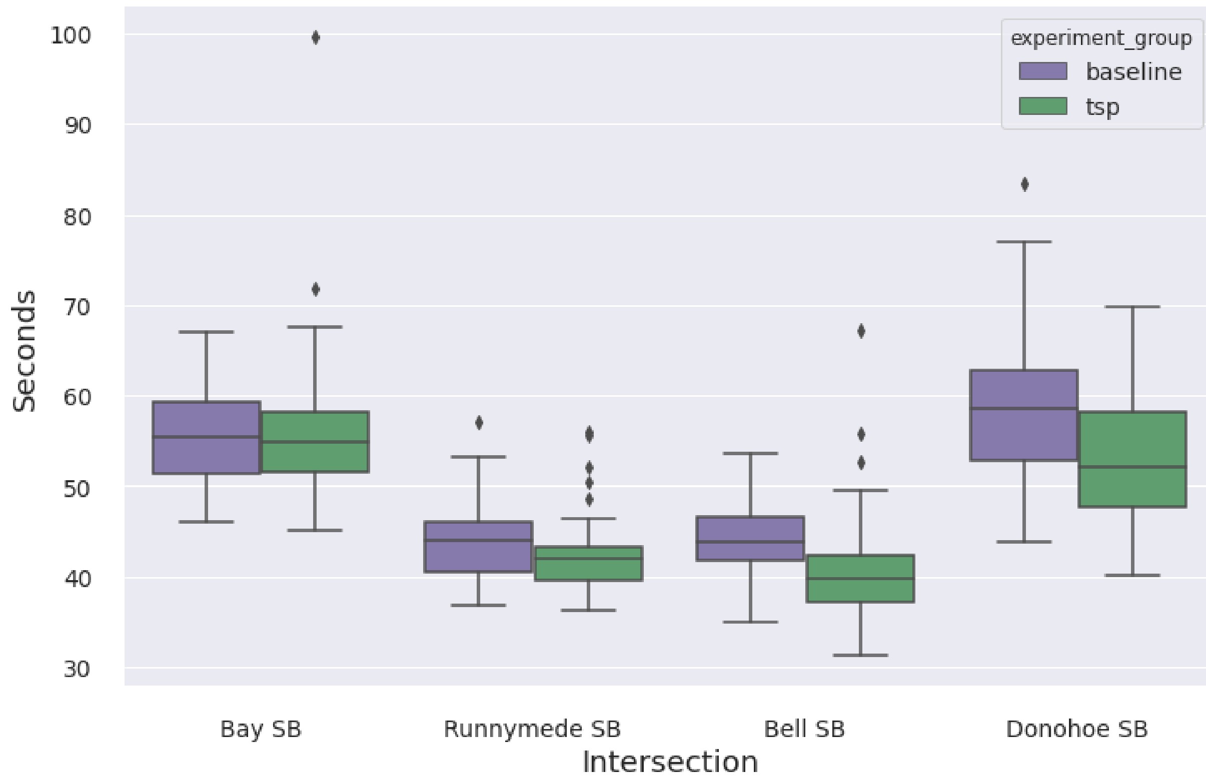


Figure 17: Route 281, Before and After iTSP, Southbound, Travel Times

Green Light Success Rate

This metric measures the fraction of trips in which the bus was able to enter and exit a signalized intersection without stopping. This is a stricter definition of success than a reduction in intersection delay, since even a substantial reduction in delay time would not count as a "success" here unless the bus never came to a stop. Table 3 presents the overall average green light success rate for all four intersections. If any direction had a green light success rate of 100%,that would mean that every bus traveling along University Ave would never encounter a red light. The following two figures 18 and 19 show the per intersection green light success rate. It is worth noting that for all but one direction of travel, green light success rate greatly improved.

	Northbound	**Southbound**
Baseline	46.00%	59.48%
iTSP	56.30%	64.02%
Increase	**10.30%**	**4.54%**

