

STRENGTHENING MOBILITY AND REVOLUTIONIZING TRANSPORTATION (SMART)
GRANT PROGRAM
FY 2022 SMART GRANT RECIPIENT

Downtown Brockton Transportation Technology Project Final Implementation Report



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1.0 Executive Summary

The Downtown Brockton Transportation Technology Project was implemented as a Stage 1 proof of concept at six intersections along a 0.4-mile segment of Warren Avenue, including traffic signal management software, GPS-based emergency vehicle preemption (EVP) and transit signal priority (TSP), video detection and analytics, air-quality and pavement-temperature sensors, smart waste receptacles, and a smart city data platform.

The objective was to demonstrate how a modular, corridor-based traffic management and infrastructure monitoring system could improve the City's ability to operate, maintain, and evaluate the corridor. The project goals were to reduce congestion and delay; improve safety for pedestrians, bicyclists, transit users, emergency vehicles, and the traveling public; improve emergency response and transit travel-time reliability; support access to jobs and essential services; and improve City operations through centralized monitoring, remote signal management, and integrated infrastructure data.

Implementation was coordinated among the City of Brockton Department of Public Works, Brockton Fire Department, Brockton Area Transit Authority, CDM Smith as project engineer, K.R. Rezendes, Inc. as construction contractor, Ocean State Signal as the traffic signal technology supplier, and Quantela, Inc. as the connected-infrastructure and data-platform provider. This partnership established the system configurations, data connections, and operating experience needed for continued use and future expansion.

The evaluation demonstrated measurable operational benefits under the tested one-way southbound condition. Compared with the 100.7-second base condition, mean afternoon-peak southbound travel time decreased to 88.2 seconds with TSP, 48.0 seconds with optical EVP, and 39.3 seconds with GPS-based EVP. These reductions of 12, 52, and 61 percent exceeded the project's 10-percent travel-time improvement target for each tested mode. GPS-based EVP also performed approximately 18 percent faster than optical EVP.

The supporting technologies also produced positive results. Traffic volume and nitrogen dioxide concentration had a positive but modest correlation ($r = 0.23$ and $R^2 = 0.052$) across 96 hourly observations, meeting the project target. Nine of 10 smart waste receptacles met the fill-level accuracy target, while pavement-temperature readings differed from handheld measurements by an average of 0.5°F and a maximum of 0.7°F.

Building on the success of Stage 1, the City developed an at-scale concept that would expand the demonstrated technologies to 12 signalized intersections and five miles of the downtown network. The estimated \$4 million deployment would build on the approximately \$1.5 million Stage 1 investment and extend benefits in emergency response, transit reliability, signal operations, safety monitoring, winter maintenance, and data-driven public works.



2.0 Introduction and Project Overview

Downtown Brockton has undergone several major changes in traffic circulation over the past several decades. Prior to the 1970s, the downtown street network generally operated with two-way traffic. In 1974, the City converted the downtown network to a one-way street system, consistent with planning practices at the time. However, over time, the one-way network created operational, safety, and economic-development challenges as the system prioritized vehicle flow over local access, impacting downtown businesses.

The City has evaluated the feasibility of restoring two-way traffic in Downtown Brockton through several prior studies, including efforts completed in 1999, 2007, and most recently in 2020. These studies reflected a long-term policy direction to improve downtown circulation, calm traffic, support local access, and create a more multimodal street network. With the construction of a new Public Safety Complex that houses the City's Information Technology, Fire, Police, and Emergency Management departments under one roof at 135 Warren Avenue, Warren Avenue was identified as the first major step in this broader downtown conversion strategy.

Prior to reconstruction, Warren Avenue operated as a one-way southbound corridor paired with northbound Main Street. Construction began in 2025 to convert Warren Avenue back to two-way traffic and implement a more complete street design, including a roadway diet, new sidewalks and curb ramps, a raised cycle track, drainage improvements, lighting, and traffic signal improvements.

The Warren Avenue conversion provides the physical and operational foundation for the Downtown Brockton Transportation Technology Project. Because the corridor was already being reconstructed to two-way traffic, the City had an opportunity to modernize the traffic signal system and deploy new technologies at the same time. The SMART Grant project builds on the roadway reconstruction by adding intelligent sensor-based infrastructure, systems integration, and smart technology traffic signals. Together, the roadway reconstruction and SMART deployment are intended to support safer and more efficient movement through Downtown Brockton while creating a scalable model for future deployment throughout the downtown roadway network.

2.1 Project Description

The Downtown Brockton Transportation Technology Project focuses on the integration of smart technology traffic signals and intelligent sensor-based infrastructure. The intent of the project is to demonstrate how a modular, corridor-based traffic management and infrastructure monitoring system can improve the City's ability to operate, maintain, and evaluate a downtown transportation corridor, specifically while converting from one-way to two-way traffic. The Stage 1 proof-of-concept focused on implementing technologies along a 0.4-mile corridor along Warren Avenue, while at-scale expansion under a potential Stage 2 would implement the technologies to the rest of the downtown roadway network as future two-way conversion continues. The Stage 1 and Stage 2 project areas are shown in Figure 1 in green.



Source: CDM Smith
Figure 1 Project Area Map

2.2 Goals

The overall goals of the project are to reduce congestion and delay, improve safety for all road users, including pedestrians, bicyclists and transit users, increase the resiliency of the downtown transportation network, and improve emergency response. The City of Brockton also has the goal of

improving its overall operations by monitoring the physical and digital infrastructure and being able to remotely operate the traffic signals.

The specific project goals are categorized under the SMART program goal areas summarized in Table 1.

Table 1 SMART Program Goal Areas and Project Goals

Goal Area	Project Goal
Safety	Improve the safety and integration of transportation facilities and systems for pedestrians, bicyclists, transit users, emergency vehicles, and the broader traveling public by using video detection, multimodal analytics, and traffic signal performance data to better understand activity at signalized intersections.
Efficiency	Reduce congestion and delays for commerce and the traveling public by modernizing traffic signal operations, enabling centralized signal monitoring, supporting data-driven timing adjustments, improving travel-time reliability, and implementing GPS-based emergency vehicle preemption and transit signal priority.
Resiliency	Increase the resiliency and reliability of the downtown transportation system by collecting pavement-temperature data, monitoring corridor conditions, supporting winter maintenance decisions, and integrating infrastructure sensor data into a centralized monitoring platform.
Workforce Development	Improve access to jobs, education, health care, and other essential services by supporting more reliable traffic signal operations, improved transit travel time reliability, and more efficient movement through the downtown transportation network.
Partnerships	Strengthen partnerships among the Department of Public Works, Brockton Fire Department, Brockton Police Department, and Brockton Area Transit Authority to support coordinated deployment, operations, maintenance, and emergency response.
Integration	Promote connectivity between traffic signal systems, connected vehicles, roadway infrastructure, pedestrians, bicyclists, transit vehicles, emergency vehicles, environmental sensors, pavement-temperature sensors, smart waste receptacles, and smart city platforms through an integrated corridor-based deployment.

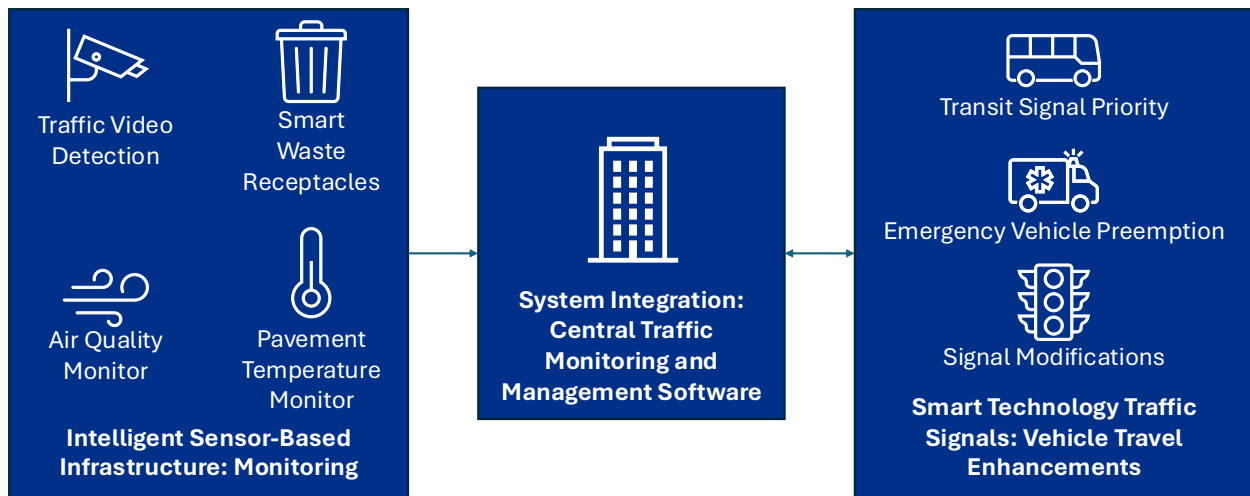
2.3 Technologies

To address the project goals, the following technologies were implemented as part of the project:

