Advance Transit
Transit Signal Priority Feasibility Study

Completed for:
Upper Valley Lake Sunapee Regional Planning Commission
(UVLSRPC)

Submitted by:

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March 21, 2017

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EXECUTIVE SUMMARY

Greenman-Pedersen, Inc. (GPI) has been retained by the Upper Valley Lake Sunapee Regional Planning Commission (UVLSRPC) in cooperation with Advance Transit (AT) to evaluate the feasibility of implementing a Transit Signal Priority (TSP) system along a portion of Advance Transit's fixed-route services. Due to budget constraints the study focused on the Blue Route in the City of Lebanon and Town of Hanover, New Hampshire and the Green Route in the towns of Hartford and Norwich Vermont and Lebanon, NH. The AT system also includes the Orange Route, with service between White River Junction, VT and West Lebanon along Route 10 to Dartmouth College in Hanover, NH, as well as the Red Route, with service between Lebanon, West Lebanon and the commercial/retail corridor along Route 12A. Portions of these routes would likely benefit from TSP and may be evaluated further as budgets permit. The project involves interagency cooperation between the New Hampshire Department of Transportation (NHDOT), Vermont Agency of Transportation (VTrans), municipal Department of Public Works, Engineering and Emergency Services as well as Advance Transit, UVLSRPC and Two Rivers – Ottauquechee Regional Commission (TRORC). A Planning Advisory Committee (PAC) has been established and consists of representatives from the following agencies:

- Advance Transit
- Upper Valley Lake Sunapee Regional Planning Commission
- Two Rivers-Ottauquechee Regional Commission
- Greenman-Pedersen, Inc.
- New Hampshire Department of Transportation
- Vermont Agency of Transportation
- Town of Hanover, NH
- City of Lebanon, NH
- Town of Norwich, VT
- Town of Hartford, VT

The PAC worked cooperatively to establish appropriate segments of the AT Green and Blue fixed routes that would be explored further for potential TSP implementation. The PAC also, provided guidance on the desired system needs and operations.

The overall goals of the project were defined by the PAC to include:
- Improve Schedule Adherence
- Improve Transit Travel Time
- Minimize Impacts to Normal Traffic Operations

Technology Review

As detailed in the report, the PAC reviewed available TSP Technologies and determined that a GPS based detection system would be the best option to consider for future deployments. Furthermore, based on the limitations of the existing infrared emergency vehicle pre-emption systems experienced by the local emergency, the PAC does not wish to invest further funds into an infrared based system.

Existing Traffic Control Infrastructure

Based on a review of the signal density and intersection operations the following four segments were determined by the PAC to warrant further analysis to determine the benefits associated with implementing a TSP system:

- Blue Route - Route 120 at the I89 interchanges and Heater Road
- Blue Route - Hanover, NH Loop
- Green Route – Route 4 Corridor
- Green Route – Route 10 at I91 and River Road into Hanover

Based on an inventory of the existing traffic control at each signalized intersection along the four corridors, it was determined that of the 18 signalized intersections recommended for TSP implementation, 8 are already capable of providing full TSP (with Green extension and Early Return to Green functionality), 4 would require software updates and 6 would require new traffic controllers.

TSP Analysis

Each of the four segments was modeled in the Aimsun simulation model. A baseline or existing condition was modeled to estimate the travel time for transit vehicles through each of these segments without any improvements to the signal operations. Next the existing signal operations were optimized to ensure that impacts to the overall intersection are minimized should TSP be requested and serviced. Finally, a TSP timing plan was developed to reallocate green times to service transit approach phases upon detection of an approaching transit vehicle. This scenario was then modeled in Aimsun.

The results indicated that optimizing the traffic signals and installing TSP system would result in a savings of approximately 3.39 minutes along the Blue Line and approximately 3.53 minutes along the Green line during the morning peak hours. While the analysis was only completed for the morning peak hour, similar time savings would be expected during the evening peak hour as well.

Implementation

In order to implement the TSP system along the four corridor sections, the infrastructure costs associated with those signals was examined. In order to provide full TSP at each of the 18 intersections, a variety of infrastructure and software upgrades are required. It is expected that the total implementation costs would be approximately $225,000. This includes all on-street signal hardware, outfitting five (5) buses with GPS TSP equipment and the design of the system. The five buses were selected as they currently service the Green or Blue Routes. AT may also consider outfitting the entire fleet of buses with TSP GPS devices to allow any bus to be used on the Green or Blue Route as well as to provide or future TSP accommodations along the Red or Orange Routes.

Cost vs Benefit

The Federal Highway Authority (FHWA) *Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2* was utilized to assess the potential benefits to Travel Time and Speed, Throughput, Energy and Efficiency. Based on the historical data compiled and maintained by the FHWA, the following benefits can be expected from TSP installation.

- Decreases in travel time
- Decrease in passenger delay
- Decrease in bus delay
- Increase in bus travel speeds
- Reduction in bus stoppage time
- Decreased bus fuel consumption
- Increase in schedule reliability and adherence

There is the increased value and attractiveness of a service that will run on time more often due to the time gained particularly during the peak periods. In addition, the expected improvement in efficiency and schedule adherence could delay the need and costs to provide additional vehicles along the routes to maintain headway and schedules.

Based on the analysis completed in reviewing the critical signalized intersections along the Blue and Green Routes, travel times are anticipated to be reduced by approximately 14% and 20%, respectfully during the morning peak hours consistent with the FHWA findings.

