Appendix F.

Transit Signal Priority Technical Memorandum

MULLER ENGINEERING COMPANY

TECHNICAL MEMORANDUM

Project: North Avenue Enhanced Transit Corridor Study

To: Mesa County Regional Transportation Planning Office
City of Grand Junction

From: Muller Engineering Co.

Date: April 1, 2022

Subject: Transit Signal Priority (Task 1A: Transit Enhancement Analysis)

The Mesa County Regional Transportation Planning Office (RTPO) and the City of Grand Junction are leading an Enhanced Transit Corridor (ETC) Study on US 6 (North Avenue) from 1st Street to the I-70 Business Loop. The purpose of this project is to define a vision for the corridor and identify a set of prioritized infrastructure projects to make the corridor more comfortable for people biking, walking, and taking transit.

The purpose of Task 1A is to analyze the existing transit and multimodal system along North Avenue to inform the development of the vision for the corridor and recommendation to transform North Avenue into an ETC. This task included multiple analyses, but the focus of this technical memorandum is specifically on Transit Signal Priority (TSP).

Study Area

The study area is depicted in Figure 1 and the corridor currently has 12 existing signalized intersections on North Avenue that are owned by CDOT (since its designation makes it a part of the US Highway System) but are operated and maintained by the City of Grand Junction under a Senate Bill 8 (SB 8) signal maintenance agreement. Accordingly, coordination with the City of Grand Junction was performed for this task to determine the traffic signal infrastructure currently deployed in the study area.

Figure 1 - Project Area
(Source: Google Maps)

Grand Valley Transit Routes

North Avenue is a highly traveled corridor by all modes of transportation and is a US Highway that runs through the heart of Grand Junction. The two Grand Valley Transit (GVT) bus routes that serve North Avenue (Route 5 and Route 9) each have double the transit ridership of any other route in the GVT system.[1] GVT currently has a total of 11 routes and all routes operate six days a week with no service on Sundays.

The GVT routes to focus on for TSP include Routes 5 and 9 because their paths traverse a sizable portion of North Avenue compared to the other nine routes.

Route 5 is designated as the Midtown route and travels both eastbound and westbound on North Avenue from 1st Street to 29 ½ Road as shown in Figure 2. This route starts operations at 5:15 am and ends at 8:05 pm.

Route 9 is designated as the North Avenue route and travels both eastbound and westbound on North Avenue from 23rd Street to 29 ½ Road as shown in Figure 3. This route starts operations at 5:15 am and ends at 8:05 pm.

As shown in Figure 4, there are three other bus routes that traverse a small portion of North Avenue and are listed below. These routes will likely not accrue the benefits of implementing TSP due to the short segments of North Avenue that each route utilizes.

- Route 6 is designated as the Orchard Mesa route and travels eastbound only on North Avenue between 29 Road and 29 ½ Road.

[1] Retrieved from https://rtpo.mesacounty.us/north-ave-etc/

- Route 7 is designated as the College Collector route and travels eastbound on North Avenue between 5th Street and 7th Street and westbound between 7th Street and 4th Street.
- Route 10 is designated as the Clifton route and travels eastbound only on North Avenue between 29 Road and 29 ½ Road.

Figure 2 - GVT Route 5

(Source: https://gvt.mesacounty.us/routes-schedules/)

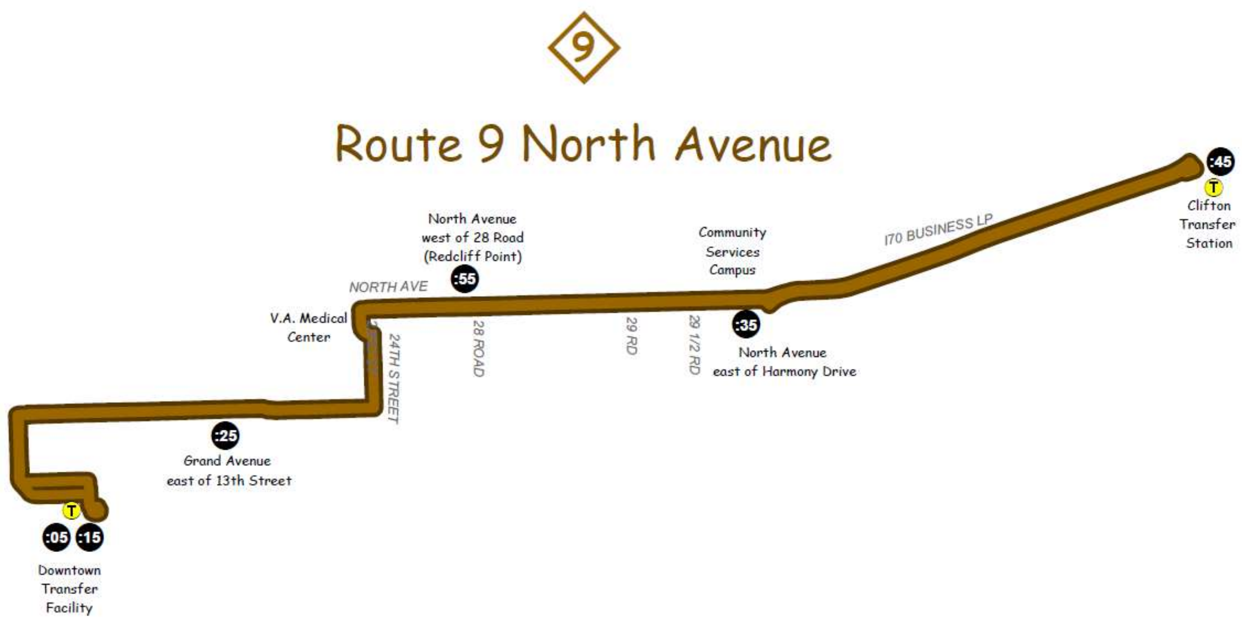

Figure 3 - GVT Route 9

(Source: https://gvt.mesacounty.us/routes-schedules/)