- **Traffic Signal Management Software** to remotely monitor, manage, and adjust traffic signal operations to reduce congestion and delays and improve the reliability of the downtown transportation network.
- **GPS-Based and Optical Emergency Vehicle Preemption** to improve emergency response through preferential signal phasing for authorized emergency vehicles.
- **Transit Signal Priority** to improve bus travel time reliability, reduce transit delay, and support access to jobs, education, health care, and other essential services.
- **Video Detection and Multimodal Traffic Analytics** to collect vehicle, pedestrian, and bicycle data and improve the safety and integration of transportation facilities for all roadway users.
- **Air-Quality Monitoring** to collect localized corridor-level data and evaluate relationships between traffic conditions, congestion, and air-quality patterns.

- **Pavement-Temperature Monitoring** to support winter maintenance operations, improve roadway condition awareness, and increase the resiliency of the transportation system.
- **Smart Waste Receptacles** to support data-driven collection schedules, reduce unnecessary maintenance trips, and improve the efficiency of public works operations.

Together, these technologies work to enable the City to both monitor and manage the traffic and roadway infrastructure, as seen in Figure 2.

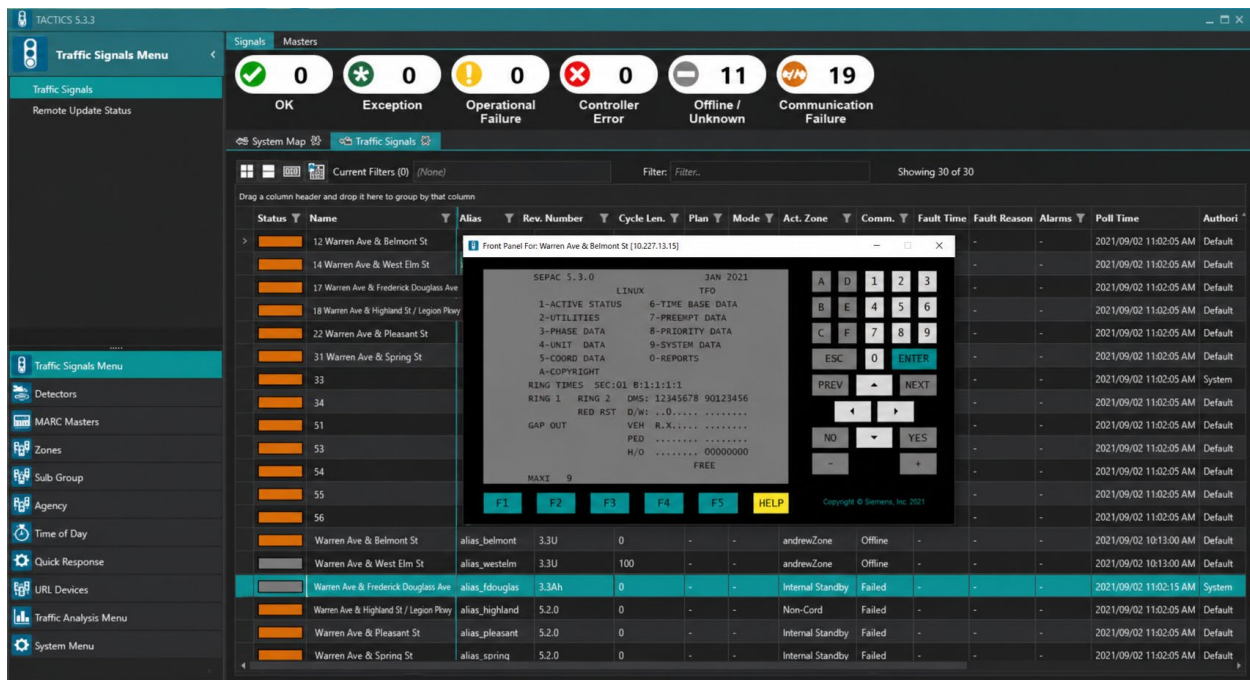


Source: CDM Smith

Figure 2 Downtown Brockton Transportation Technology System Architecture

2.3.1 Traffic Signal Management Software

At the heart of the Downtown Brockton Transportation Technology Project is the traffic signal management system, which is supported by Yunex TACTICS™. TACTICS is an advanced traffic management software platform that provides centralized traffic signal monitoring, remote management, controller communications, and automated traffic signal performance measure capabilities. TACTICS communicates with the Yunex M60 traffic signal controllers installed along Warren Avenue as part of the project and provides the City with a central interface to monitor signal operations along the corridor. The TACTICS interface is shown in Figure 3.



Source: CDM Smith

Figure 3 YuneX TACTICS Software

TACTICS is particularly important for evaluating the Warren Avenue conversion from one-way to two-way traffic. After conversion, traffic volumes, turning movements, pedestrian activity, queues, and signal progression patterns are expected to change as drivers adjust to the new street network. The software allows the City to monitor the operating status of each signal, review controller and video detection data, identify communications or equipment issues, and evaluate whether the initial signal timing plans are operating as intended. This information can be used to make timing adjustments during the initial post-conversion period, including modifications to cycle lengths, splits, offsets, phase sequencing, detection settings, coordination plans, and priority/preemption operations where appropriate.

TACTICS also supports future at-scale deployment by providing a common traffic signal management platform for additional downtown corridors. As the City continues converting other streets from one-way to two-way traffic and upgrades existing signalized locations across the city, the same central software environment can be used to monitor new operating conditions, compare performance across corridors, troubleshoot field equipment, and make data-informed adjustments to signal timing and coordination.

2.3.2 Video Detection and Multimodal Traffic Analytics

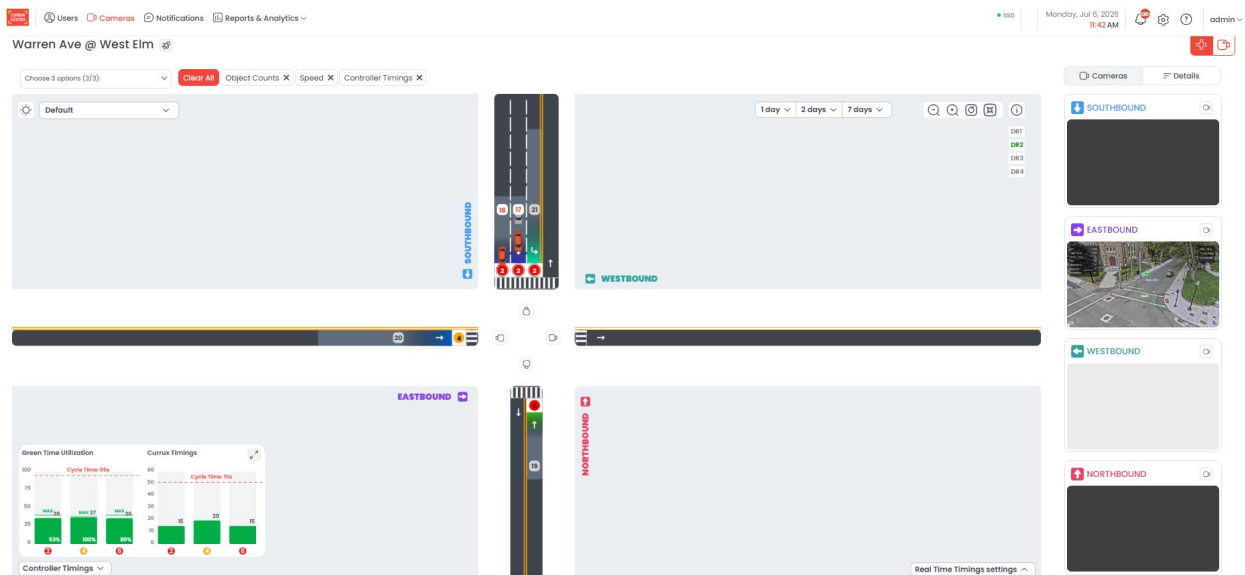
The video detection and traffic analytics component includes AXIS® panoramic cameras and Currux Vision video analytics. The AXIS cameras provide 360-degree intersection coverage and serve as the video source for both traffic signal detection and post-processing analytics. For the Warren Avenue deployment, eight AXIS panoramic cameras were installed at signalized intersections within the study area. An installed AXIS panoramic camera is shown in Figure 4.