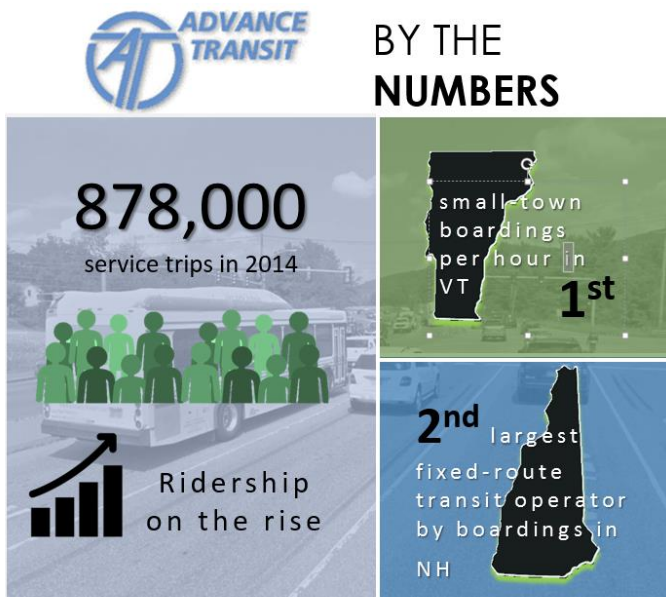
Standards and Policies

The PAC has determined that should the installation of TSP system along the Blue and Green AT routes move forward, the following standards shall be part of the system requirements:

- Vehicle to intersection communications shall be provided by a GPS based radio in the transit vehicle and a roadside GPS receiver installed in the traffic controller cabinet
- All new traffic controllers shall be NEMA compatible Advanced Traffic Controllers capable of providing full TSP.
- The TSP system shall be compatible with all NEMA controllers, regardless of manufacturer.
- The TSP system shall, at a minimum, provide both Early Return to Green, Green Extension and Conditional Service (with Advance Transit AVL system integration)
- TSP shall be backwards compatible to provide continued integration with optical infrared based pre-emption systems and provide dual detection (GPS/Infrared) as well as coded and uncoded detection. System shall distinguish between pre-emption and priority service calls.
- The TSP system shall be capable of future expansion and or modification based on changes to or modifications of AT’s AVL system.

SECTION 1 – PROJECT OVERVIEW

Figure 1 - Advance Transit Operations



Greenman-Pedersen, Inc. (GPI) has been retained by the Upper Valley Lake Sunapee Regional Planning Commission (UVLSRPC) in cooperation with Advance Transit (AT) to evaluate the feasibility of implementing Transit Signal Priority (TSP) along a portion of Advance Transit's fixed-route services. Due to budget constraints the study focused on the Blue Route in the City of Lebanon and Town of Hanover, New Hampshire and the Green Route in the towns of Hartford and Norwich Vermont and Lebanon, NH. The AT system also includes the Orange Route, with service between White River Junction, VT and West Lebanon along Route 10 to Dartmouth College in Hanover, NH, as well as the Red Route, with service between Lebanon, West Lebanon and the commercial/retail corridor along Route 12A. Portions of these routes would likely benefit from TSP and may be evaluated further as budgets permit. The project involves interagency cooperation between the New Hampshire Department of Transportation (NHDOT), Vermont Agency of Transportation (VTrans), municipal Department of Public Works, Engineering and Emergency Services as well as Advance Transit, UVLSRPC and Two Rivers – Ottauquechee Regional Commission (TRORC). A Planning Advisory Committee (PAC) has been established and consists of representatives from the following agencies:

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The PAC worked cooperatively to establish appropriate segments of the AT Green and Blue fixed routes that would be explored further for potential TSP implementation. The PAC also, provided guidance on the desired system needs and operations.

Advance Transit (AT) is the second largest fixed-route transit operator by boardings in the State of New Hampshire and first in small-town boardings per hour in the State of Vermont. Residential and non-residential development pressure in Advance Transit's service area is straining the capacity of existing transportation infrastructure. Under existing conditions, many of the signalized intersections along AT's

Green and Blue routes experience long delays and excessive queues. Vehicles regularly experience multiple signal cycles to pass through critical intersections, resulting in a degradation of schedule adherence.

Fortunately, transit ridership in the region is continually growing, and transit is becoming increasingly important as one of the few available options to maximize the capacity of existing transportation infrastructure. In FY 2014, Advance Transit provided more than 878,000 fixed-route and shuttle service trips. Ridership on the Green and Blue lines this past year (2015) was in excess of 100,000 boardings for the Green line and in excess of 200,000 boardings for the Blue line, with daily averages of approximately 400 and 800 boardings respectively on the Green and Blue lines. However, the increased ridership and increasing traffic delays along the routes are straining schedules and over time could result in degraded transit operations and reliability, a need for additional buses to maintain headways and potentially a decline or leveling off of ridership.

Transit signal priority can be an effective tool to improve transit schedules by decreasing delay and improving on-time reliability for public transit commuters. Transit signal priority for buses can improve travel times for commuters and the same componentry can also provide improved emergency vehicle response by providing traffic signal pre-emption for emergency responders.

This study examines the feasibility of implementing TSP to improve service for the Blue and Green AT routes. The study is comprised of several sections, including:

- Section 2 – Review of Transit Signal Priority Technology
- Section 3 – Assessment of Existing Traffic Signal Equipment
- Section 4 – Operational Analysis and Route Selection
- Section 5 – Implementation
- Section 6 – Standards and Policies

SECTION 2 – REVIEW OF TRANSIT SIGNAL PRIORITY TECHNOLOGY

Introduction

Figure 2 - Blue Route Bus

In order to assess the benefits a TSP system could provide, it is critical for the stakeholders to fully understand the currently available TSP technology.

The purpose of this section is to describe the various technology options available for implementing TSP along the Advance Transit routes.

In this evaluation, each system type will be briefly defined and a matrix established to illustrate the benefits or disadvantages associated with each type of technology. As with any comparative evaluation, each technology will have positives and negatives but only one system will be the best fit for this project. It should be noted that often the best fit for a particular project is based upon a “site specific” approach reflecting local constraints and conditions.

The selected technology will consider TSP system objectives, technology compatibility with the local infrastructure, ease of implementation, installation and maintenance costs (overall costs).