Figure 4 - GVT Transit Routes That Utilize or Cross North Avenue
(Source: North Avenue ETC Study, Technical Team Meeting #3, December 6, 2021)

Existing Conditions

This section of the technical memorandum addresses the equipment already installed on GVT buses that support the implementation of TSP, its corresponding back office equipment, and the roadside equipment at existing signalized intersections.

On-Board Equipment and Bus Fleet

GVT uses Routematch Fixed Route solution, which appears to support various functionality such as incident management, rider communication, and service reliability.[2] It also supports Computer-Aided Dispatch (CAD)/Automatic Vehicle Location (AVL) services that are an important consideration when looking to implement TSP. It is important because the Global Positioning System (GPS) that is associated with AVL combined with Mesa County's existing Geographic Information System (GIS) can determine where each bus is relative to where it should be based on its schedule and the time of day.

The Routematch software is hosted in-vehicle as part of the on-board equipment. The on-board equipment is known as the Routematch Velocity Vehicle Logic Unit (VLU), and it is described as a "black box" in the Fixed Route Brochure. It can be surmised to be an industrial Single Board Computer (SBC) that is loaded with the Routematch software and has physical interfaces to support various components normally found in buses such as automated voice annunciators, next stop signs within the bus, etc.

GVT's near-term fleet has approximately 29 buses with three replacement buses expected soon. The buses consist of 14 long cutaways, six short cutaways[3] (dedicated paratransit) and nine low floor buses.[4] With this fleet, it is anticipated that there will be 23 buses (low floor and long cutaways) that are dedicated for fixed-route or mixed fleet that could utilize TSP in fixed-route service. GVT will be expanding by three

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[2] Based on Routematch Fixed Route brochure obtained from https://www.routematch.com/fixed/.

[3] A cutaway is a vehicle in which a bus body designed to transport passengers is mounted on the chassis of a van or a light- or medium-duty truck chassis.

[4] Email from Andrew Gingerich (Transit Coordinator for RTPO) to Nate Algoe (Muller), dated February 25, 2022.

paratransit buses in 2023, however the use of TSP on its dedicated paratransit fleet is not expected. Based on an email conversation with RTPO, all GVT buses are equipped with a Velocity VLU.[5] The email also went on to say that GVT currently has many buses that are "mixed fleet" and are commonly used for either fixed route or paratransit service. GVT is moving gradually towards a dedicated fleet for fixed route and paratransit service with a fewer number of mixed fleet vehicles.

However, it is not out of the question that even GVT's paratransit buses could be run on fixed routes with the current Routematch set up. This is an important consideration for the proposed TSP section because it provides interchangeability to service routes, especially when a bus is out of commission due to unforeseen circumstances such as mechanical issues. If a replacement bus is available but has not been outfitted to support TSP, it can have a negative effect on the route's schedule reliability since TSP requests cannot be initiated if the route is behind schedule. As a result, the number of buses that would need TSP equipment interfaced to the existing Velocity VLU is an open question, but GVT has indicated that it is unlikely that TSP will be needed on their dedicated paratransit fleet.

Since a data sheet for the Velocity VLU is not available on the Routematch website, the following was determined through email correspondence that indicated "*with our current system we have a simple interface that triggers based off of Schedule Adherence to send an on or off command to a TSP. We currently support the Opticom J1708 interface.*"[6] This information from Routematch was useful to determine the next steps, since we now know the physical layer interface that can be used to support the TSP call request. This is explained in more detail in the ensuing sections.

Back Office Equipment

The Velocity VLU in each bus needs to correspond with Routematch's central system, which is a cloud-based system. It is assumed that any communications with each Velocity VLU and the central system is accomplished through the use of a 4G LTE cellular modem outfitted on each bus.

Based on the information provided by Routematch on how TSP is performed, the majority of the functions associated with schedule adherence are inherent to the Routematch system. Consequently, for the purposes of implementing TSP, it does not appear that any additional back office equipment will be needed.

Roadside Equipment

There are 12 existing signalized intersections on North Avenue that are operated and maintained by the City of Grand Junction in the study area as depicted in Figure 1.

Table 1 provides information on the equipment utilized at each signalized intersection.

[5] Email correspondence from Andrew Gingerich (RTPO) to Jason Osaki (Muller), Thomas Coogan (Routematch/Uber), and Dale Kartushyn (Routematch/Uber) regarding Routematch Questions, dated January 11, 2022.

[6] Email correspondence from Dale Kartushyn (Routematch/Uber) to Jason Osaki (Muller) regarding Routematch Questions, dated January 11, 2022.