Table 3: Route 281, Before and After iTSP, Green Light Success Rate

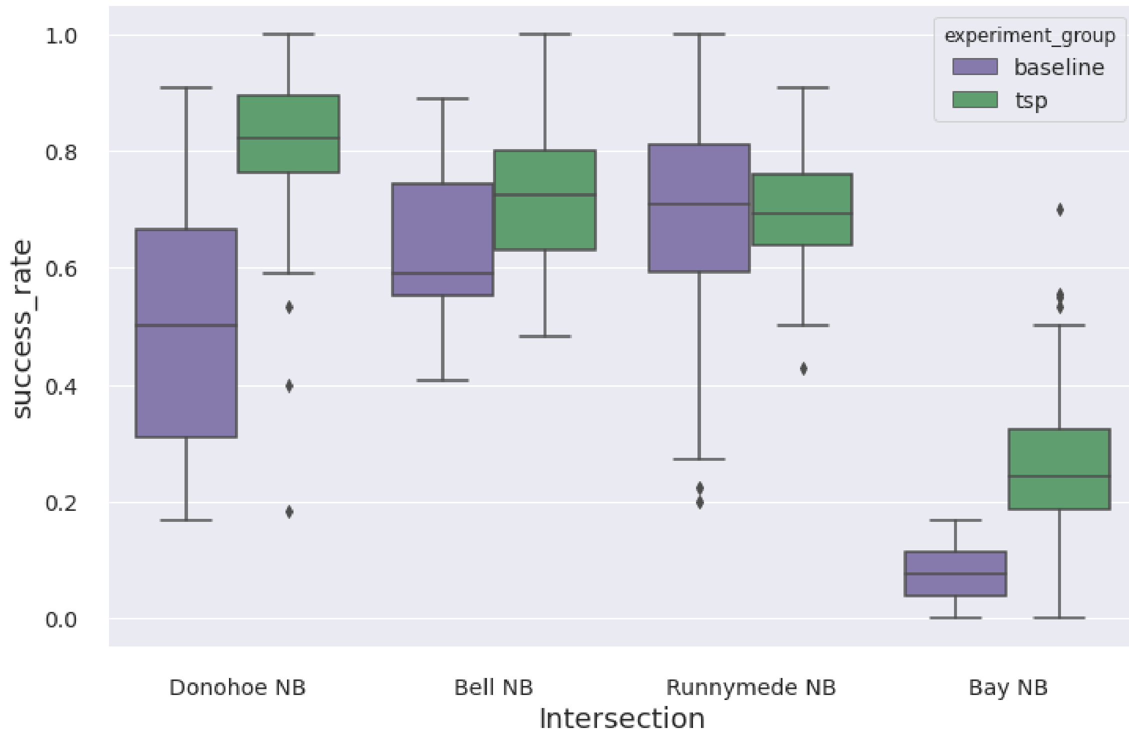


Figure 18: Route 281, Before and After iTSP, Northbound, Green Light Success Rate

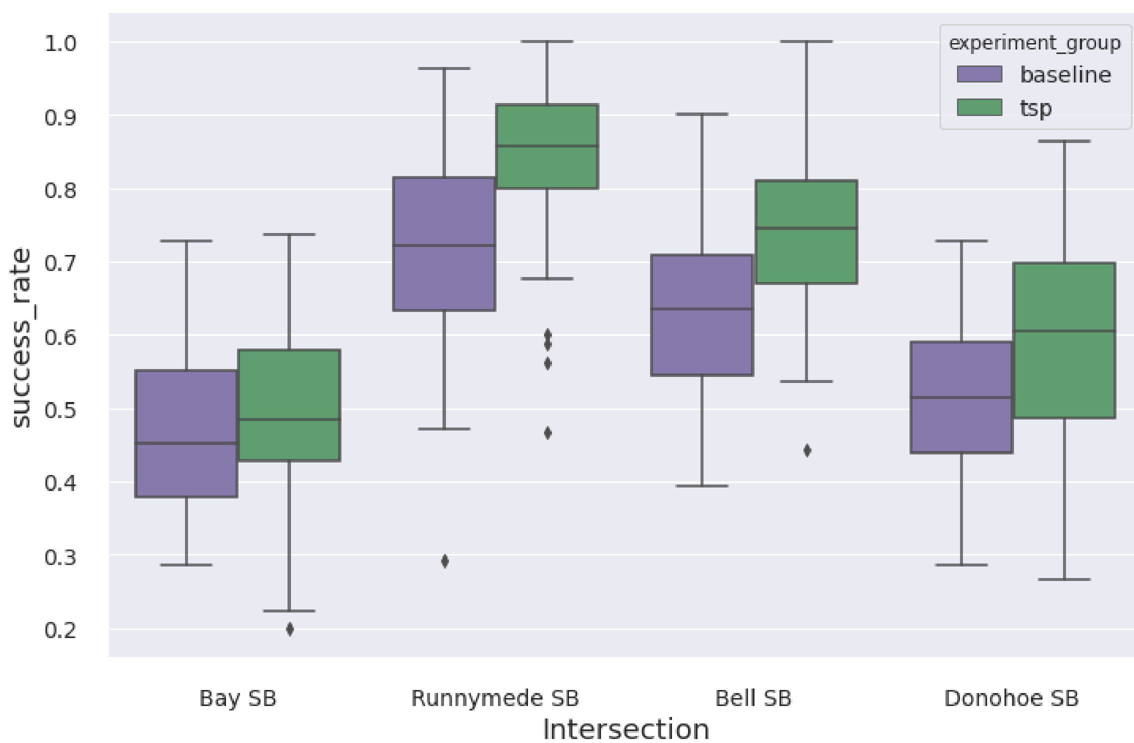


Figure 19: Route 281, Before and After iTSP, Southbound, Green Light Success Rate

Travel Speed

This metric captures the average speed of buses in the corridor, excluding any dwell periods at bus stops. Increases in average speed will largely mirror reductions in intersection delays. Table 4 presents the overall average traveling speed along University Ave. Figures 20 and 21 show the average traveling speed of buses crossing each intersection. It is interesting to note the change at Runnymede in the Northbound direction. Possible reasons for the slight decrease in travel speed include ridership returning to the bus stop before Runnymede, traffic congestion returning, and the fact that the bus needs to cross two lanes of traffic in order to arrive in the left turn at Bay Rd.