The above considerations must be balanced with the needs and concerns of the UVLSPRC, Advance Transit, the municipalities (Lebanon and Hanover, NH and Hartford and Norwich, VT) and the state agencies (NHDOT and VTrans) that operate the traffic signals. The intended goal of this section is to provide sufficient information about the options so that the committee can be comfortable with the recommended technology.

What is TSP?

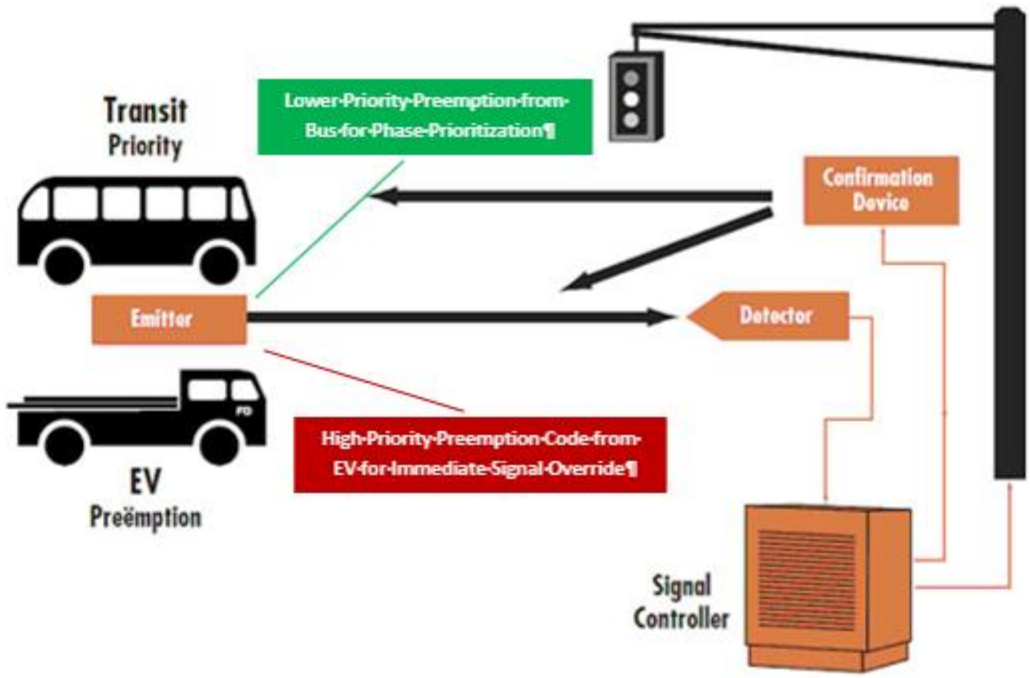
According to ***Transit Signal Priority: A Planning and Implementation Handbook***[1], TSP is an operational strategy that facilitates the movement of transit vehicles, either buses or streetcars, through traffic signal controlled intersections.

[1] Transit Signal Priority: A Planning and Implementation Handbook, May 2005, US DOT,

Transit Signal Priority vs Emergency Vehicle or Railroad Pre-Emption

Signal priority should not be confused with signal pre-emption, which while similar (and the terms are often used synonymously), they are in fact different processes.

Figure 3 - TSP Operations



While they may utilize similar equipment, signal priority *modifies* the normal signal operation process to better accommodate transit vehicles, while pre-emption *interrupts* the normal process for special events such as an approaching train or a responding fire truck. The objectives of emergency vehicle pre-emption include reducing response time to emergencies, improving safety, reducing stress levels of emergency vehicle responders and reducing accidents involving emergency vehicles at intersections. There is generally an impact on traffic.

Objectives of TSP include improved bus schedule adherence and improved transit travel time efficiency—while minimizing impacts to normal traffic operations.

In order to accommodate an approaching bus and implement signal priority, a TSP system must have hardware and software elements designed into the system which are compatible with local traffic controller firmware and/or central control system software.

Conditional vs. Unconditional TSP

There are two types of operational modes for TSP. *Conditional* TSP service only activates the priority request if pre-established criteria are established such as; adherence to schedule, level of ridership, express vs. standard service, etc. For example, if a bus is behind schedule then a request for TSP is generated and processed; however, if the bus approaches the signal and is ahead of schedule or on schedule, then there is no reason to provide TSP and the priority request is not generated. This type of operation reduces the impacts to other vehicles at the intersection by only providing TSP when needed. However, this type of system typically requires two-way communications between the buses and a Transit Operations Center (TOC) and may also require communications between the TOC and a Traffic Management Center (TMC) to interact with the on-street traffic control.

Unconditional TSP provides a call for priority service any time a transit vehicle approaches a traffic signal. This type of operation requires less infrastructure as communications regarding the bus location is transmitted between the bus and on-street traffic control only and communications to a TOC or TMC are not required.

TSP Operations

Depending upon the sophistication of the system, TSP is delivered via four functional applications including **vehicle detection**, **priority request generation** (PRG), **priority request server** (PRS), and **TSP control.** Each are briefly defined as follows:

- Vehicle detection – This is the method used to deliver traveling bus data (location, arrival time, approach, etc.) through a device that is routed to equipment at the intersection to accept the detection. A transit signal priority implementation requires that the system be able to explicitly detect a transit vehicle and determine the intersection approach for which priority should be granted.

  While a variety of detection means are available to initiate the process, most TSP implementations have used their own transit vehicle detection systems because existing vehicle detection systems at a traffic signal cannot identify transit vehicles from other vehicles in the traffic stream.

- Priority Request Generator/Server - Detection equipment mounted at the intersection communicates with a priority request generator in the controller cabinet to request priority from the traffic control system firmware and to triage multiple requests as necessary.

- TSP Control Strategies – This is a traffic control system software enhancement that provides a range of "TSP Control Strategies" that address the functional requirements of the traffic jurisdiction. This is built into the controller TSP firmware.