Table 1 - Existing Signalized Intersection Equipment
(Source: City of Grand Junction)

Intersection ID	Intersection	Controller Type	Controller Firmware	Cabinet Type
1078	North Ave & 1st St	Econolite Cobalt	32.65.30	TS2
1079	North Ave & 5th St	Econolite ASC/3	2.61.00	TS1
1080	North Ave & 7th St	Econolite ASC/3	2.59.00	TS2
1081	North Ave & 10th St	Econolite ASC/3	2.61.00	TS1
1082	North Ave & 12th St	Econolite ASC/3	2.61.00	TS2
1083	North Ave & 23rd St	Econolite ASC/3	2.61.00	TS1
1084	North Ave & 28 Rd	Econolite ASC/3	2.61.00	TS1
1085	North Ave & 28 ¼ Rd	Econolite ASC/3	2.61.00	TS1
1086	North Ave & 28 ½ Rd	Econolite Cobalt	32.65.30	TS2
1125	North Ave & 28 ¾ Rd	Econolite ASC/3	2.61.00	TS2
1088	North Ave & 29 Rd	Econolite Cobalt	32.66.20	TS2
1129	North Ave & 29 ½ Rd	Econolite ASC/3	2.61.00	TS2

All of the Econolite controller firmware support TSP at no extra cost for optional software[8], however for each controller type it appears that there are different versions of firmware being utilized. As an example, the ASC/3 controllers primarily have v2.61.00 with one controller running v2.59.00. In May of 2020, the ASC/3 had v2.67.20 released so it appears that the existing controllers are a few versions behind. This may be due to the lack of budget for upgrading the firmware/controllers on the corridor or it could be intentional by the City to avoid bugs in the system when multiple firmware versions for the same controller type exist, but it would be worthwhile to convene with the City, CDOT, and Econolite to discuss the controller firmware versions to ensure that the most up to date functionality is available for deploying TSP. For the Cobalt controllers, the firmware versions look to be recent but should also be discussed with the City, CDOT, and Econolite since the new EOS firmware has been introduced.

The communications infrastructure to interconnect the traffic signals are a mix of City-owned fiber optic cables and wireless radios with Cisco Industrial Ethernet switches in the controller cabinets. Where fiber is available, optical transceivers are utilized in the switches to support communications between controllers along with communications back to the core network. Where fiber is not available, the City

[8] Email correspondence between Matt Gilbertson (Econolite) and Jason Osaki (Muller) regarding TSP Questions, dated October 29, 2021.

utilizes 5 GHz Intuicom Nitro58 broadband radios. The controllers that have communications are connected back to the Econolite Centracs central system located at City Hall and is remotely accessible for designated City personnel. Decisions related to priority and pre-emption are distributed, meaning that they are typically made at the local controller level based on incoming requests. Priority and preemption decisions does not need to be negotiated via the central system.

For Emergency Vehicle Preemption (EVP), the City utilizes the Global Traffic Technologies (GTT) Opticom Infrared (IR) detection system at the signalized intersections in the study area. The purpose of the Opticom IR system is to grant signal preemption to authorized emergency vehicles responding to a call by providing a green signal indication to prevent the vehicles from having to stop. This is significant because Routematch has indicated that they support the Opticom J1708 interface and the City already has Opticom infrastructure deployed at the signalized intersections. It is important to note that the current placement of Opticom IR detectors on the mast arms at signalized intersections have been installed specifically to support EVP and may need to be reexamined if the same IR detectors are used to support TSP since the buses normally operate in the shoulder lanes.

Conceptual TSP Solutions

For the purposes of this memo and based on the existing conditions, Muller developed two conceptual TSP solutions to advance for further analysis in this memo. The conceptual TSP solutions both focus on leveraging the existing capital investments by GVT for Routematch and the City's Opticom infrastructure to implement TSP. As previously mentioned, the Routematch Velocity VLU supports the Opticom J1708 interface, which is based on the Society of Automotive Engineers (SAE) J1708 standard for *Serial Data Communications Between Microcomputer Systems in Heavy-Duty Vehicle Applications*. At the signalized intersections, the City has already deployed Opticom IR detectors and phase selectors in support of EVP, so the marriage of the two technologies make sense for the initial deployment of TSP, especially if the investment of existing IR detectors and phase selectors can be utilized to support the implementation of TSP.

<u>Conceptual TSP Option 1: Infrared (IR)-Based System</u>

The IR-based system uses transmitters that would be mounted on GVT buses and securely communicate with the signalized intersections to request TSP using coded requests. Because this option uses IR transmitters and detectors, it is considered a line-of-sight system where the emitters on the buses need unobstructed views to the detectors normally located on the mast arms at each signalized intersection. Since the City already uses Opticom IR for EVP, they are familiar with the required infrastructure and interface requirements within the controller cabinet.

<u>Conceptual TSP Option 2: Global Positioning System (GPS)-Based System</u>

The GPS-based system uses GPS equipment and unlicensed radios on GVT buses to relay each bus's speed, direction, and heading to the GPS intersection equipment. As the bus enters the unlicensed radio range, the GPS intersection equipment relays the TSP request to the controller. Because this option is GPS and radio-based, it can rely on geofencing rather than line-of-sight for establishing check-in and check-out zones for requesting and cancelling TSP requests, respectively.