	Northbound	Southbound
Baseline	15.18 mph	15.32 mph
iTSP	16.79 mph	15.95 mph
Absolute Increase	1.61 mph	0.63 mph
Relative Increase	**10.61%**	**4.11%**

Table 4: Route 281, Before and After iTSP Travel Speed Results

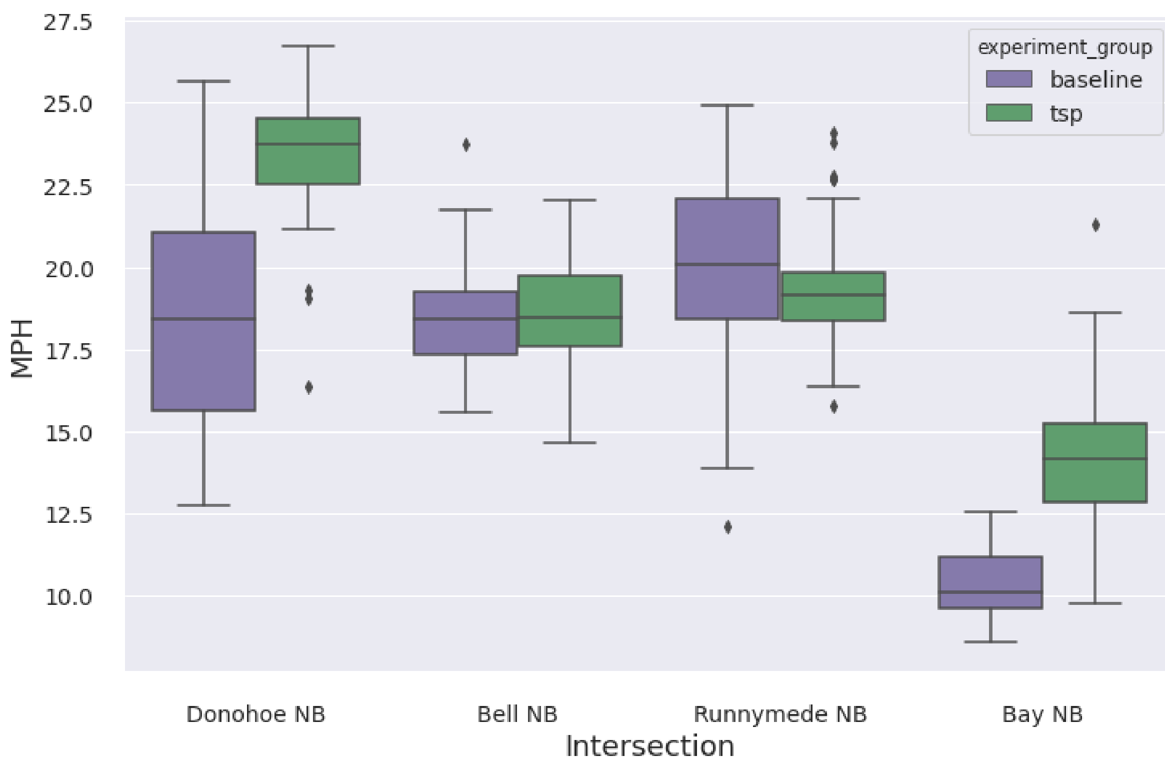


Figure 20: Route 281, Before and After iTSP, Northbound, Travel Speed

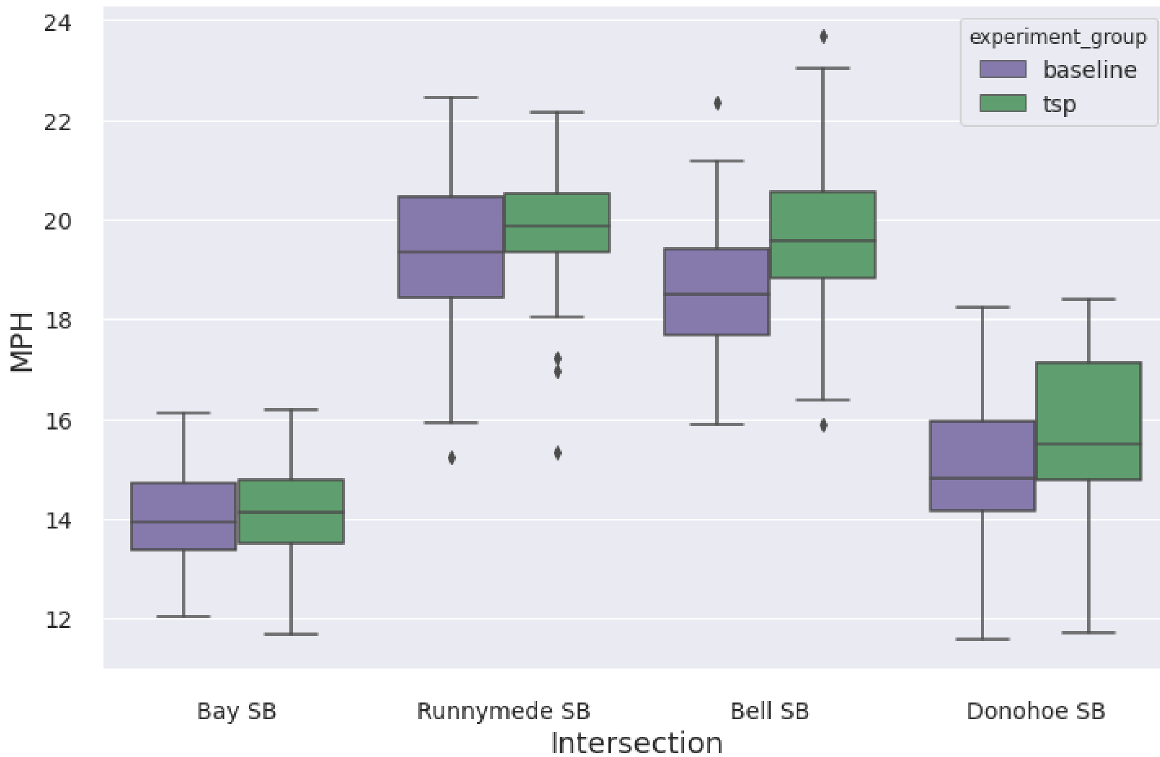


Figure 21: Route 281, Before and After iTSP, Southbound, Travel Speed

Dwell Time

The dwell time metric measures the amount of time spent stopped at bus stops. While not a direct indicator of TSP performance, significant intersection delay reductions could show up as increased dwell time, since the bus would potentially arrive at time points sooner. This effect was not observed in this pilot study, but dwell time charts are included below for completeness. Zero values below indicate that there are no applicable bus stops.