Source: CDM Smith

Figure 4 AXIS Panoramic Camera installed at West Elm Street

Currux Vision processes the camera video streams to detect, classify, and count roadway users. The system can collect vehicle, pedestrian, and bicycle volumes, classify roadway users such as passenger vehicles, trucks, buses, motorcycles, bicyclists, and pedestrians, and report measures such as lane-by-lane counts, occupancy, speed, trajectory, and movement activity. These data can be reviewed by location, approach, movement, time period, or user type depending on the configured analytics outputs. The Currux Vision interface is shown in Figure 5.



Source: CDM Smith

Figure 5 Currux Vision Platform

This technology is particularly important for the Warren Avenue conversion from one-way to two-way traffic. After conversion, vehicle travel patterns, pedestrian activity, and bicycle activity are expected to change. The video analytics data allow the City to monitor these changing conditions, evaluate whether the new signal timing and detection configuration is operating as intended, and identify locations where additional signal timing, signing, pavement marking, or geometric adjustments may be warranted.

2.3.3 GPS-Based Emergency Vehicle Preemption and Transit Signal Priority

The GPS-based emergency vehicle preemption and transit signal priority component is supported by Applied Information's Glance® platform. Glance uses vehicle location, heading, speed, and communications data to generate preemption or priority requests at equipped traffic signals. Field Monitoring Units (FMUs) installed in the traffic signal cabinets provide the cabinet-level interface between the Glance platform and the traffic signal controllers. A Glance field monitoring unit is shown in Figure 6.



Source: CDM Smith

Figure 6 Applied Information Glance Field Monitoring Unit

Emergency vehicle preemption (EVP) was implemented for the Brockton Fire Department, which currently uses optical preemption at existing signalized intersections. Optical preemption relies on an emitter mounted on the emergency vehicle and a detector mounted at or near the traffic signal. Because the detector must receive the optical signal from the approaching vehicle, performance can be affected by line-of-sight limitations, detector orientation, weather, obstructions, intersection geometry, or distance from the signal.

GPS-based EVP addresses these limitations by using the vehicle's real-time location and approach information rather than requiring a direct optical path between the vehicle and the signal. Under a typical GPS-based EVP deployment, an on-board unit (OBU) installed on the emergency vehicle transmits the vehicle's location, heading, speed, and status to the Glance platform. Glance then determines whether the vehicle meets the configured preemption criteria for an equipped intersection and places the applicable preemption request through the Field Monitoring Unit in the traffic signal cabinet. For the Stage 1 deployment, permanent OBUs were procured but not yet installed permanently on municipally owned fleet vehicles. Instead, a portable OBU was used for testing to evaluate GPS-based preemption functionality along Warren Avenue. A portable on-board unit is shown in Figure 7.

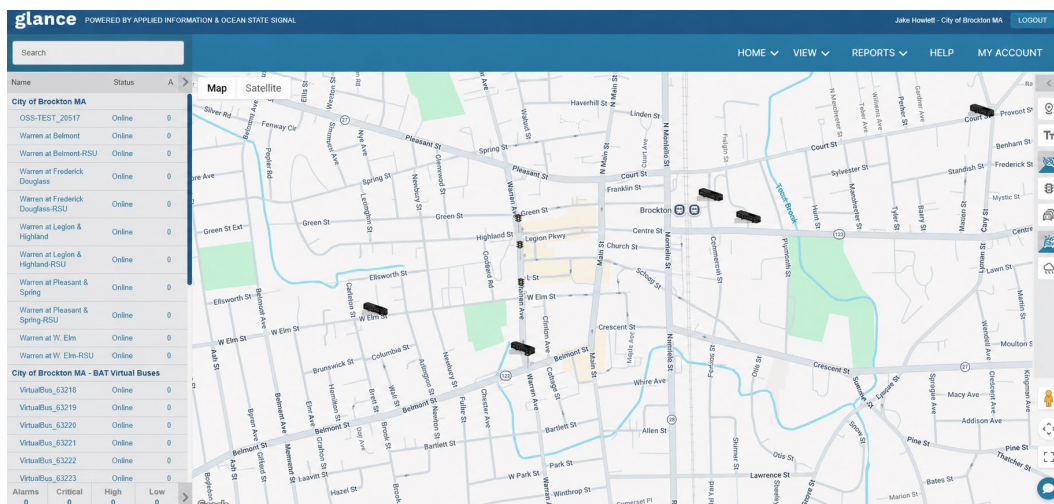


Source: CDM Smith

Figure 7 Applied Information Portable On-Board Unit

For Warren Avenue, GPS-based EVP was included to support Brockton Fire Department response through the corridor and improve emergency access to and from the newly constructed Public Safety Complex, which will house fire and police operations. The system can be configured by intersection approach and can generate a preemption request before the emergency vehicle reaches the intersection. This allows preemption to be requested farther upstream than traditional optical preemption.

Transit signal priority (TSP) was also implemented through the Glance platform in coordination with Brockton Area Transit Authority for buses operating along Warren Avenue. BAT uses GPS-based fleet monitoring for its buses. For the Stage 1 deployment, BAT provided a live data feed through a REST API to transmit bus location and operating data to Glance. The initial TSP data feed focused on the core data elements needed to identify and track approaching buses: vehicle ID, latitude/longitude, speed, and heading. The Glance interface with BAT bus locations is shown in Figure 8.



Source: CDM Smith

Figure 8 Applied Information Glance Platform with BAT Bus Locations

Unlike EVP, which can interrupt or modify normal signal operations for emergency response, TSP provides conditional priority for transit vehicles while maintaining normal signal coordination to the extent practicable. Depending on the signal timing configuration, TSP may reduce bus delay by extending green time for an arriving bus (i.e., green extension), terminating a conflicting phase early (i.e., red truncation), or modifying phase service within the limits of the timing plan (i.e., phase rotation). For the purposes of Stage 1 deployment, green extension was the only TSP methodology used.

2.3.4 Connected Infrastructure

The connected infrastructure component of the project includes TELLUS AirU Pro air-quality sensors, Apogee Instruments infrared radiometers for pavement-temperature monitoring, and Victor Stanley Relay® smart waste receptacles. These devices were deployed to collect various types of data along the Warren Avenue corridor and provide the City with additional operational information for roadway maintenance and public works decision-making. An installed air-quality and pavement-temperature sensor assembly is shown in Figure 9.



Source: CDM Smith

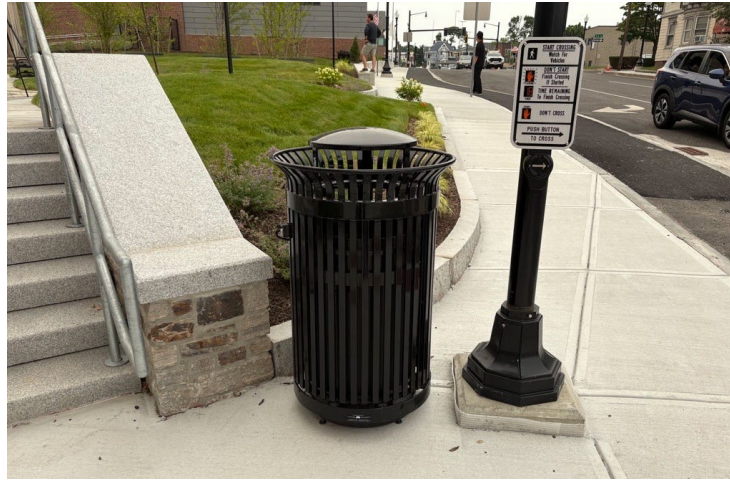
Figure 9 Air Quality & Pavement Temperature Sensor

Seven TELLUS AirU Pro sensors were installed along Warren Avenue to collect localized air-quality and environmental data. The AirU Pro sensors measure particulate matter, gases, temperature and humidity data in real time. For the Stage 1 deployment, the sensors were used to collect corridor-level air-quality readings that can be reviewed by location and time period and compared with traffic conditions. It is important to note that these sensors are used for localized monitoring and operational analysis and are not intended to replace regulatory air-quality monitoring stations or support regulatory air-quality determinations.