  - TSP System Management – A management tool that incorporates both traffic and transit TSP functions that can configure settings, log events, and provide reporting capabilities. This is not necessarily part of all systems and is not anticipated to be part of a TSP system in the Upper Valley.

Based on the existing infrastructure in place, this technical memorandum focuses on the detection of a transit vehicle and how the TSP call is initiated as well as what equipment is needed both on the bus and on the street to identify an approaching bus and allocate the appropriate right of way through the intersection.

Evaluation Process- Detection Methods/Technologies

Over the past decade, the advancement of TSP technology has become more prevalent and more agencies across the United States are implementing these systems into their networks. Depending on the type of corridor and agency budget, there are a variety of TSP technologies to choose from.

1. Automatic Vehicle Identification (AVI) Loops
2. Optical/Infrared (light-based) Detection
3. Radio Frequency Identification (RFID)
4. Global Positioning System (GPS)
5. Centralized Automatic Vehicle Locator System
6. Wi-Fi or Cellular Wireless Communication

TSP Technology – Vehicle Detection

The following provides additional descriptions of the operations as well as the advantages and limitations of each of the various detection options to provide detection of transit vehicles.

Automatic Vehicle Identification (AVI) Loops

AVI loops are typically used in conjunction with an overall Transit Automatic Vehicle Identification system, but may also be installed solely for the use of signal prioritization. The system consists of three components:

- A coded transmitter mounted to the underside of the vehicle
- An inductive loop in the pavement surface
- Receiver mounted in the traffic control cabinet.

Advantages

- Installation of loops is similar to standard vehicle loop installation.
- Can provide “check in” and “check out” functionality if additional loop is installed in departure lane.
- Reduced chance of false calls due to short communication range between transmitter and receiver
- Unique code for each vehicle
- Not impacted by weather conditions.
- In pavement loops can also be used to detect traffic and provide actuated signal operations; however, the optimal placement for transit detection may not provide optimal vehicle detection.

Limitations

- Placement of loop detectors is critical.
- May need additional loops cut if existing loop detection is not adequately spaced.
- Requires pavement to be in good condition to cut new loops.
- Loop detectors can be damaged by pavement failures, utility cuts, etc.

Optical/Infrared (Light Based) Detection

Optical technology has been in use for emergency vehicle preemption since the late 60's - early 70's. According to **Transit Signal Priority Research Tools** published by the USDOT in May 2008, this technology is the most common of all technologies. Similar to the AVI, the system is comprised of three components:

- Emitter mounted on each vehicle
- Receiver mounted at or near the intersection
- Phase selector in the controller cabinet

This technology detects approaching buses equipped with ***coded or uncoded infrared optical emitters***. Each intersection approach selected for TSP is equipped with an ***optical infra-red receiver***, which will interpret that a bus is approaching.

The receiver is typically mounted on signal mast arms, but may also be attached to other roadside poles. Receivers can also be mounted on auxiliary structures in advance of an intersection if there are line of sight obstructions.

Figure 4 - Infrared Emitter

The receivers transmit information to the ***phase selector*** which in turn will initiate an action to the controller. The controller software then implements the desired priority phasing and will employ strategies, which will make the determination to extend the main street "green," or return early to the main street "green."

This technology is simple and well-proven. However, it is less "smart" or dynamic than a GPS type system, as detection is based upon a predetermined vehicle speed along the corridor. Within a specified range, a bus at any speed can trigger a call for TSP activation. This distance range between the bus emitter and the intersection receiver is adjustable. So while there is some predictability to this technology it is not demand responsive since speeds can fluctuate considerably based upon roadway operational conditions at the time of the call. It is also a line of sight technology so roadway geometry and physical roadside features such as tree lines and large signage must be accounted for when designing the system.

Advantages

- Can be used simultaneously by both emergency service providers and by transit vehicles (with different frequencies).
- Optical receivers may already be installed for Emergency Vehicle pre-emption.
- Variable detection point settings allow flexibility in setting the range for priority requests.
- Emitters and receivers can be coded or uncoded. Coded restricts the ability to override the signal operations to authorized vehicles only. Uncoded systems allow use by any vehicle with standard emitter settings. Emergency pre-emption is typically run uncoded to allow preemption for mutual

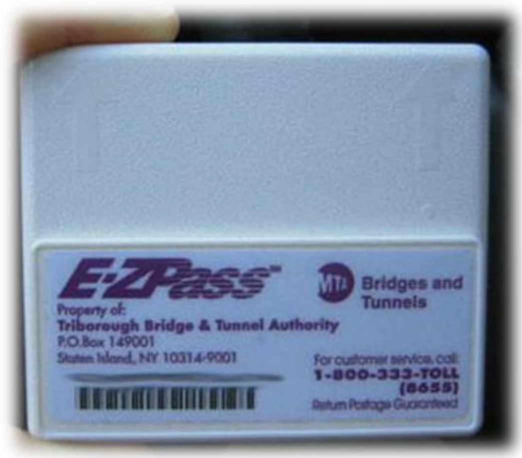
aid vehicles and adjacent municipalities that may need to cross multiple jurisdictions enroot to a hospital.
- In-cabinet technology can log priority requests and there is little customization of traffic controller cabinets required.
- This technology has been field-tested and is a proven technology.

Limitations

- Requires direct line of sight between the emitter and detector.
- Data transfer is limited to an identification code.
- Latency in receiving requests from optical emitter may occur due to range acquisition
- Higher Installation costs (as compared to most systems), especially when large numbers of intersections are desired for TSP. This is due to the need to hire signal contractors to install the TSP receivers at each of the intersections.
- Maintenance of traffic needs to be addressed during the installation process through lane closures, etc. Other systems technologies only require equipment upgrades or installations at the cabinet, whereas optical systems require roadside cabinet work but also the over roadway receiver installations.
- Each bus assigned to the Green or Blue routes would need to be equipped with optical emitters (new piece of equipment).