Conditional vs Unconditional TSP

The purpose of TSP is to change the signal timing at an intersection or group of intersections along a corridor to give priority to an approaching transit vehicle. Conditional TPS looks for a metric to determine if a TSP request is needed, and most often this metric is schedule adherence. If a bus is on schedule, it will not need to issue a TSP request. In unconditional TSP, the bus will always request TSP irrespective of schedule.

It has been discussed that RTPO's preference is conditional TSP since the Routematch Velocity VLU can support schedule adherence and this functionality will prevent the signal timing on the North Avenue corridor to be altered each time a Route 5 or 9 bus comes along. This decreases the likelihood that cross street traffic on North Avenue will have longer wait times, since only buses that have late runs will activate TSP. A flow chart of the process used by the Velocity VLU to request and cancel TSP calls to each signalized intersection appears in Figure 5.

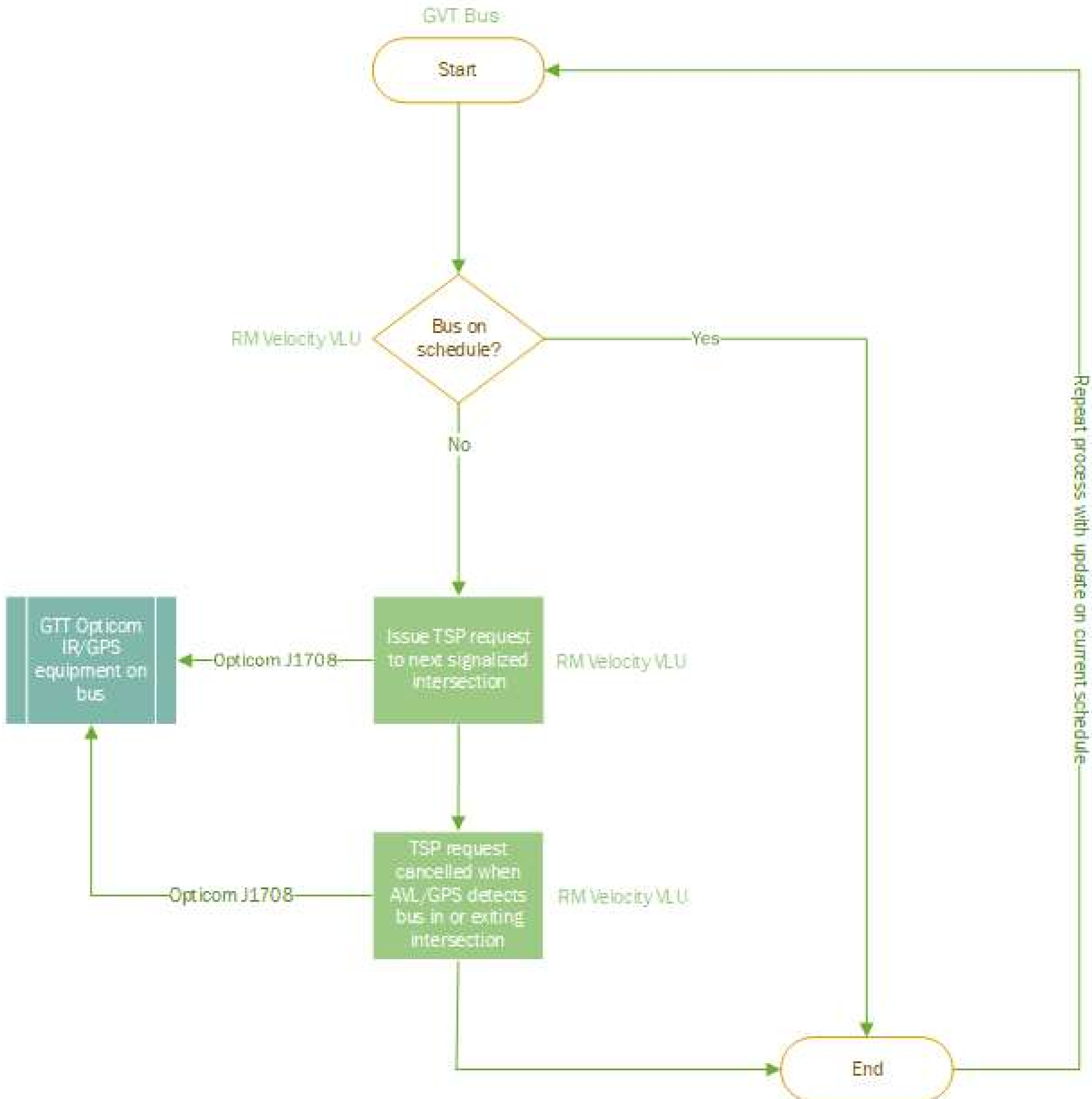


Figure 5 - Flow Chart for Requesting and Cancelling TSP Calls

Infrastructure to Implement Conceptual TSP

This section outlines the infrastructure needed to implement the two conceptual TSP options and is broken down into two sections: on-board and roadside equipment. It has been determined for now that there is no need for back office equipment for both conceptual TSP implementation options.