Apogee Instruments infrared radiometers were installed to collect pavement surface temperature data. The sensors provide non-contact surface temperature measurements by measuring infrared radiation emitted from the pavement surface. Pavement temperature is a key input for winter maintenance because roadway treatment decisions are based on pavement conditions rather than air temperature.

alone. The data can support pretreatment, salting, plowing, and post-storm monitoring decisions and can help the City evaluate how pavement conditions vary by location, time of day, and weather condition.

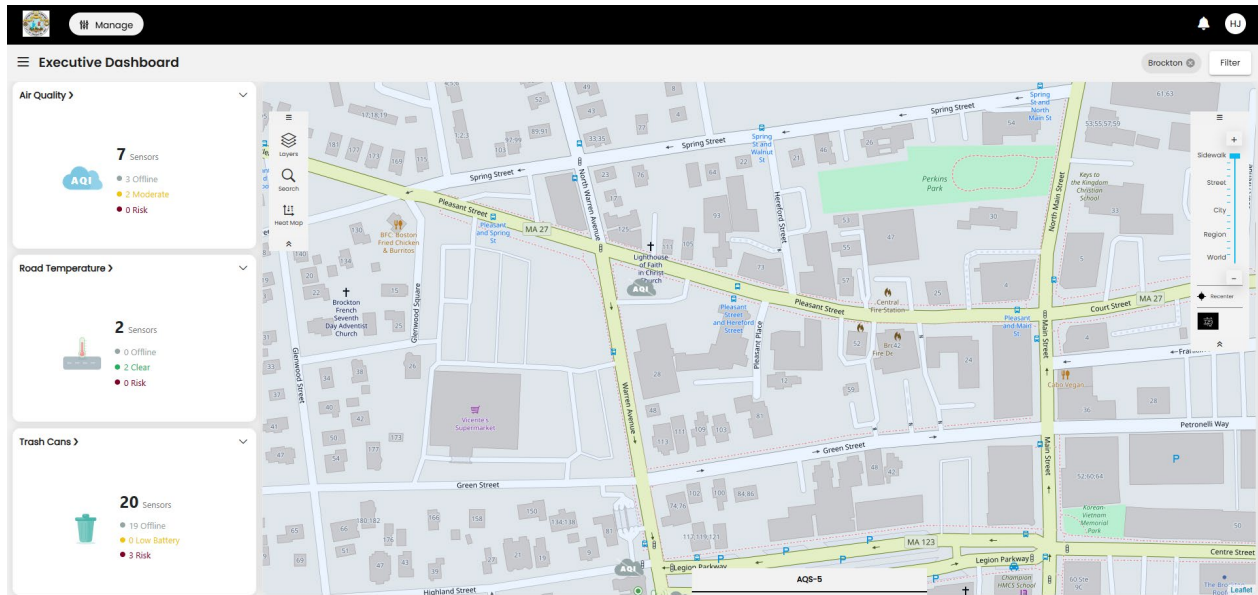
Victor Stanley Relay smart waste receptacles were installed to collect fill-level and related operational data for public works operations. The Relay system monitors receptacle conditions so that collection needs can be evaluated based on observed fill levels rather than fixed collection schedules. These data can help identify receptacles that are approaching capacity, underutilized receptacles, and locations where collection frequency may need to be adjusted. An installed smart waste receptacle is shown in Figure 10.



Source: CDM Smith

Figure 10 Smart Waste Receptacle Installed Along Warren Avenue

The sensor data are incorporated into a single smart city platform developed by Quantela. The Quantela platform allows the City to view real-time and historical sensor data from the connected infrastructure devices in one location. This provides a common interface for reviewing air-quality readings, pavement-temperature data, and smart waste receptacle status, rather than requiring each technology to be evaluated only through separate vendor systems. The platform supports corridor-level monitoring, trend analysis, and comparison of sensor data by location and time period. The integrated Quantela dashboard is shown in Figure 11.



Source: CDM Smith
Figure 11 Quantela Platform

2.4 Stage 1 Deployment Activities Summary

The Stage 1 proof-of-concept deployment was implemented through coordination among the City of Brockton, CDM Smith, Ocean State Signal, Quantela, and the Warren Avenue reconstruction contractor (K.R. Rezendes). The City of Brockton served as the SMART Grant recipient and project owner. CDM Smith served as the project engineer and was also the designer for the Warren Avenue Two-Way Reconstruction project. Because the SMART deployment was tied directly to the roadway reconstruction, CDM Smith incorporated the smart signal and sensor-based infrastructure elements into the roadway construction plans and specifications.

Ocean State Signal served as the traffic signal technology supplier and provided the smart traffic signal equipment, including the Yunex M60 controllers, Yunex TACTICS traffic signal management software, Applied Information Glance Field Monitoring Units, video detection equipment, and related signal system components. Quantela provided the sensor-based infrastructure components and developed the platform. The construction contractor installed the field infrastructure and physical components necessary to support the SMART deployment, including signal equipment, poles, mast arms, conduit, wiring, cabinets, mounting infrastructure, and sensors.

The project schedule was affected by delays associated with the Warren Avenue reconstruction, including delays in private electrical utility work required to provide power to portions of the corridor, traffic signal equipment delivery and installation delays, mast arm delivery delays, and roadway construction delays caused by inclement weather. Because of these delays, the City requested and received schedule extensions to allow the proof-of-concept deployment to be completed and evaluated. The extension requests did not alter the originally proposed scope of work, but rather they were requested to accommodate construction-related delays and preserve the ability to conduct a meaningful evaluation of the SMART Grant components.

The pedestrian push-button behavior evaluation at signalized crossings initially planned was not completed because critical pedestrian infrastructure, including the final sidewalk network and marked crosswalks, remained incomplete. These temporary construction conditions created an unsafe and nonrepresentative environment for collecting pedestrian behavior data.

3.0 Proof-of-Concept Evaluation Findings

Due to unanticipated construction delays, the various components of the project were tested under one-way traffic operation, as roadway construction had not advanced to two-way operation during the period of performance. Despite this limitation, the testing occurred in May of 2026 and yielded promising results for the implemented technologies.

As defined in the project's Evaluation Plan, five key performance measures were developed to evaluate the key technologies implemented under the project. The evaluation questions, performance measures, and targets are summarized in Table 2.

Table 2 Performance Measures

Evaluation Question	Performance Measure	Performance Measure Target
How well does emergency vehicle and transit GPS preemption work within the system compared to traditional optical preemption?	Distance for preemption activation; travel times through corridor during peak hour traffic	Distance to activate GPS preemption is increased by at least 10% compared with traditional optical preemption; travel times decrease by 10%
Do computer vision models analyze vulnerable user behavior at signalized intersections?	How often do pedestrians use push button and wait for walk phase; how often do pedestrians use push button and not wait for walk phase; how often do pedestrians not use push button	85% accuracy rate (computer vision model vs manual verification)
Is there an apparent correlation between air quality and traffic patterns?	Correlation coefficient (r)	Correlation coefficient, $r > 0$
How well do self-monitoring waste receptacles perform?	Accuracy of fill rates	Fill rates are 90% accurate (visually confirm and record with photographs)
How well do pavement temperature sensors perform?	Accuracy of pavement temperature; accuracy of ambient temperature	95% accuracy (measure using infrared thermometer)

3.1 Emergency Vehicle Preemption and Transit Signal Priority

How well does emergency vehicle and transit GPS preemption work within the system compared to traditional optical preemption?

Travel-time testing was conducted during the afternoon peak period to evaluate the operational effect of emergency vehicle preemption (EVP) and transit signal priority (TSP) along Warren Avenue. The test compared four operating conditions: base conditions, traditional optical EVP, GPS-based EVP, and GPS-based TSP. Base condition travel times were recorded in a regular passenger vehicle operating without preemption or priority. Optical EVP testing was conducted using the Brockton Fire Department's existing optical preemption system. GPS-based EVP and TSP testing were conducted in a passenger car using a portable On-Board Unit (OBU) to transmit vehicle location and approach information to the Applied Information Glance platform.