RFID Technology (EZ Pass)

Figure 5 - RFID Tag

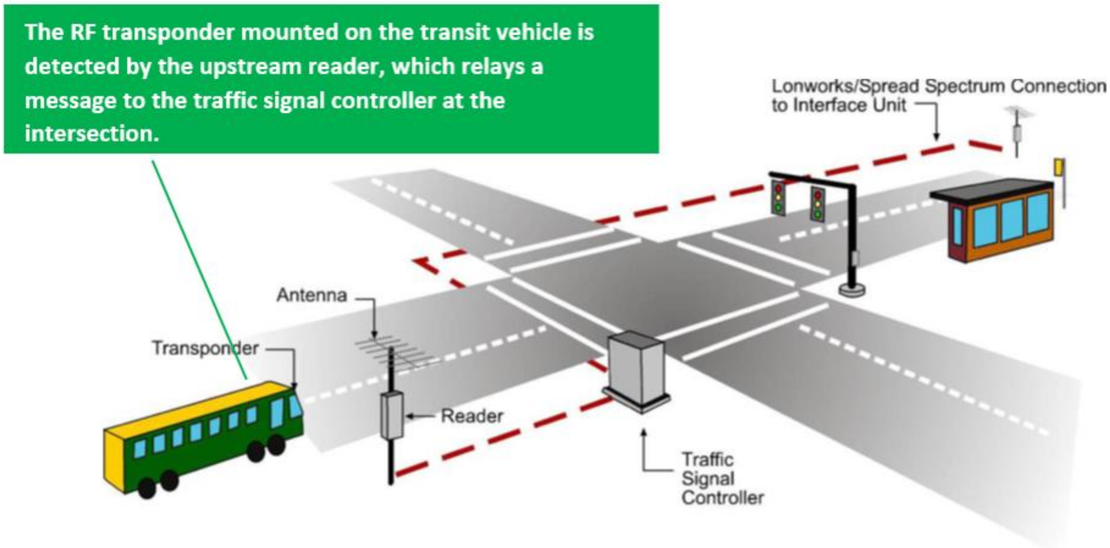


RFID (Radio Frequency Identification) is a wayside, reader-based detection technology. Though this technology is commonly used for highway tolling systems, these readers have not seen much use in the transit industry.

This detection system option consists of three parts: 1) a vehicle mounted RF transmitter, 2) a wayside reader, and 3) a priority interface device.

As the bus approaches an intersection, the transmitter sends a radio signal to a wayside receiver mounted on a roadside pole upstream of the intersection. This wayside receiver then relays the signal to a priority interface device located in the traffic control cabinet either in a distributed system, or forwards the message onto a traffic and/or transit management center in a centralized system to determine if and how much priority should be granted. Note: for the Advance Transit project there will be no centralized control. TSP would be initiated locally (decentralized control).

Figure 6 - RFID Operations



Graphic credit: King County, WA

Advantages

- Line of sight and visibility are not required for detection.
- Requires little new equipment on the bus, and per vehicle cost of installing is low. The low installation costs could allow all Advance Transit buses in the fleet to be fitted with such technology.
- The transponders are very small, are easy to install and require no direct interface or source of power from the bus.

Limitations

- Equipment required is not easily retrofitted into existing controller equipment cabinets. The labor and configuration costs can be high. More specifically, equipment needs to be installed within the cabinet to interface between the controller and the tag reader. This will require a radio and perhaps a serial interface, in addition to software modifications so the tag reader can communicate with the various municipal and state controllers.
- Requires suitable curbside mounting locations upstream of the intersections for the tag readers and communications. The RF reader technology requires installation upstream on a utility pole or cantilever structure with access to power. Finding a suitable location, obtaining approvals, and installing it is sometimes difficult and can be a lengthy process.
- Communications (in most cases conduit and cable) needs to be installed between the curbside monitoring location and the traffic controller. This results in increased equipment and construction costs as well as potentially requiring full sidewalk reconstruction complete with ADA compliance, if the conduit is under an existing sidewalk.
- Check-in/check-out capabilities can be provided if two wayside detectors (and mast arms) are installed on each side of the intersection, which can be very costly.

- Additional mast arms or roadside poles may have a visual impact upon the streetscape, as well have high installation costs.
- This technology is not predictive. Thus, a bus approaching the intersection at very slow speeds may trigger a premature request for TSP, which if granted, may not be utilized by the bus.

GPS Technology

Functionally the GPS interface operates similar to the Optical system; however, with GPS, the positioning and speed of a bus can be used to more efficiently send a call for a TSP application as the bus approaches an intersection. In addition, line of sight is not required for the GPS priority call to be received by the traffic controller.

Unlike the Optical system, the GPS receiver can be mounted in the controller cabinet and therefore does not require additional infrastructure (cabling, receivers, etc.) to be installed at the intersection.

A GPS device will be required for each bus serving the Blue and Green routes, as well as appropriate detection equipment at the local intersection cabinet. As the oncoming bus enters the intersection’s radio range, the bus sends speed, heading and position information that is updated every second to an antenna located in proximity to the traffic controller cabinet and to the GPS Phase Selector in the controller cabinet, which then requests green-light priority through normal controller functions.

Advantages

- Wireless communications reduce infrastructure costs needed to implement TSP, eliminating the need for supplemental mast arms or other such infrastructure.
- Line of sight and visibility are not required for TSP detection.
- Potential to utilize the same system equipment on both emergency (for preemption) and on transit buses (for TSP) routines (with different coding).
- GPS can offer check-in/check-out capabilities to allow efficient return to non-TSP operations. This will minimize impacts upon cross street traffic.
- TSP manufacturers GPS technology could potentially be integrated into a transit agencies bus Maintenance and Management System.