Changes in dwell time at the southbound Bay and University stop could be explained by minor schedule adjustments to Route 281 in January 2022, which may have resulted in some vehicles running ahead of schedule. As University/Bay is a timepoint, such vehicles would have dwelled here longer than previously in order to depart on schedule. This time point is after the intersection so any reduction in signal time will increase time at the bus stop. No major changes to route- or stop-level ridership were recorded during the pilot timeframe.

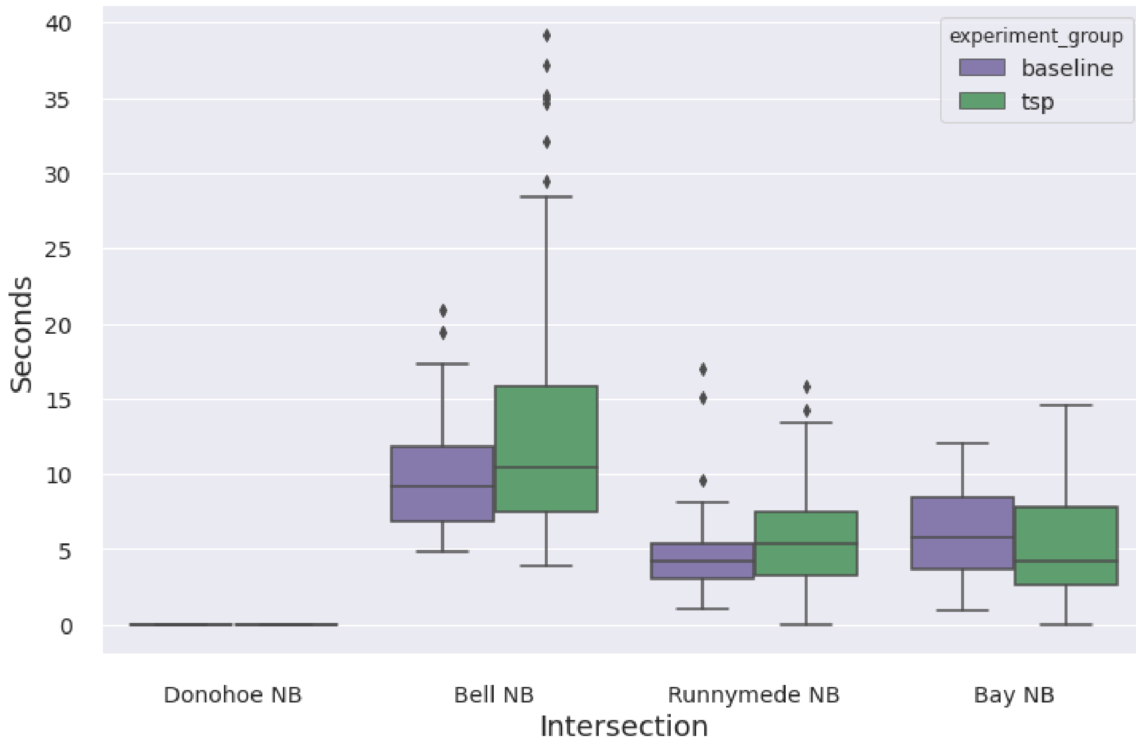


Figure 22: Route 281, Before and After iTSP, Northbound, Dwell Time

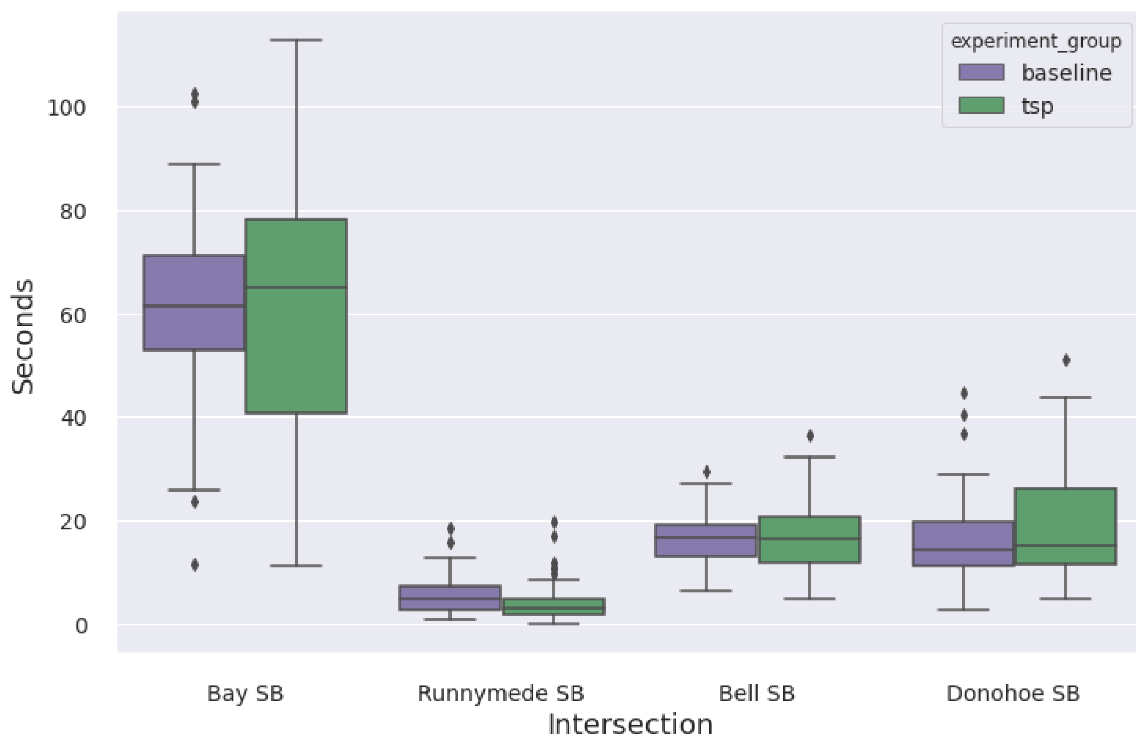


Figure 23: Route 281, Before and After iTSP, Southbound, Dwell Time

TSP Request Saturation

This metric demonstrates the value of iTSP directly by showing the effect of increased TSP intervention on intersection delay. TSP request saturation is defined as the percentage of trips on a given day during which a TSP request was made – in other words, the total number of trips during which a TSP call was made divided by the total number of trips. In the baseline period, no TSP requests are created, which corresponds to 0% TSP