Travel-time runs were recorded along Warren Avenue between a point just south of Legion Parkway and Belmont Street, a distance of approximately 0.25 miles, as shown in Figure 12. Due to ongoing

construction activity, Warren Avenue had not yet been opened to two-way traffic during the testing period. Therefore, all travel-time runs were conducted in the existing one-way southbound direction.



Source: CDM Smith

Figure 12 Travel Time Study Limits

Three travel-time runs were recorded for each condition, except for optical EVP. Only two optical EVP runs were completed because the fire emergency vehicle was not available for a third test run. All travel-time runs were conducted during the afternoon peak period to provide a consistent testing window.

Figure 13 summarizes the mean travel time for each tested operating mode. The mean base travel time was 100.7 seconds. All preemption and priority modes reduced travel times compared to the base condition.

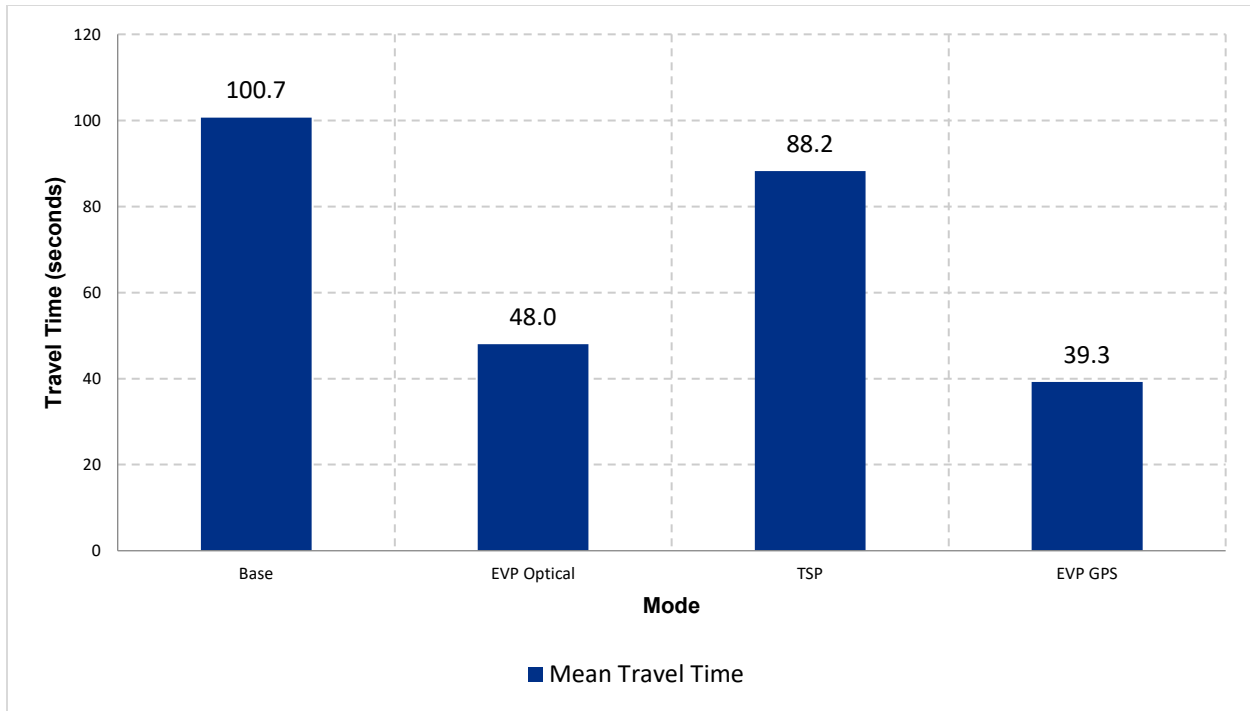


Figure 13 Southbound PM Peak Travel Times

GPS-based EVP produced the lowest mean travel time, with an average travel time of 39.3 seconds. This represents a travel-time savings of 61.4 seconds, or a 61 percent decrease compared to the base condition. Optical EVP also produced a substantial improvement, with an average travel time of 48.0 seconds, representing a savings of 52.7 seconds and a 52 percent decrease compared to the base condition. TSP resulted in an average travel time of 88.2 seconds, representing a savings of 12.5 seconds and a 12 percent decrease compared to the base condition.

GPS-based EVP also outperformed optical EVP in the direct comparison between preemption technologies. The mean GPS-based EVP travel time was 8.7 seconds faster than the mean optical EVP travel time, representing an approximate 18 percent reduction compared to optical EVP. Under the tested conditions, GPS-based EVP provided an additional travel-time benefit beyond the City's existing optical preemption system.

This difference is consistent with the primary operational limitation of optical EVP. Optical EVP is limited by line of sight between the vehicle-mounted emitter and the detector mounted at or near the traffic signal. During field testing, the southbound distance at which the optical preemption request was recognized by the controller varied by intersection. These distances were measured by identifying the point at which the optical preemption request was recognized by the controller and recording the emergency vehicle location at that moment. The maximum observed optical detection distances are summarized in Table 3.

Table 3 Southbound Optical EVP Detection Distances

Intersection	Maximum Observed Optical Detection Distance
Frederick Douglass Avenue	350 ft
West Elm Street	700 ft
Belmont Street	330 ft

The observed optical detection distances show that optical EVP performance varied by intersection and was constrained by field conditions, including line of sight, detector placement, roadway geometry, and the position of the emergency vehicle. By contrast, GPS-based EVP is not constrained by a direct optical path between the vehicle and the signal. In the Glance platform, preemption request zones are established using geofences and configurable approach parameters. As a result, GPS-based preemption can be configured to place requests farther upstream than the observed optical detection points, giving the signal system more time to transition to the desired phase before the emergency vehicle reaches the intersection.

The evaluation performance target for EVP/TSP testing was that GPS preemption activation distance would increase by at least 10 percent compared to traditional optical preemption and that travel times would decrease by at least 10 percent compared to base conditions. The travel-time component of the target was met for all tested priority and preemption modes. Optical EVP reduced travel time by 52 percent, TSP reduced travel time by 12 percent, and GPS-based EVP reduced travel time by 61 percent compared to base conditions. GPS-based EVP also reduced travel time by approximately 18 percent compared to optical EVP.

The activation-distance component of the target should be interpreted based on the difference between the optical detection range and the configurable GPS geofence. Based on the observed optical detection distances, a 10 percent increase over optical detection would require GPS activation distances greater than approximately 385 feet at Frederick Douglass Avenue, 770 feet at West Elm Street, and 363 feet at Belmont Street. Because GPS-based EVP requests are generated through configurable geofences in Glance rather than optical line-of-sight detection, the system is capable of exceeding these thresholds where the geofence is configured upstream of the optical detection distance.

The results indicate that both emergency vehicle preemption and transit signal priority can reduce travel time along the Warren Avenue corridor under the tested one-way southbound condition. GPS-based EVP produced the greatest travel-time reduction, which is consistent with the technical advantage of GPS-based preemption: request zones can be configured in software and are not limited to optical detection range. TSP also reduced travel time compared to base conditions, though the reduction was lower than EVP because TSP is designed to provide conditional priority while maintaining normal signal operations to the extent practicable.

3.2 Vulnerable User Behavior

Do machine-learning algorithms analyze vulnerable user behavior at signalized intersections?

The intended evaluation method was to use the AXIS panoramic cameras to record pedestrian activity at signalized intersections along Warren Avenue and apply a computer vision model to detect pedestrians

and pedestrian crossing movements. The video-based detections were intended to be compared with high-resolution event logs from the Yunex M60 traffic signal controllers. By matching pedestrian detections from the video analytics with controller events, the City intended to evaluate pedestrian push-button use, pedestrian phase activation, and observed crossing behavior.

The analysis was intended to classify pedestrian behavior into several operational categories. A compliant pedestrian crossing would be identified when the controller log showed a push-button actuation, the pedestrian phase was served, and the video showed a pedestrian entering the crosswalk during the pedestrian phase. A non-compliant pedestrian crossing would be identified when the video showed a pedestrian entering the crosswalk while the pedestrian phase was not active or when a pedestrian crossed without a corresponding push-button actuation.

This evaluation was not completed during Stage 1 due to active construction along Warren Avenue. The corridor had not yet been opened to final two-way operation, and sidewalk, curb ramp, crosswalk, and pedestrian routing conditions were not representative of the completed project, making the crossings unsafe for pedestrians. Conducting the analysis under temporary construction conditions would not have provided reliable or transferable results for final corridor operations. For this reason, pedestrian push-button behavior and vulnerable user compliance analysis were removed from the Stage 1 evaluation scope.