Conceptual TSP Option 1: IR-Based System

On-Board Equipment

With the Routematch Velocity VLU installed on each bus, and the fact that it supports its TSP triggers through the Opticom J1708 interface, the most prudent and cost effective method to get TSP up and running is through the use of GTT Opticom LED emitter as shown in Figure 6. On day one, these emitters will work with the existing GTT Opticom IR detectors installed by the City at signalized intersections in the study area. The multimode version of the Opticom LED emitter supports both IR and GPS should GVT decide to upgrade to an Opticom GPS system in the future. The LED emitter on each vehicle would not need to be changed out since GPS antennas are built within each unit.

Figure 6 - GTT Opticom 794TM Multimode LED Emitter
(Source: GTT, LLC)

The Opticom Multimode LED emitter emits precisely timed pulses of IR light at the base flash rate of approximately 10 or 14 Hz according to GTT. It also inserts programmed encoded pulses that carry the vehicle class and ID number so that it can be logged at the intersection. There are two models that are available, and it is recommended that the Transit Multimode LED emitter be used since it is a low priority emitter. If a GVT bus and a higher priority emergency vehicle are approaching an intersection at the same time, having the low priority emitter ensures that the emergency vehicle will be served first since it has the higher priority. Each LED emitter would be mounted on the roof of each bus per GTT’s recommendations so holes will need to be drilled in the roof of each vehicle for mounting the equipment and for routing the cables. The equipment mounting should use gaskets and silicone sealants, as recommended by GTT, to prevent water infiltration into the vehicle. The emitter includes 25 foot cables for DC power and for the Opticom J1708 interface to the Velocity VLU using the pins and wire pair designated to J1708 data link + and J1708 data link.

Figure 7 - Bus Equipped with GTT Opticom LED Emitter
(Source: Advanced Traffic Analysis Center)

The maximum range of the LED emitter is about 1,800 to 2,500 feet so it will work within the parameters of this study area as shown in Figure 8 with the segment between North 12th Street and North 23rd Street being the longest at 3,960 feet and North 5th Street to North 7th Street being the shortest at 970 feet.

Figure 8 - Signal Spacing on North Avenue
(Source: North Avenue ETC Study, Technical Team Meeting #3, December 6, 2021)

One of the keys for success will be how often the Velocity VLU updates its schedule adherence information on each bus since it is responsible for triggering the TSP requests. Longer intervals between updates increases the chances that a bus may need to stop at an intersection because a trigger for requesting TSP was not made in a timely manner.

Intersection Equipment

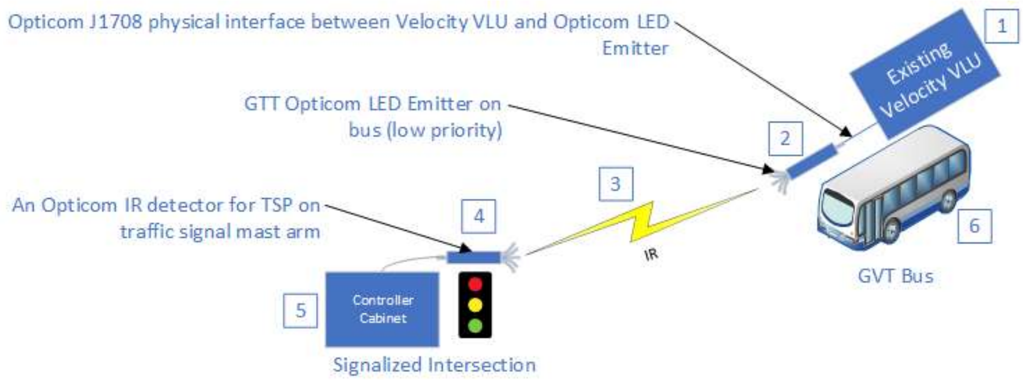
Most of the roadside Opticom equipment at signalized intersections are already existing, but these IR detectors have been located on the traffic signal mast arms specifically for EVP. Consequently, it is recommended that additional IR detectors, as shown in Figure 9, be installed for both eastbound and westbound directions of North Avenue at each signalized intersection on the project corridor exclusively to support TSP. This would place the IR detectors in the centerline area of the shoulder lane where the buses tend to travel most frequently. The existing EVP IR detectors would remain, and the two sets of detectors would coexist to support both EVP and TSP.

Figure 9 - GTT Opticom IR Detector
(Source: GTT, LLC)

Through coordination with the City, it has been determined that the Opticom Model 562 phase selector cards are used at all of the signalized intersections and these need to be upgraded to the Opticom Model 764 multimode phase selector card. The Opticom Model 764 support four channels, high/low priority, and is considered a "multimode" device because it can encode signals from both IR and GPS-based systems. An additional Auxiliary Interface Panel (AIP) should be provided at each signalized intersection to interconnect the phase selector cards to the .

The phase selector card recognizes and distinguishes the IR emitter frequency rates to determine if it is a high priority (emergency vehicle) or low priority (transit). It can also decipher the agency that the vehicle belongs to, the vehicle ID, and the vehicle classification. The phase selector card internally records each system activation such as intersection name, date/time of activity, and if priority was granted.

Figure 10 outlines the process of how TSP is proposed on the corridor through the use of the Velocity VLU and Opticom system.