request saturation. As the TSP system is fully operationalized, TSP requests are made much more frequently, some days on all trips (100% saturation). The correlation between more TSP requests and decreased intersection delay is illustrated in the following chart. The more TSP calls that are made, the less time buses sit at red lights.

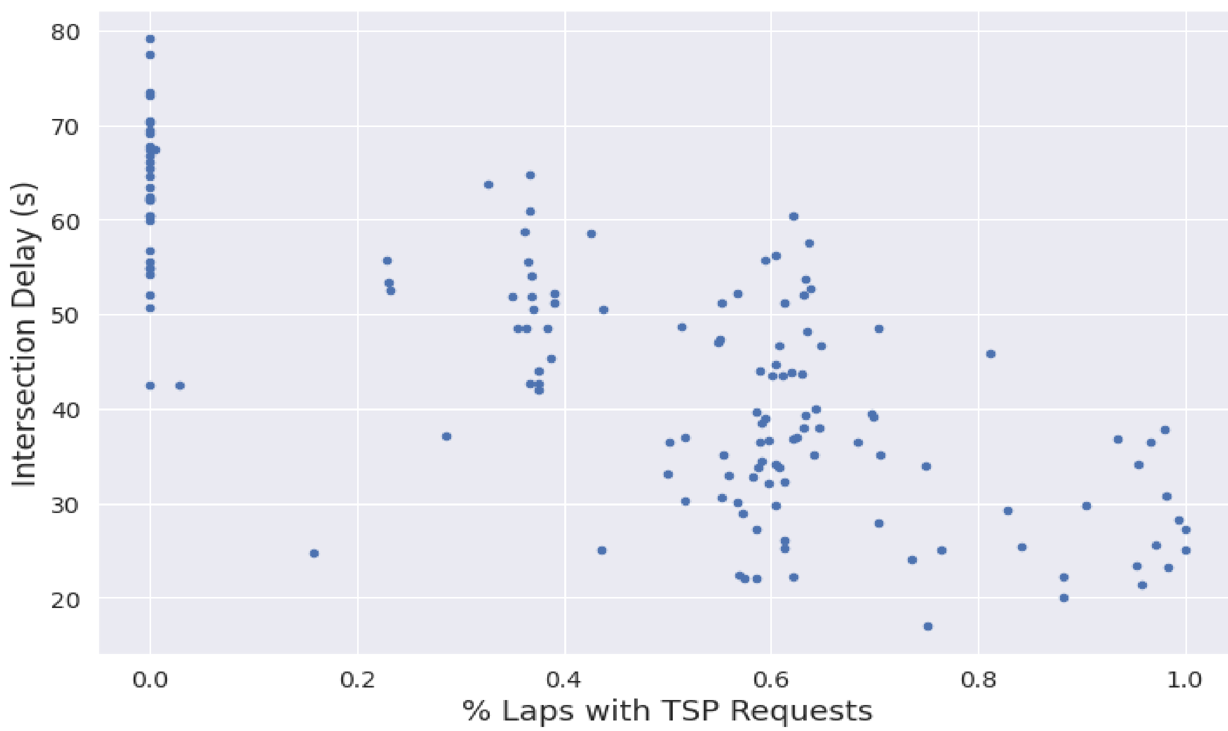


Figure 24: TSP Requests vs. Intersection Delay

Priority Status Counts

Whenever TSP requests are made, the iTSP system records traffic controller priority statuses corresponding to those requests. These status values indicate how the controller is servicing the request for priority. Priority statuses include the following values:

- Extend: The traffic signal is extending the green light to allow the bus extra time to clear the intersection.
- Early: The traffic signal is truncating the green time for other directions of travel to provide a green light for the bus sooner.
- No Adjust / No Call: The traffic signal does not need to make any changes to the normal operation of the signal.

Inspecting the breakdown of priority status by intersection reveals which strategies each intersection needs to use when providing bus prioritization.