3.3 Air Quality and Traffic Patterns

Is there an apparent correlation between air quality and traffic patterns?

The performance measure was the correlation coefficient between hourly traffic volume and measured nitrogen dioxide (NO₂) concentration, with a target of $r > 0$. NO₂ was selected for this analysis because it is associated with fuel combustion and can be evaluated against traffic activity at the corridor level.

The analysis used hourly NO₂ readings and hourly traffic volumes collected over the course of one week in May of 2026. The dataset included 96 hourly observations. During the monitoring period, Warren Avenue remained under active construction and had not yet opened to final two-way traffic operations. Therefore, the results reflect construction-period operating conditions and should not be interpreted as final post-construction corridor air-quality conditions.

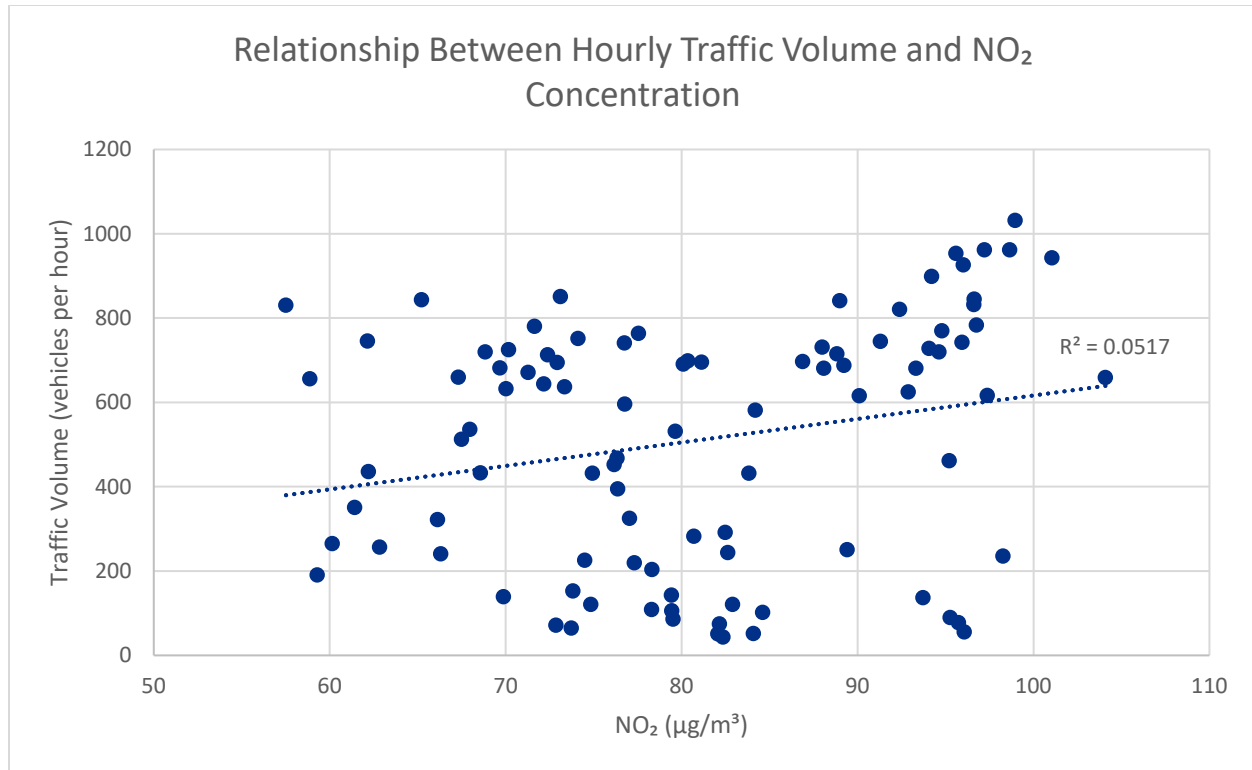


Figure 14 Relationship Between Hourly Traffic Volume and NO₂ Concentration

Figure 14 shows the relationship between hourly traffic volume and NO₂ concentration. The correlation between hourly traffic volume and NO₂ concentration was positive, with a correlation coefficient of $r = 0.23$. This meets the performance target of $r > 0$ and indicates that higher traffic volumes were generally associated with higher NO₂ concentrations during the analysis period. The coefficient of determination was $R^2 = 0.052$, meaning hourly traffic volume alone explained approximately 5.2 percent of the variation in NO₂. This indicates a positive but modest relationship. The key correlation statistics are summarized in Table 4.

Table 4 Air Quality Correlation Results

Metric	Result	Interpretation
Correlation coefficient, r	0.23	Positive relationship between hourly volume and NO ₂
Coefficient of determination, R^2	0.052	Hourly volume explained approximately 5.2% of NO ₂ variation

The measured NO₂ values were also compared to federal NO₂ air-quality standards for context. However, this is a screening-level comparison only as the Warren Avenue sensors are localized corridor sensors, the dataset represents only four days of monitoring, and the federal standards are based on specific regulatory monitoring methods and averaging forms. As a result, the comparison **should not be interpreted** as a formal National Ambient Air Quality Standards compliance determination. The screening-level comparison is presented in Table 5.

Table 5 Comparison with Federal NO₂ Standards

Federal NO ₂ Standard	EPA Standard Level	Warren Measured Level
1-hour NO ₂	188 µg/m ³	104.1 µg/m ³ (maximum)
Annual NO ₂	100 µg/m ³	81.0 µg/m ³ (four-day average)

The maximum observed hourly NO₂ concentration was 104.1 µg/m³, which is below the federal 1-hour NO₂ standard level of 188 µg/m³. The four-day average NO₂ concentration was 81.0 µg/m³, which is also below the federal annual standard level. These comparisons are provided only for context because a four-day dataset cannot be used to determine annual air-quality compliance.

The time-of-day results provide additional context. The PM peak period had the highest average traffic volume and the highest average NO₂ concentration among the major daily analysis periods. From 3:00 PM to 6:00 PM, average traffic volume was 827 vehicles per hour and average NO₂ concentration was 85.8 µg/m³. This supports the finding that higher traffic activity corresponded with higher measured NO₂ during the monitoring period. The time-of-day results are summarized in Table 6.

Table 6 Air Quality and Traffic Volume by Time Period

Time Period	Average NO ₂ (µg/m ³)	Average Volume (veh/hr)
Overnight (12 AM–5 AM)	82.7	128
AM Period (6 AM–9 AM)	75.3	529
Midday (10 AM–2 PM)	83.9	735
PM Peak (3 PM–6 PM)	85.8	827
Evening (7 PM–11 PM)	76.7	478

The comparison between higher-volume and lower-volume hours also indicates higher NO₂ concentrations during heavier traffic conditions. Hours with volumes of 700 vehicles per hour or greater had an average NO₂ concentration of 85.7 µg/m³, compared with 78.9 µg/m³ during hours below 700 vehicles per hour. This represents an average increase of approximately 6.8 µg/m³ during higher-volume conditions. The higher-volume and lower-volume comparison is summarized in Table 7.

Table 7 Air Quality by Traffic Volume Group

Traffic Volume Group	Number of Hours	Average Volume (veh/hr)	Average NO ₂ (µg/m ³)
Lower-volume hours (<700 veh/hr)	66	373	78.9
High-volume hours (≥700 veh/hr)	30	814	85.7

The modest R² value indicates that air quality was influenced by factors beyond hourly traffic volume. Localized NO₂ concentrations may also be affected by background pollutant levels, wind speed and direction, temperature, humidity, atmospheric mixing, nearby construction activity, construction equipment, temporary traffic control conditions, idling, queueing, and sensor placement. This is particularly important for the Stage 1 evaluation because data were collected while Warren Avenue was still under construction. Construction activity has affected traffic patterns, localized emissions, and measured air-quality conditions.

Average daily NO₂ concentrations also varied substantially by date, even when average daily traffic volumes were similar. For example, June 4 had an average NO₂ concentration of 92.9 µg/m³ with an average volume of 538 vehicles per hour, while June 6 had an average NO₂ concentration of 69.5 µg/m³ with a similar average volume of 525 vehicles per hour. This variation reinforces that traffic volume was not the only factor affecting measured NO₂ concentrations during the monitoring period.