1. Existing Velocity VLU updates its schedule and determines bus is behind schedule so it triggers a command to activate TSP.
2. Pins J1708 (+) and J1708 (-) are used to transport the trigger from Velocity VLU to GTT Opticom LED emitter mounted on bus.
3. The Opticom LED emitter sends a secure, encoded low priority request to the intersection using IR technology. A low priority request is used because an emergency vehicle will have a higher priority.
4. An Opticom IR detector for TSP on the traffic signal mast arm receives the IR signal and relays the request to the controller cabinet.
5. In the cabinet, an upgraded Opticom phase selector validates the request from the IR detector and sends a request for TSP through the controller's input file. Since the Opticom IR detector cannot inform the controller that it has successfully proceeded through the intersection because the detector can no longer see the emitter, the TSP request should have a timeout set in the controller to terminate the call request after a set period of seconds has elapsed.
6. AVL/GPS location information notifies Velocity VLU when bus is in or exiting the intersection. VLU then triggers a command to the GTT Opticom LED emitter to deactivate TSP.

Figure 10 – Conceptual IR-Based TSP Process

Conceptual TSP Option 2: GPS-Based System

On-Board Equipment

Similar to Option 1, the GPS-based solution will work with the existing Routematch Velocity VLU installed on each bus and support the triggering of TSP triggers through the Opticom J1708 interface. One GTT Opticom Vehicle Control Unit (VCU), vehicle interface cable, and GPS/radio antenna, as shown in Figure 11, will need to be installed on each bus. The GPS-based solution utilizes the GPS position of each bus and the GPS location of the signalized intersection that the bus is approaching. TSP requests will be accompanied by the bus location, speed, and heading so the system can anticipate arrival time and signal phase.

Figure 11 - GTT Opticom VCU, Vehicle Interface Cable, and GPS/Radio Antenna
(Source: GTT, LLC)

The Opticom GPS/radio antenna broadcasts the bus's location, speed, and heading along with the low priority request using the unlicensed 2.4 GHz spread spectrum transceiver. The Opticom GPS intersection equipment receives the radio transmission from the bus and compares it with the data stored in the intersection equipment's memory. If the bus meets the programmed parameters (i.e., date, time, vehicle ID, agency ID, etc.), the phase selector at the intersection will send an output to the controller's input file requesting TSP.

The GPS/radio antenna would be mounted on the roof of each bus per GTT's recommendations so holes will need to be drilled in the roof of each vehicle for mounting the equipment and for routing the cables. The equipment mounting should use gaskets and silicone sealants, as recommended by GTT, to prevent water infiltration into the vehicle. Each GPS/radio antenna needs to include coaxial cables for GPS/2.4 GHz radio interface and 25 foot vehicle interface cable for DC power and for the Opticom J1708 interface to the Velocity VLU using the pins and wire pair designated to J1708 data link + and J1708 data link.

The range of the radio is about 2,500 feet so it will work within the parameters of this study area as shown in Figure 8.

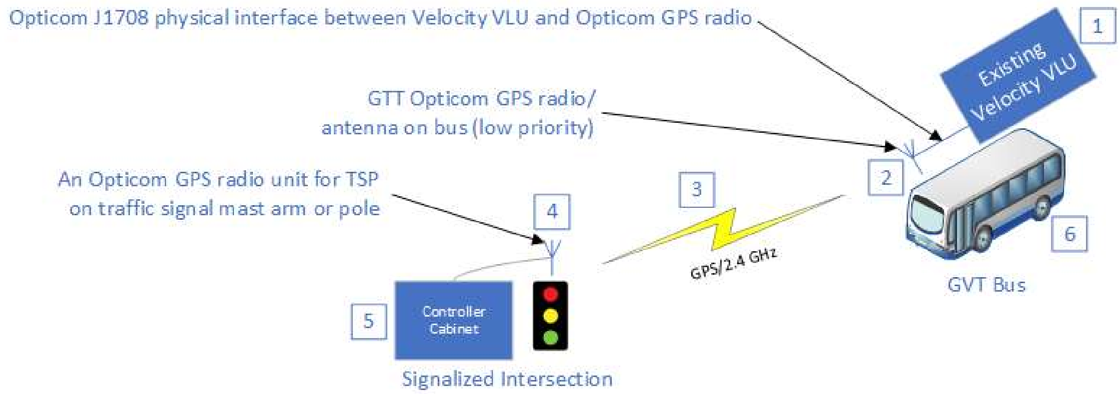
Intersection Equipment

The existing Opticom IR equipment at signalized intersections on the traffic signal mast arms specifically for EVP will remain but additional equipment will be necessary to support GPS and unlicensed radios. An Opticom GPS radio unit, as shown in Figure 12, will need to be provided at each signalized intersection where TSP will be implemented and mounted on the mast arm of the signal over North Avenue. The GPS radio unit contains a GPS receiver and a 2.4 GHz spread spectrum transceiver with antenna. An Opticom Model 764 multimode phase selector will be needed at each signalized intersection to replace the existing Opticom Model 562 phase selector cards that only support IR emitters on emergency vehicles. The Model 764 is a "multimode" phase selector, so it supports both IR and GPS equipment. An Opticom auxiliary interface panel will also be needed at each signalized intersection to provide up to 12 additional channel outputs.