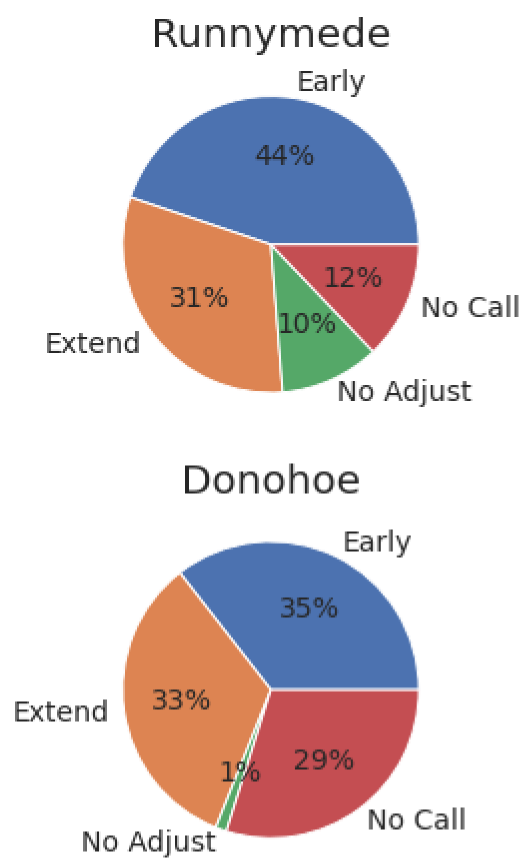


Figure 25: Breakdown of Each Intersection's Priority Strategy

A key takeaway from these charts is that a TSP solution which is able to give the bus early greens (corresponding to the Early priority status) is advantageous over one in which only green light extension is possible (Extend). For example, Bay Rd., where much of the northbound intersection delay reduction occurred, benefits heavily from truncating other phases in order to give the bus an early green. If the system were only able to accommodate green light extension, this intersection would have seen only a fraction of the intersection delay reductions. Another way of reading these pie charts is by observing the sum of No Call and No Adjust. The resulting sum totals to the likelihood of a bus traveling through an intersection with the signal being normally green.

Conclusion:

iTSP Pilot Project Conclusions

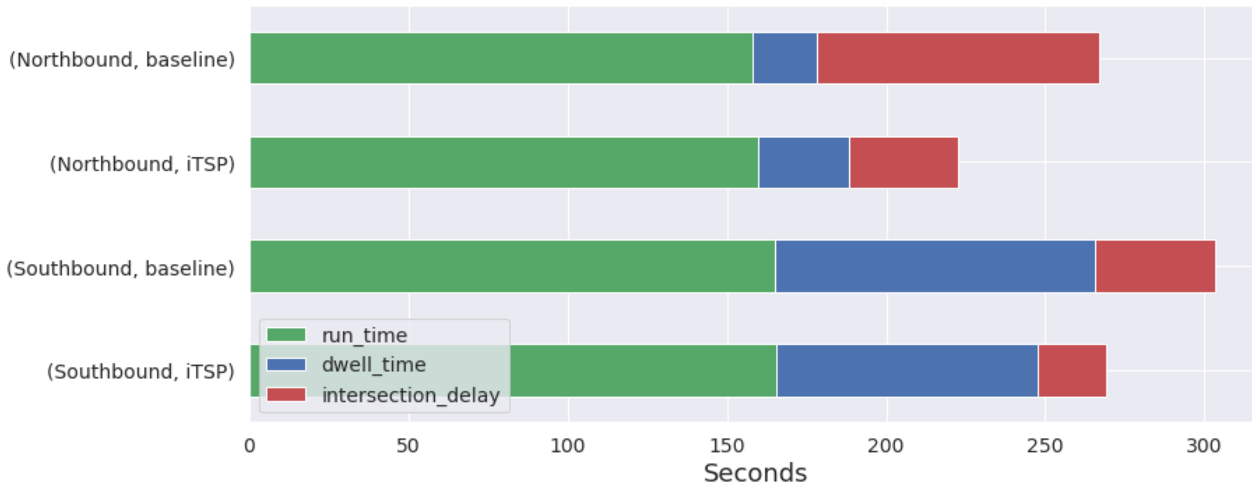


Figure 26: Route 281, Comparison between Baseline Trip & iTSP Composition

The iTSP project demonstrated a statistically significant improvement on the travel times for buses participating in the project (Figure 26). The deployment on University Ave. reduced northbound intersection delay by 45% (40 seconds) and southbound intersection delay by 19% (7 seconds). These translate to 18% and 7% reductions in travel time for northbound and southbound respectively. The signal controller TSP records (Figure 25) demonstrate that each of the four signals applied a prioritization strategy at least 70% of the time. It was further demonstrated that every signal primarily used the early green strategy. Restated another way, without iTSP providing a bus prioritization strategy, the probability of having to come to a stop would have been at least 70%.

Figure 26 demonstrates the reduction in intersection delay and its effects on dwell time. Dwell time is the amount of time parked at a bus stop. Since buses must adhere to their schedule, reductions in intersection delay can place vehicles ahead of schedule, causing them to wait at bus stops longer. This can happen when comparing the blue bars of the Northbound, baseline to the Northbound, iTSP. The shorter intersection delay resulted in buses no longer being behind schedule.

The methodologies used for calculating iTSP's performance are reusable for other TSP projects. This project highlighted the value of having high-frequency location data. Much of this project's ability to achieve month-over-month improvements was a direct result of having accurate bus route performance measurements, including high frequency (every one second) bus location, bus schedule, and traffic signal operations data. The collected information was used by the project team to provide a precise understanding of all the variables that can make or break a TSP's performance. As SamTrans completes the upgrade of its CAD/AVL system, they will collect ample data to use in determining where they can produce operation efficiencies, scheduling changes, and TSP deployments to be able to meet transit service goals.