The proof-of-concept demonstrated that localized air-quality sensor data can be compared with traffic volume data to evaluate corridor operating conditions. The performance target was met because the observed correlation between traffic volume and NO₂ was positive. However, the low R² value shows that traffic volume alone was not a strong predictor of NO₂ during the short construction-period dataset. Future analysis should include a longer monitoring period, final two-way traffic operations, multiple sensor locations, weather data, construction activity documentation, and additional traffic performance measures such as speed, delay, queueing, and idling to better isolate the relationship between traffic operations and localized air-quality conditions.

3.4 Smart Waste Receptacles

How well do self-monitoring waste receptacles perform?

The project performance target was 90 percent accuracy for reported fill levels by the Victor Stanley Relay receptacles. Ten receptacles were installed within the project area and available for field evaluation during Stage 1 due to ongoing construction activities.

Field validation was conducted by visiting each of the 10 installed receptacles and comparing the observed fill level with the corresponding fill level reported through the connected platform. The contents of each receptacle were visually inspected in the field and the estimated fill level was recorded. Because the fill level was estimated visually, observations were recorded in 25-percent increments of 0, 25, 50, 75, or 100 percent. The platform reported fill levels as a more precise percentage, so some difference between the field observation and platform reading was expected. The field-observed and sensor-reported fill levels are compared in Table 8.

Table 8 Smart Waste Receptacle Fill-Level Validation

Location	Field-Observed Fill Level	Sensor Fill Level	Absolute Difference
Warren at West Elm #1	25%	25%	0%
Warren at West Elm #2	50%	46%	4%
Warren at Frederick Douglass	0%	0%	0%
Highland	25%	21%	4%
Warren at Green	25%	14%	11%
Warren at Highland	50%	37%	13%
Warren at Legion #1	0%	0%	0%
Warren at Legion #2	50%	53%	3%
Public Safety Complex #1	0%	0%	0%
Public Safety Complex #2	75%	83%	8%

Overall, the sensor-reported fill levels closely matched the conditions observed in the field. The average difference between the field observations and platform readings was approximately 4 percentage points, and 8 of the 10 readings were within 10 percentage points of the visually estimated fill level. When the platform readings were considered relative to the 25-percent increments used during the field inspection, 9 of the 10 receptacles were consistent with the observed fill-level category, meeting the project's 90 percent accuracy target.

The small differences between the platform and field observations are reasonable given that the field measurements were visual estimates rather than exact measurements. For example, a receptacle recorded as 50 percent full in the field could reasonably have been somewhat above or below that value, while the sensor provided a more specific percentage.

The results indicate that the smart receptacles provided fill-level data that were representative of actual field conditions. This supports their intended use as a tool for monitoring receptacle capacity and helping the City identify when collection may be needed without requiring staff to inspect each receptacle individually.

3.5 Pavement Temperature Sensors

How well do pavement temperature sensors perform?

The evaluation question for this proof-of-concept was whether pavement-temperature sensors could provide reliable surface temperature data to support roadway operations and maintenance. Two pavement-temperature sensors were installed along Warren Avenue: one near Belmont Street and one near Legion Parkway/Highland Street. The sensors were Apogee Instruments infrared radiometers, which measure pavement surface temperature without direct contact.

The field validation process compared sensor-reported pavement surface temperatures to spot measurements collected with a handheld infrared thermometer gun. Measurements were collected over a two-day period at different times of day to capture changing pavement temperature conditions. At each location and time period, three handheld infrared thermometer readings were taken from the pavement surface and averaged. The average handheld reading was then compared to the corresponding surface temperature reported by the pavement-temperature sensor. The individual validation measurements are presented in Table 9.

Table 9 Pavement Temperature Sensor Validation Measurements

Location	Time	Handheld Measure 1 (°F)	Handheld Measure 2 (°F)	Handheld Measure 3 (°F)	Handheld Average (°F)	Sensor Reading (°F)	Difference: Sensor - Handheld Average (°F)
Belmont Street	9:00 AM	75.6	74.8	74.8	75.1	75.5	0.4
Belmont Street	3:00 PM	78.0	78.6	79.1	78.6	79.0	0.4
Legion Parkway/Highland Street	10:00 AM	76.2	76.8	76.0	76.3	77.0	0.7

Location	Time	Handheld Measure 1 (°F)	Handheld Measure 2 (°F)	Handheld Measure 3 (°F)	Handheld Average (°F)	Sensor Reading (°F)	Difference: Sensor - Handheld Average (°F)
Legion Parkway/Highland Street	4:00 PM	77.8	77.8	77.0	77.5	78.0	0.5

The pavement-temperature sensors closely matched the handheld infrared thermometer readings at both locations. Across the four validation checks, the sensor readings were between 0.4°F and 0.7°F higher than the average handheld measurements. The average absolute difference was approximately 0.5°F, and the maximum observed difference was approximately 0.7°F. This indicates strong agreement between the installed sensors and the independent field measurements. The validation statistics are summarized in Table 10.

Table 10 Pavement Temperature Validation Summary

Metric	Result
Number of validation comparisons	4
Average handheld pavement temperature	76.9°F
Average sensor-reported pavement temperature	77.4°F
Average difference: Sensor - handheld average	+0.5°F
Average absolute difference	0.5°F
Maximum absolute difference	0.7°F

The results indicate that the pavement-temperature sensors were reporting surface temperatures consistent with independent field measurements during the validation period. The sensors showed a slight warm bias compared to the handheld infrared thermometer, but the difference was small and consistent across both locations and both time periods. This level of agreement is appropriate for a proof-of-concept field validation and supports the use of the sensors for operational awareness.

The pavement-temperature data are intended to support winter maintenance and roadway condition monitoring. Surface temperature is an important operational measure because pavement temperature can differ from ambient air temperature and can influence decisions related to pretreatment, salting, plowing, and post-storm monitoring. By providing continuous, location-specific pavement temperature data, the sensors can improve the City's ability to monitor corridor conditions and make more informed maintenance decisions.

The proof-of-concept demonstrated that the installed pavement-temperature sensors provided reliable corridor-level pavement surface temperature data during the validation period. The sensors closely matched independent handheld infrared measurements, with all four comparisons differing by less than 1 degree, meeting the 95 percent accuracy target. The sensors provide a practical data source for winter operations, maintenance planning, and transportation system resiliency.

4.0 Anticipated Costs and Benefits of At-Scale Implementation

The Stage 1 deployment provided a proof-of-concept for integrating smart traffic signal technology, emergency vehicle preemption, transit signal priority, multimodal video analytics, air-quality monitoring, pavement-temperature monitoring, and smart waste collection along Warren Avenue. The at-scale deployment would extend the Stage 1 technology beyond Warren Avenue to the broader downtown street network, which includes 12 intersections that operate using signal equipment similar to the Warren Avenue base condition. The expanded network would include the major downtown north-south corridors of Main Street, Montello Street, and Commercial Street, along with the signalized cross streets and connecting roadways that intersect with those corridors. This approach would allow the City to move from a single-corridor pilot to a connected downtown traffic management network that supports signal operations, emergency response, transit priority, multimodal monitoring, and infrastructure sensor data across the core downtown area. The Stage 1 and planning-level at-scale deployments are compared in Table 11.

Table 11 Stage 1 and At-Scale Deployment Comparison

Item	Stage 1 Deployment	At-Scale Deployment
Signalized intersections	6	12
Roadway coverage	Approximately 0.4 miles	Approximately 5 miles
Stage 1 / planning-level cost	Approximately \$1.5 million	Approximately \$4 million
Primary systems	Signal management, EVP, TSP, video analytics, air-quality sensors, pavement-temperature sensors, smart waste receptacles	Expanded downtown network deployment of applicable Stage 1 systems

At-scale implementation would require a larger investment than the Stage 1 pilot because the deployment would extend the technology to additional signalized intersections and install smart waste receptacles throughout a larger portion of the downtown network. For planning purposes, the at-scale deployment is estimated to cost approximately \$4 million.

The planning-level estimate was developed using actual Stage 1 equipment costs as the basis for future deployment. The Stage 1 signal and technology equipment cost approximately \$1.22 million across five signalized locations, resulting in an average cost of approximately \$244,000 per location. This unit cost was escalated at an assumed annual inflation rate of 3 percent from 2024 to an anticipated 2028 implementation year, resulting in an estimated cost of approximately \$275,000 per location. Applying this cost to 12 signalized locations results in approximately \$3.3 million in signal and technology equipment costs.