Figure 12 - GTT Opticom GPS/Radio Unit at Each Signalized Intersection
(Source: GTT, LLC)

The phase selector card recognizes and distinguishes if it is a high priority (emergency vehicle) or low priority (transit). It can also decipher the agency that the vehicle belongs to, the vehicle ID, and the vehicle classification. The phase selector card internally records each system activation such as intersection name, date/time of activity, and if priority was granted.

Figure 13 outlines the process of how TSP is proposed on the corridor using the Velocity VLU and Opticom GPS system.



1. Existing Velocity VLU updates its schedule and determines bus is behind schedule so it triggers a command to activate TSP.
2. Pins J1708 (+) and J1708 (-) are used to transport the trigger from Velocity VLU to GTT Opticom GPS equipment mounted on bus.
3. The Opticom GPS equipment on bus transmits bus speed and direction to GPS intersection equipment. A low priority request is used because an emergency vehicle will have a higher priority.
4. As bus enters unlicensed radio range, Opticom GPS intersection equipment relays the check-in TSP request to the Opticom multimode phase selector in cabinet.
5. In the cabinet, the Opticom multimode phase selector validates the request from the GPS receiver and sends a request for TSP through the controller's input file.
6. AVL/GPS location information notifies Velocity VLU when bus is in or exiting the intersection. VLU then triggers a command to the GTT Opticom GPS equipment on bus to deactivate TSP. This can also be performed using the Opticom GPS equipment.

Figure 13 – Conceptual GPS-Based TSP Process

Infrastructure Considerations For Both TSP Options

Because the TSP check-in zone is a trial-and-error aiming process, the calculations during the design process and testing/adjustment during the implementation phase need to be considered and addressed. Since there is an ongoing discussion on the bus stop locations for North Avenue (i.e., far-side vs near-side stops), it is recommended that the doors on the bus be wired to either the VLU or the LED emitter on the bus. If a bus is dwelling at a near-side stop with its doors open, it will disable the TSP request even if it is behind schedule and in the line-of-sight of the IR detector. Once the doors have been closed, the TSP request will be made to the traffic signal controller at the downstream signalized intersection.

While the focus on this section is primarily infrastructure-based, it is important to consider that time will need to be spent evaluating the current signal timing plans in the study area to determine how TSP will impact the overall phasing and cycle lengths at each signalized intersection. Typically, TSP timing strategies such as green extension provide extra time to a phase in order to accommodate a TSP request, but that time has to be taken from somewhere else in the cycle without affecting any change/clearance intervals and minimum pedestrian crossing times. As a result, there are also some labor hours and cost involved in evaluating the signal timing prior to TSP implementation.

Maintenance Considerations

For Option 1, the front face of each GTT Opticom Multimode LED emitter installed on each bus should be cleaned monthly or after each rain and snow event to ensure that communications between the emitters and detectors are not obscured. Other maintenance procedures should be as recommended by GTT.

There is minimal to no maintenance considerations to outline for Option 2 since it is GPS and radio based.

Conceptual TSP Solution Implementation Cost

The cost associated with the initial implementation of TSP is expected to be in the order of $52,900 based on Table 2. This includes the procurement of the GTT Opticom Multimode LED emitter for each bus in the GVT fleet and installation and testing on each bus. It also includes up to 25 feet of cabling for each bus to connect the emitter to 12 VDC power and to the Velocity VLU.

Table 2 - Opinion of Probable Cost for Implementing Option 1 IR-Based TSP

Item	Quantity	Equipment Unit Cost	Installation & Testing Unit Cost	Total Cost	Extended Cost
On-board Equipment					
GTT Opticom 794TM Multimode LED Emitter (Low Priority for TSP Applications)	23	$1,300	$1,200	$2,500	$57,500
Intersection Equipment					
GTT Opticom Model 138 500' Spool Detector Cable	12	$400	$400	$800	$9,600
GTT Opticom Model 711 One Channel, One Direction Detector	24	$600	$600	$1,200	$28,800
GTT Opticom Model 764 4-Channel Multimode Phase Selector	12	$3,000	$1,500	$4,500	$54,000
GTT Opticom Model 768 AIP	12	$600	$600	$1,200	$14,400
Pelco Astro Mini-Brac Clamp Kit for Opticom Detector Mount on Mast Arm	24	$100	$600	$700	$16,800
Option 1 IR-Based TSP – Opinion of Probable Cost					**$181,100**

Table 3 - Opinion of Probable Cost for Implementing Option 2 GPS-Based TSP

Item	Quantity	Equipment Unit Cost	Installation & Testing Unit Cost	Total Cost	Extended Cost
On-board Equipment					
GTT Opticom GPS Preemption Vehicle Kit (Low Priority)*	23	$3,400	$3,000	$6,400	$147,200
Intersection Equipment					
GTT Opticom Model 3100 GPS Radio Unit (Mast Arm Mount)	12	$2,900	$2,800	$5,700	$68,400
GTT Opticom Model 764 4-Channel Multimode Phase Selector	12	$3,000	$1,500	$4,500	$54,000
GTT Opticom Model 768 AIP	12	$600	$600	$1,200	$14,400
Pelco Astro Mini-Brac Clamp Kit for Opticom GPS Radio Unit Mount on Mast Arm	12	$100	$600	$700	$8,400
Option 2 GPS-Based TSP – Opinion of Probable Cost					**$292,400**