Recommendations

The pilot demonstrates that buses can spend less time idling and thus get riders to their destinations more efficiently. If these travel-time savings are scaled across the entire route 281 service area, then a 7% reduction in end-to-end trip time (conservative estimate) would result in 2 minutes average savings during morning commutes, and 3 minutes during afternoon commutes. This route is serviced by 35 buses a day in each direction for a total of 70 buses. The morning commutes are serviced by 24 total buses, a time savings of 2 minutes per bus equals 48 minutes of reduced operational, maintenance and emission costs. The afternoon commutes are serviced by a total of 28 buses. A time savings of 3 minutes per bus equals 84 minutes, or almost an hour and a half of reduced operational, maintenance and emission costs. These can contribute to improved rider experience across the majority of the SamTrans service area, and lead to greater utilization of transit options. Furthermore, increased fuel efficiency and lower emissions will help cities and transport agencies reach their climate goals.

Lastly, given the demonstrated higher impact of TSP on routes which include left turns, the incidence of left turns on potential routes should be a factor considered in future pilots and implementations. There are several SamTrans routes that would benefit from TSP on left turns, particularly Route ECR, which is the longest, most-resource intensive route for SamTrans and carries over a quarter of all SamTrans riders each day.[12]

Further research, implementation and expansion of iTSP systems is highly recommended:

- There is a clear potential to realize these gains on a larger scale, and create momentum behind improved transit systems and more viable and appealing transit options. These are especially vital to transit-dependent communities, where such improvements are most needed and can have the greatest impact.
- Increasing the scale of the project has additional co-benefits. During the timespan of the pilot project, as the machine learning systems became more accurate and inclusive, the rate of iTSP system performance improved.
- Also, as more routes and intersections are included in future implementations, the gains across the system are compounded in a kind of ‘network effect’, which can lead to exponential improvements over the system as a whole.

[12] Source: SamTrans

With the return to in-person as well as hybrid options for work, school and services, communities are establishing new routines and habits around mobility. This presents a unique window of opportunity for enhancing transit options and systems. Transit is also a critical component in helping EPA and other Silicon Valley cities to meet their established climate goals by reducing the percentage of trips made in single occupancy vehicles (SOV). The lessons and experience from this project will inform a countywide TSP plan, which in turn can serve as a blueprint for future capital investments in San Mateo County.

Project Partners Experiences

City of East Palo Alto (EPA)

The LYT web portal was also used by EPA staff for items beyond the scope of TSP. Staff were able to utilize the LYT web portal to monitor the performance of the four signals throughout the day. Throughout the duration of the project, staff used the portal to verify issues in real time. When signal performance complaints were received from EPA residents, data from the platform were used to confirm the issues. This enabled the city to make adjustments based on easily-accessible data. EPA operates a small number of traffic signals in one of the most heavily-trafficked regions of the Bay Area. Clear communication with city staff and contracted maintenance teams is extremely important, as the city's resources and staff are very limited, and it does not operate and manage all of the signals within its border. .

In projects of this kind, the following steps are vital for success: researching the area's infrastructure, including status of repairs and upgrades, prior to implementation; determining exactly which stakeholders have authority over which areas, teams and technologies, and securing all the correct contacts ahead of time. This way, when issues arise, the correct people can be notified, and the solutions can be streamlined.

If this project is to be expanded throughout the city and beyond its borders, an inventory of all signal controller conditions is advised, and clear channels of communication are of paramount importance.

San Mateo County Transit District (SamTrans)