Smart waste receptacles were estimated separately based on the Stage 1 unit cost of approximately \$3,000 per receptacle. After applying the same 3 percent annual escalation through 2028, the estimated unit cost is approximately \$3,400 per receptacle. Assuming approximately 200 receptacles for an at-

scale downtown deployment results in an additional cost of approximately \$675,000. Combined, the estimated signal technology and smart waste receptacle costs total approximately \$4.0 million.

The anticipated benefits of at-scale implementation would extend the alignment of the goals across the City's transportation operations, emergency response, transit operations, public works, and data management functions. The anticipated benefits are summarized by SMART goal area in Table 12.

Table 12 Anticipated At-Scale Benefits by Goal Area

Goal Area	Anticipated At-Scale Benefit
Safety	Expanded video analytics and signal monitoring would improve the City's ability to observe pedestrian, bicycle, and vehicle activity at signalized intersections and identify locations where timing, detection, signing, markings, or geometric adjustments may be needed.
Efficiency	GPS-based EVP, TSP, centralized signal monitoring, and ATSPM would support reduced delay, improved travel-time reliability, faster identification of signal issues, and more data-driven signal timing adjustments.
Resiliency	Pavement-temperature sensors and centralized monitoring would improve roadway condition awareness during winter events and support more targeted maintenance responses.
Workforce Development	The deployment would increase City staff experience with traffic signal management software, connected infrastructure, sensor data, analytics, and multi-system operations.
Partnerships	At-scale implementation would continue coordination among the City, Brockton Fire Department, Brockton Area Transit Authority, traffic signal vendors, technology providers, and engineering support staff.
Integration	The deployment would expand integration across signal systems, EVP/TSP, video analytics, environmental sensors, pavement-temperature sensors, and smart city data platforms.

The Stage 1 evaluation indicates that the technologies have potential operational value if deployed at scale. Under the tested one-way southbound condition at six intersections, GPS-based EVP reduced mean travel time by 61 percent compared to base conditions, optical EVP reduced mean travel time by 52 percent, and TSP reduced mean travel time by 12 percent. GPS-based EVP also reduced mean travel time by approximately 18 percent compared to optical EVP. These results indicate that expanding GPS-based EVP and TSP to additional intersections across Main Street, Montello Street, Commercial Street, and connecting downtown roadways can improve emergency response and transit travel times and reliability across a broader downtown network.

The at-scale benefit-cost comparison should be interpreted qualitatively at this stage, with an expected positive ratio given the widescale operations and safety impact the technology has on all road travelers in the City. Stage 1 demonstrated measurable travel-time benefits and confirmed that traffic, environmental, and infrastructure data can be collected and compared through a corridor-based deployment.



5.0 Challenges and Lessons Learned

The primary challenge during Stage 1 was the dependency between the SMART technology deployment and the Warren Avenue two-way reconstruction schedule. The signal systems, cameras, sensors, communications equipment, and connected infrastructure were coordinated with the roadway construction project so they could be installed as part of the final corridor buildout. However, delays in construction sequencing, utility coordination, traffic signal installation, mast arm installation, power service, and weather-sensitive work affected the technology installation schedule and reduced the time available for testing and evaluation.

Because Warren Avenue had not opened to final two-way traffic operations by the end of the Stage 1 period, some evaluation activities had to be modified. Travel-time testing was completed under the existing one-way southbound condition, rather than under final two-way operations. The vulnerable user behavior analysis was not completed because sidewalk, curb ramp, crosswalk, and pedestrian routing conditions were still affected by construction and were not representative of final conditions.

The key lesson learned is that future smart technology deployments should not be fully dependent on the schedule of a separate roadway reconstruction project. Where possible, the preferred approach would be to complete roadway construction first, allow the corridor to operate under its permanent traffic pattern, and then retrofit or install the smart signal equipment, sensors, cameras, and communications systems. This approach would reduce schedule risk, provide more representative operating conditions, and allow the evaluation to measure actual post-construction performance.

If technology installation must occur during roadway construction, the project should include a contingency testing plan. The plan should identify which components can be bench tested, field tested, or functionally verified before the roadway is complete, such as controller communications, camera feeds, sensor data transmission, dashboard functionality, and GPS-based preemption logic.

Stage 1 also showed the importance of treating technology readiness and corridor readiness as separate milestones. A system may be installed, communicating, and functionally operational before the roadway is ready for full evaluation. Future deployments should define those milestones separately and provide enough time after construction for traffic patterns, pedestrian activity, transit operations, and signal performance to stabilize before final evaluation.



6.0 Deployment Readiness

The Stage 1 project demonstrated that the core technology systems are feasible for continued use and future deployment in downtown Brockton. The City established an integrated system for traffic signal management, vehicle priority, video analytics, connected infrastructure monitoring, and data management. Stage 1 also established the initial procedures, system configurations, partnerships, and operational experience needed to support continued use and future expansion.

Several elements of long-term operational readiness were initiated during Stage 1. City staff and project partners participated in installation, configuration, testing, and evaluation of the traffic signal and connected infrastructure systems. This provided hands-on experience with system operation and coordination among the Brockton Department of Public Works, Brockton Fire Department, Brockton Area Transit Authority, technology vendors, and engineering support staff. As the systems continue to be used, these practices can be further refined and documented as standard operating procedures.

Training and knowledge transfer will remain an important part of continued operation. Stage 1 demonstrated the feasibility of using GPS-based emergency vehicle preemption and the Glance system. Future training can build on this experience by formalizing routine operating, maintenance, and troubleshooting procedures. Similar documentation and training can be developed for other City and partner staff based on their respective system responsibilities.

Stage 1 also established a foundation for system maintenance and vendor coordination. Through installation and testing, the City gained experience with equipment dependencies, communications, technical support, and system troubleshooting. As the systems transition into routine operations, these practices can be formalized through documented maintenance responsibilities and support procedures, with vendor assistance used where specialized expertise is needed.

The Warren Avenue deployment provides a foundation for future system growth. The configurations, procedures, and operational practices developed during Stage 1 can be standardized and carried forward as additional intersections and corridors are incorporated into the system. Continued use of the Stage 1 deployment will also allow the City to build institutional knowledge and refine its approach before a larger deployment is undertaken.

Overall, the successful Stage 1 proof-of-concept established much of the technical and organizational foundation needed for continued City operation and future at-scale planning. The systems, partnerships, and experience developed along Warren Avenue position Brockton to expand the technology to additional downtown roadways as future funding and implementation opportunities become available.



7.0 Wrap-up

The Downtown Brockton Transportation Technology Project met the City's expectations for a Stage 1 proof-of-concept. The project demonstrated that smart traffic signal systems, connected infrastructure, and centralized data platforms can be successfully deployed and integrated along an urban corridor. The evaluation demonstrated measurable operational benefits from emergency vehicle preemption and transit signal priority under the tested one-way southbound condition, while the air-quality, pavement-temperature, and smart waste systems demonstrated the value of collecting additional infrastructure data to support City operations. Most importantly, Stage 1 established the technology, partnerships, and operational experience needed to continue using the systems beyond the grant period.

The City does not anticipate making substantial changes to the overall technology approach for an at-scale implementation. Instead, future deployment should build on the systems and experience established during Stage 1. As the Warren Avenue systems continue to operate, the City can further standardize equipment configurations, operating procedures, staff training, and maintenance practices before expanding to additional corridors. Future deployment should also be coordinated so that technology installation and evaluation are not overly dependent on the schedule of a separate roadway construction project. Where possible, permanent roadway and traffic operations should be established before final system evaluation so that performance can be measured under representative conditions.

One of the most important lessons from Stage 1 was the value of coordination among City departments, transit and emergency response agencies, engineering staff, contractors, and technology vendors. Smart transportation projects require more than installation of individual devices; the systems must communicate with one another and fit into the day-to-day operations of the agencies that will ultimately use and maintain them. Other communities pursuing similar projects should establish these relationships early, clearly define operational and maintenance responsibilities, and involve the future system users throughout installation, testing, and training.

Communities should also treat the initial deployment as an opportunity to develop institutional knowledge rather than only as a technology demonstration. Allowing staff to work directly with the systems during Stage 1 helped establish familiarity with their operation and provided a foundation for continued training and documentation. A successful proof-of-concept should therefore leave a community not only with functioning technology, but also with the experience, procedures, and partnerships needed to operate the system and expand it over time. The Warren Avenue deployment achieved that objective and provided Brockton with a foundation for future expansion throughout the downtown transportation network.