*Includes Model 2101 Low Priority GPS VCU, Model 1050 GPS/Radio Antenna, Model 210 GPS Vehicle Interface Cable, and Vehicle Hardware Installation Kit

The costs for Options 1 and 2 do not include the following costs that may be necessary to implement TSP:

- The cost does not include any cables, splitters, amplifiers, extenders, adapters, converters, or other hardware recommended by Routematch to facilitate the J1708 interface from its Velocity VLU to the Opticom multimode LED emitters, including any firmware changes needed for the Velocity VLU.
- The cost does not include any work by Routematch to evaluate the J1708 interface once the connection is made between the Velocity VLU and Opticom emitter for each vehicle.
- The cost does not include any consultant support for signal timing analysis and adjustments or bench testing the conceptual TSP solution. That support may not be necessary if the City or Mesa County personnel can undertake those activities.

Summary of IR-Based TSP System vs GPS-Based TSP System

Table 4 contains a summary of the technology comparison between an IR-based TSP system and a GPS-based TSP system.

Table 4 - TSP System Technology Comparison

Criteria	IR-Based TSP System	GPS-Based TSP System
Check-in zone for requesting TSP	Need to be estimated visually when installing IR detector on mast arm	Geofenced location
Check-out zone for terminating TSP request	Not available since line-of-sight is needed and IR detector would be behind bus	Geofenced location
Technology	Strobe emitter on bus that requires line-of-sight to IR detector on mast arm	Satellite-based GPS coordinates
Arrival Calculation	Not available	Based on bus speed
Activation Trigger	Fixed distance from IR detector	Pre-defined range that adjusts to the speed of traffic
Communications	One-way (bus to IR detector)	Two-way (updates once per second)

Benefits of TSP and Other Factors to Consider

There have been many implementations of TSP across the country and the benefits of utilizing TSP include a reduction in transit delay as highlighted below.

- TSP applications using AVL technology was demonstrated to reduce total bus trip times during peak hours between 4% and 15% in Minneapolis. Applications in Portland, Seattle, and Los Angeles noted 8-10% travel time decreases.[9]
- A number of studies of TSP implementation on streetcar routes in Toronto recorded widely varying travel time improvements, even up to 50% reductions in delays at some intersections. Factors such as stop siting, service frequency and ridership, and separation from traffic all impacted TSP effectiveness in reducing spot delay.[10]

Other factors to consider with regard to the implementation of TSP include the following:

- Without schedule adherence, the wait times for passengers can increase significantly especially at transfer points if the arriving bus is late and the departing bus has already left without passengers that were planning to transfer.
- Far-side stops maximize TSP efficacy since arrival at the signal can be anticipated more easily than dwell time.[11]
- Dwell time can increase with on-board fare payment systems as passengers try to gather up the correct fare while trying to board. Free fares or innovative fare payment systems can help enable quicker boarding time, reduce dwell time, and help to expedite travel time.

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[9] Jia Hu, Byungkyu (Brian) Park, and A. Emily Parkany. *Transit Signal Priority with Connected Vehicle Technology*. Transportation Research Record 2418, Journal of the Transportation Research Board, Washington, DC: 2014.
[10] Danaher, Alan R. *Bus and Rail Transit Preferential Treatments in Mixed Traffic*. TCRP Synthesis 83, Transportation Research Board, Washington, DC: 2010.
[11] National Association of City Transportation Officials. *Transit Street Design Guide*. New York, NY: 2016.

- The utilization of in-line stops eliminate delays associated with the bus merging back into traffic. However, this configuration causes vehicles to queue behind the bus during its dwell time. Pull-out stops, if wide enough, allow the buses to clear the lane and prevent vehicle queues but is subject to travel delays if it takes time to find a gap where the bus can reenter traffic.

Next Steps

It is recommended that RTPO utilize a systematic approach to the TSP planning and implementation process. Using the Systems Engineering Analysis (SEA) process such as the one utilized by CDOT examines the needs and expectations of the desired system to ensure the success of the project by building the right system. This process also examines not just the initial capital cost but the operations and maintenance of the system. Any project that utilizes federal funds will need to show that the SEA process has been followed.

The proposed next steps associated with the SEA process are:

1. TSP Planning
    a. Needs Assessment
    b. Stakeholder Roles and Responsibilities
    c. Concept of Operations (ConOps) and Requirements Document
    d. Corridor and Signalized Intersections
    e. Technology Alternatives Analysis
2. TSP Design
    a. Detailed Data Collection and Inventory of Traffic Control System
    b. Define System Components
    c. Detailed Design and Engineering for On-Board Equipment and at Signalized Intersections
    d. Preparation and Optimization of Signal Timing Plans
    e. Development of Micro-Simulation Model for TSP Control Strategy (As Needed)
3. TSP Implementation
    a. Bidding/Procurement Process
    b. Construction/Implementation
    c. Testing (Validation and Verification)
4. Operations and Maintenance for TSP
    a. Ongoing Performance Monitoring and Management
    b. Development of Procedures to Ensure TSP System is Operating
    c. Maintenance Activities (Planned and Unplanned)
5. Evaluation, Verification, and Validation of TSP
    a. Evaluation Study
    b. Ongoing Data Collection to Monitor Performance