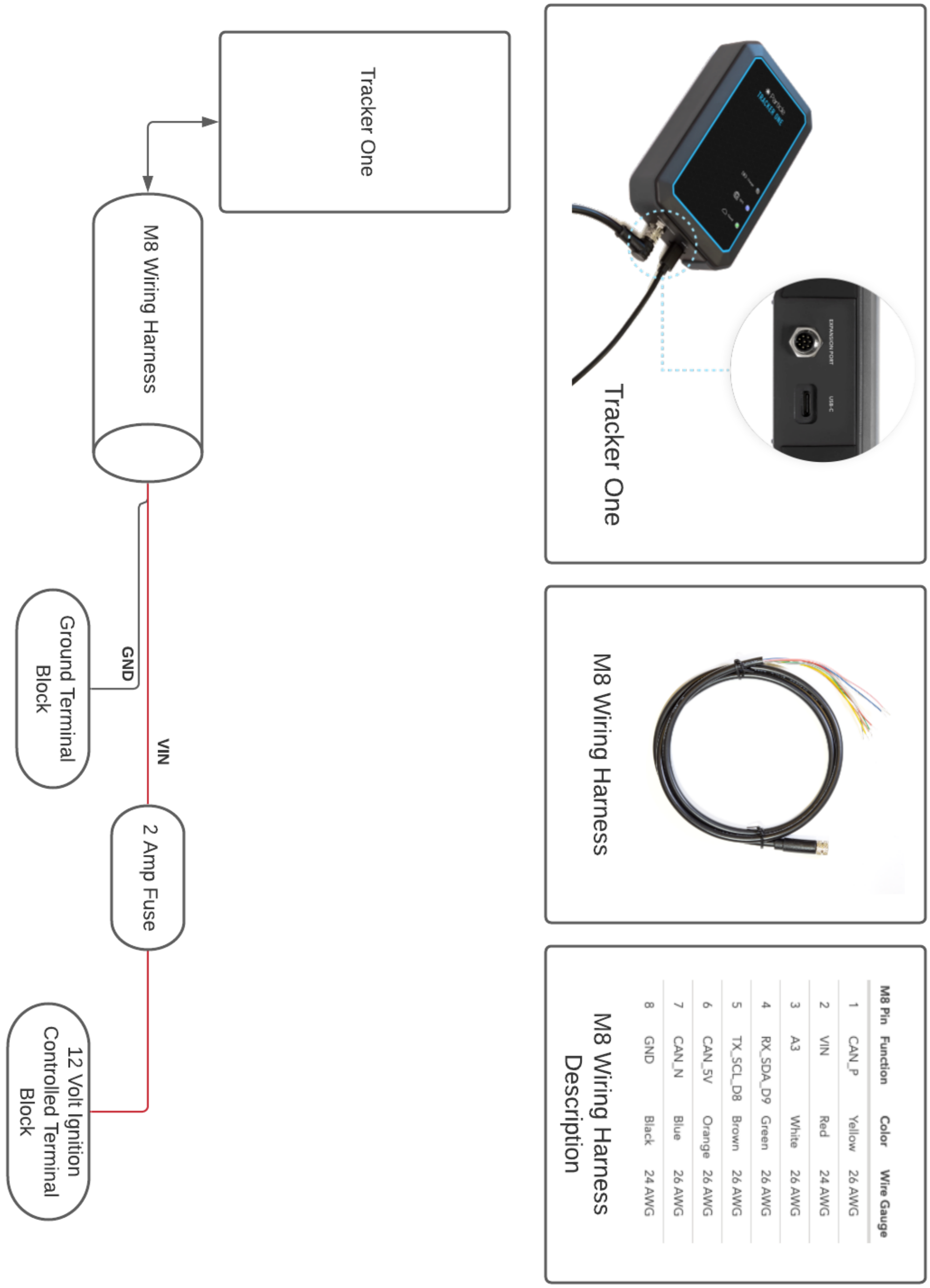
SamTrans staff were interested in participating in this pilot for a number of reasons. First, after having just implemented a GPS -based TSP system on El Camino, staff wanted to understand the differences in data and analytical tools offered by the iTSP and LYT system. Staff were also interested in the ability to see signal status information such as current phase, the ability to see how often priority has been granted in the past, and the methods used to determine when priority is requested (estimated arrival times). This rich data assists with quantifying the benefits as well as assists with ongoing performance monitoring of the transit signal priority system. Of additional interest to SamTrans staff was the relatively low implementation cost of iTSP, due to its use of existing on-board systems and signal technology. With Wi-Fi being installed throughout the

SamTrans fleet, there may be an opportunity to leverage enhanced vehicular connectivity for additional iTSP in the future.

Finally, staff were impressed by the LYT system's ability to offer more types of signal priority beyond just green light extensions — specifically left turns, which are often time-intensive and very costly for bus operations. SamTrans has a frequent route network where buses make left turns in and out of BART, Caltrain or other route terminus locations, and would benefit from a TSP system that enabled priority for left turns. This pilot was particularly valuable to SamTrans in highlighting the potential for TSP systems beyond those which they had previously used.

The lessons and experience from this project will inform a countywide TSP plan, which will serve as a blueprint for future capital investments in TSP throughout San Mateo County.

Appendix A: SamTrans Tracker One Schematic



M8 Pin	Function	Color	Wire Gauge
1	CAN_P	Yellow	26 AWG
2	VIN	Red	24 AWG
3	A3	White	26 AWG
4	RX_SDA_D9	Green	26 AWG
5	TX_SCL_D8	Brown	26 AWG
6	CAN_5V	Orange	26 AWG
7	CAN_N	Blue	26 AWG
8	GND	Black	24 AWG

Appendix B: Terminology

Acronyms & Abbreviations

- **CAD/AVL:** Computer-Aided Dispatch and Automatic Vehicle Location
- **C/CAG:** City/County Association of Governments of San Mateo County
- **EPA:** City of East Palo Alto
- **iTSP:** Intelligent Transit Signal Priority
- **HTTP:** Hypertext Transfer Protocol
- **JSON:** JavaScript Object Notation
- **LYT:** SinWaves, Inc. doing business as LYT
- **NTCIP:** National Transportation Communications for ITS (Intelligent Transportation Systems) Protocol
- **SamTrans:** San Mateo County Transit District
- **SOV:** Single Occupancy Vehicle
- **SSV:** Sustainable Silicon Valley
- **TDM:** Traffic Demand Management
- **UDP:** User Datagram Protocol

Terms Used in the Metrics, Measurements & Performance Section

- **Segment:** A section of road that starts at one intersection and ends at another. A segment will be used as general terminology for the section road controlled by a traffic signal controller that is configured for iTSP.

- **Dwell time:** Total time spent stopped within 30 meters of a bus stop. Not directly a measure of iTSP performance, but rather a factor subtracted out of some metrics in order to focus on travel time and travel speed.

- **Travel time:** Total time spent in a segment minus dwell time. Dwell time is outside the scope of what is being captured in terms of metrics for how fast the system can move buses through the corridor. Subtracting this out isolates the desired effect, and reduces noise in the data.

- **Travel speed**: Total distance traveled / travel time (MPH).

- **Intersection delay**: Total time spent stopped at a red light.

- **Lap:** A historical record of a bus's travel behavior through the iTSP pilot area.

- **Success rate**: The percentage of trips on a given segment where the bus was able to clear the intersection without stopping at a red light.