Limitations

- Existing GPS, if present for agencies Automatic Vehicle Location (AVL) systems may not be compatible with the TSP GPS system.
- Requires manufacturer’s GPS device mounted in each bus utilizing the Blue or Green Route.
- Introduces another GPS device on-board the transit vehicle as each bus operating along Blue and Green Line.
- GPS system may fail to locate the transit vehicle in some locations due to “urban canyon” effect (where the GPS signal cannot be properly received), which would prevent adequate TSP operations. However, this is not anticipated to be an issue for the Advance Transit Routes.

Centralized Automatic Vehicle Locator System

An AVL (Automatic Vehicle Location) system continually senses or calculates, at intervals, the location of transit buses along the roadway corridor. Bus location can be used in various applications, including schedule adherence monitoring, operational control and incident management through computer-assisted dispatching, real-time customer information, passenger counting, and transit signal priority, etc. Most AVL systems now use GPS to determine vehicle location.

This type of detection system is the most reliant on the existing communication infrastructure on the transit vehicle, using the Automatic Vehicle Location (AVL) system. The equipment is comprised of a GPS unit connected to a radio system, which sends information to the Transit Management Center or Traffic Management Center. If sent directly to the traffic management center, the signal system can directly act on the request based on established criteria.

Advantages

- No additional hardware on the transit vehicle if a functional AVL system is already in place.
- Data flows may be directed to the traffic or transit management center.
- Ability to transfer information such as vehicle location, speed, and schedule adherence.
- System provides check-in and check-out capabilities to allow efficient return to non-TSP operation.
- Line of sight and visibility are not required

Limitations

- Latency in receiving requests from buses per their polling rate (communication frequency) (unless priority messages are given higher status).
- Requires real-time communication between Traffic Management Center (signal system) and local traffic signal controller (not currently in place within the Advance Transit Routes).

Wi-Fi Wireless Communication

Wi-Fi and Cellular Digital Packet Data (CDPD) wireless communication systems is becoming increasingly popular for ITS applications. The IEEE 802.11 spread spectrum wireless local area network (WLAN), after some initial refinement, has been very successful and is being expanded. The wireless communication system is fairly similar to what is implemented on mobile technology devices. Packets of information are sent via radio waves between the transit vehicle (mobile client) and each intersection (terminal client), both of which are IP addressable.

Infrastructure on the bus and in the traffic signal controller cabinet communicates within the available range of the network.

Advantages

- Effective use of new technology for implementation of NTCIP messages.
- Greater range than many other detection technologies.
- Data flows may be between the vehicle and traffic signal controller, and between the traffic signal controllers using various communications medium available

- Relatively low hardware cost

Limitations

- Initial costs associated with development of specific hardware tailored to meet local traffic signal systems' needs
- Detection range may be limited by the coverage of the network
- May be sensitive to line-of-sight restrictions depending on type of antenna used.

Evaluation

While the AVI system may be feasible, the need to ensure proper location of loop detection in each approach lane is a deterrent, particularly for a system that is trying to be retrofitted into existing signalized intersections. To function properly, additional loops may need to be installed which could require additional conduit, cable and could potentially exceed the controller cabinets detection capabilities. Furthermore, the detection is in pavement and may require additional resurfacing costs if current pavement conditions are deteriorated. This technology is not commonly used in the northeast and may not be familiar to local contractors. **This technology should be eliminated from further consideration.**

The RFID is non–predictive in terms of bus arrival predictability and costliness of the wayside/roadway detection devices and mounting systems are a deterrent. The roadside detection devices and mountings can be an aesthetic issue as well. There may also be cabinet interface issues as additional equipment must be installed within the cabinet to communicate between the tag reader and the controller. Furthermore, the technology does not seem to have been used in many deployments across the country. **This technology should be eliminated from further consideration.**

Without the development of an extensive communications backbone throughout the GREEN and BLUE routes to and between each local intersection and a Transit Management Center at Advance Transit, a centralized AVL is not possible. **The costs associated with the development of a robust communications backbone likely make this technology impractical for this project.**

Wi-Fi or Cellular based system could be feasible. However, this is fairly new technology for TSP applications particularly in the northeast region. **It is recommended that this technology be eliminated in favor of a more proven and familiar application.**

Two very good and reliable technology options are left for consideration. Both optical and GPS are very similar in their benefits. GPS, is the more state-of-the-art technology and has much better predictive capabilities. GPS has the benefit of not being limited by line of sight issues and the detection range can be adjusted. In addition, most manufacturers currently provide "dual mode" phase selectors which allow a gradual transition from Infrared Technology to GPS technology. This is a significant benefit for locations where emergency pre-emption is utilizing infrared technology.

As new equipment is purchased (emergency vehicles or transit vehicles) they can be equipped with GPS radios (emitters) and take advantage of that technology, while older infrared technology on existing equipment remains functional.

Overall costs are comparable. While the vehicle's GPS unit is a bit more costly than the infrared emitter, the on-street hardware and installation is less costly for the GPS system as additional cabling, conduit, and traffic management is not required.

Rough Order of Magnitude Cost for the two systems is illustrated in Table 1

Table 1 - GPS vs Optical TSP Equipment Costs

	GPS	OPTICAL
BUS COSTS (per bus)		
	$4,000.00 Unit (Furnish & Install)	$3,000.00 Emitter (Furnish & Install)
Field Installation (per intersection)		
	$4,000.00 - $6,000.00	$4,500.00 - $9,000.00 New Installation (Furnish & Install $4,500.00 - $6,000.00 Existing Receivers (Furnish & Instal * Prices dependent on number of approa

NOTE: Prices above do not include cost for traffic controller software or new conti
NEW TRAFFIC CONTROLLER ≈ $7,000
SOFTWARE UPGRADE ≈ $3,000

GPI cross examined the multiple options listed above to determine a recommended technology that would be compatible with the local infrastructure, relatively simple to implement, and cost efficient. The results are summarized in Table 2 below and indicate that a GPS based detection system would be the best option to consider for future deployments. Furthermore, based on the limitations of the existing infrared emergency vehicle pre-emption systems experienced by the local emergency services, the PAC does not wish to invest further funds into an infrared based system.

Table 2 - TSP Technology Review

TSP Technology Review Evaluation

ISSUES	AVI Loops	Optical Infrared	GPS	RFID	Centralized AVL	Wi-Fi
Interface with Existing On-Street Signal Equipment	Red	Green	Green	Red	Red	Red
Ease of Installation	Green	Yellow	Yellow	Green	Yellow	Yellow
Additional Field Requirements/Construction	Red	Yellow	Green	Red	Red	Red
Impacts on Corridor Aesthetics	Green	Green	Green	Red	Green	Green
Check-In/Predictability	Green	Green	Green	Red	Green	Green
Check-Out	Yellow	Green	Green	Red	Green	Green
Maintenance	Red	Yellow	Green	Red	Yellow	Yellow
Proven Technology	Red	Green	Green	Yellow	Yellow	Red
Expandability	Red	Yellow	Green	Red	Red	Yellow
Construction-Implementation Cost	Yellow	Yellow	Green	Red	Red	Yellow
Vehicle Installation Cost	Green	Green	Yellow	Green	Yellow	Yellow
Software Cost	Green	Green	Green	Yellow	Red	Yellow
OVERALL	Yellow	Green	Green	Red	Yellow	Yellow

Table 3 provides additional detail on each of the above criteria.

Table 3 - GPS vs Infra-Red Optical Detailed Comparison

Issue	GPS	Infra-Red Optical
Installation	Requires only mounting radio & GPS antenna at the traffic controller. No need for interruption of traffic during installation	Detector wire must run across mast arms or through conduit. Detectors need to be placed in line of sight. Traffic stoppage needed for bucket or platform vehicle.
Maintenance	There is no required periodic maintenance.	Detectors and emitters must be cleaned annually to remove dirt and buildup of film on optical receiver which can affect performance. Detector heads occasionally need resetting due to movement from vibration which can effect line of sight and thereby system performance.
Line of Sight	GPS is not effected by line of sight issues. Curves in the road, tree branches, larger vehicles in front of the responder and hills do not effect performance	Requires clear line of sight to vehicle. Curves in the road and hills can affect performance and an advance detector must be added to the installation to improve range. Long wire runs may be necessary for installation of advance detector. Tree limbs and leaves blocking detector heads must be trimmed or removed annually. Bus lanes in the right lane usually experience the line of sight obstructions which can affect system performance.
Turn Signal Dependent Mode	Sends signal to the next intersection when vehicle turn signal is used. This improves system efficiency and minimizes effect on signal coordination	There is no turn signal dependent mode. Intersection will not react until vehicle is in line of sight. Can false trigger corridor signals when vehicle is turning.
Effect on Signal Coordination	The intersection is tracking bus speed and location to estimate time of arrival and thus, when TSP should be activated.	Once vehicle is in range the call is placed to preempt regardless of bus speed or operational delay that may occur prior to reaching the intersection.
Controller Clock Update	Uses an atomic clock that can provide updates to the controller to keep time accurate for time–based coordination. Time based is what Yonkers currently employs.	There is no atomic clock
Precision of Call	GPS measures speed and location and requests TSP based on an accurate estimated time of arrival	Infra-red is limited by line of sight.

Conclusion

Based upon the above information, existing conditions along the project corridors and the disadvantages of the alternative system technologies, the PAC has determined that the desired communications between transit vehicles and on-street traffic signal control be provided utilizing GPS technology. The annual maintenance costs associated with a GPS based system are lower and reliability and efficiency are maximized. Furthermore, current equipment provided by GPS TSP control manufactures provide backwards compatible with infra-red emergency pre-emption systems allowing a gradual transition for emergency service providers to migrate to a GPS based vehicle pre-emption system while maintaining the functionality of the existing infra-red system currently on vehicles.

SECTION 3 – ASSESSMENT OF EXISTING TRAFFIC CONTROL EQUIPMENT

Introduction

In order to identify the potential to provide TSP throughout the AT Blue and Green routes, it was critical to have an understanding of the existing traffic control systems in place along the corridors, as well as to determine the capabilities of the various control equipment.

To assess the existing traffic signal infrastructure, a physical inventory of 31 signalized intersections under the jurisdiction of four (4) agencies (City of Lebanon, NH, Town of Hanover, NH, Vermont Transit Agency (VTrans) and New Hampshire Department of Transportation (NHDOT)) was completed. The intersection of West Park Street at South Park Street and Church Street while on the Blue line is a pedestrian only signal and would not be considered for TSP. The intersections of Route 120 at the Medical Center Drive (Lebanon) and South Main Street at Maple Street (Hanover), are not active signals on the transit routes but are coordinated with signals that may be considered for TSP and therefore an inventory of the hardware was included.

The results of the signal inventory are included in Appendix A.

Existing Traffic Controller Operations

There are a variety of traffic controllers present throughout the intersections and the capabilities range from legacy controllers in excess of 30 years old to new state of the art traffic controllers. The traffic signal inventory focused on obtaining the existing operational parameters (signal timing, coordination, phasing, etc.) as well as assessing the capabilities to provide TSP. If critical operational issues were identified that would impact the analysis and evaluation (i.e. malfunctioning vehicle detection, etc.) that information was noted. All controllers are NEMA based controllers and include the following manufacturers:

- McCain
- Econolite
- PEEK
- Naztec

Table 4 highlights the Controller information by Route.

Table 4 - Traffic Signal Controller Information

Location	Jurisdiction	Bus Route	Controller Manufacturer	Controller Model #	Controller Firmware
Route 120 at Lebanon St and Co-Op Driveway	Hanover	Blue	McCain	ATC eX NEMA	Omani eX V:1.5.0.4509
Route 120 at Summer St and Summer Ct	Hanover	Blue	McCain	ATC eX NEMA	Omni eX V: 1.3.3.4291
Lebanon St at Summer St	Hanover	Blue	McCain	ATC eX NEMA	Omni eX V: 1.7.0.5664
Main St at Lebanon St	Hanover	Blue	McCain	ATC eX NEMA	Omani eX V: 1.5.0.4509
Main St at Wheelock St	Hanover	Green	McCain	ATC eX NEMA	Omani eX V: 1.7.0.5664
Route 120 at Lyme Rd & Dewey Field Road	Hanover	Blue	McCain	ATC eX NEMA	Omani eX V: 1.6.1.4766
Route 120 at Wheelock St	Hanover	Blue	McCain	LMD 9200	Rev 4B
Route 120 at Heater Rd	NHDOT	Blue	Naztec	Series 900 ATC. 980-B230	76.13M. Build 4732
Route 120 at I-89 NB	NHDOT	Blue	Naztec	900 ATC. 980-B230	76.13M. Synchro Green
Route 120 at I-89 SB	NHDOT	Blue	Naztec	900ATC. 980-A0300-1	76.13 M. Local, Sync Green
Mt. Supprt Rd at Lahaye Dr	Lebanon	Blue	Econolite	ASC/2S-2100	1.78
Route 120 at Medical Center Dr	NHDOT	Blue	Naztec	NT900-TX	V14.16
Route 120 at Greensboro Rd	NHDOT	Blue	Naztec	NT900TXII/CL	V14.16
Maple St at Bridge St & Pine St	VTrans	Green	Econolite	ASC/2-2109	32787 Ver 1.64
Maple St at Prospect St	VTrans	Green	McCain	ATC eX NEMA	Omni eX V: 1.6.3
Hartford Ave at Maple St (Rte 4 at Rte 5)	VTrans	Green	Naztec	980-A0200-1	V61.49
Route 5 at Highland Ave and Worcester Ave	VTrans	Green	Naztec	981-A1200-1	V61.49
Main St at Railroad Ave & Tracy St	Lebanon	Green	Peek	LMD 8000	0807798 Rev: 7.4.17
Main Street at Bridge St & Dana St	Lebanon	Green	Peek	LMD 8000	0807170 Rev. 8L
Route 10A at Route 5 & I-91 SB	VTrans	Green	Econolite	ASC/2-2100	1.74. 32787
Route 10A at I-91 NB	VTrans	Green	Econolite	ASC/2-2100	1.30. 32787
Route 10A at River Road	VTrans	Green	Econolite	ASC/2S-2100	1.79. 34556

The Town of Hanover recently upgraded to McCain Advanced Traffic Control (ATC) units. At the time the inventory was completed the controller at the intersection of Route 120 at Wheelock St was a legacy PEEK LMD-8000 controller. The controller has been scheduled to be upgraded to a McCain ATC controller. Therefore, for the purposes of this study it has been assumed that the newer McCain controller would be installed prior to the implementation of the TSP system. The majority of the intersections in Hanover are interconnected and provide Ethernet communications over copper wire. Of the locations inventoried, the signals in the Town of Hanover provide the most advanced traffic signal controllers and communications system.

The three Naztec controllers at the intersections of Route 120 at I-89 NB, I-89 SB and Heater Road are under the jurisdiction of NHDOT and are also new ATC controller units and are currently running the Synchro Green Adaptive Signal Control software.

Existing Pre-Emption Systems

As part of the field inventory, the presence of an Existing Emergency Vehicle Pre-Emption System was noted. Table 5 summarizes the locations based on the presence of an Emergency Vehicle Pre-Emption system. All the pre-emption systems currently provided operate with infrared, line of sight communication between the emergency vehicles equipped with an emitter on each approach to the intersection.

While these systems have the potential to be upgraded to provide a basic Green Extend TSP operation, insight from the PAC indicated that emergency services in the area towns are generally experiencing poor operations of the Emergency Vehicle Pre-Emption system due to line of sight issues and/or misalignment of the emergency vehicle pre-emption receivers. As such, the PAC has decided that moving forward and investing further money in an infrared based TSP system is not practical or cost effective.

Table 5 - Existing Emergency Vehicle Pre-Emption

Location	Municipality	Jurisdiction	Bus Route	Pre-Emption Present	Pre-Emption Card Manufacturer
Route 120 at Lebanon St and Co-Op Driveway	Hanover	Hanover	Blue	Yes	Opticom
Route 120 at Summer St and Summer Ct	Hanover	Hanover	Blue	Yes	Opticom
Lebanon St at Summer St	Hanover	Hanover	Blue	Yes	Opticom
Main St at Lebanon St	Hanover	Hanover	Blue	Yes	Opticom
Main St at Wheelock St	Hanover	Hanover	Green	Yes	Opticom
Route 120 at Lyme Rd & Dewey Field Road	Hanover	Hanover	Blue	Yes	Opticom
Route 120 at Wheelock St	Hanover	Hanover	Blue	Yes	Opticom
Route 120 at Heater Rd	Lebanon	NHDOT	Blue	Yes	Tomar
Route 120 at I-89 NB	Lebanon	NHDOT	Blue	Yes	Tomar
Route 120 at I-89 SB	Lebanon	NHDOT	Blue	Yes	Tomar
Mt. Supprt Rd at Lahaye Dr	Lebanon	Lebanon	Blue	Yes	Opticom
Route 120 at Medical Center Dr	Hanover	NHDOT	Blue	No	
Route 120 at Greensboro Rd	Hanover	NHDOT	Blue	No	
Maple St at Bridge St & Pine St	Hartford	VTrans	Green	No	
Maple St at Prospect St	Hartford	VTrans	Green	No	
Hartford Ave at Maple St (Rte 4 at Rte 5)	Hartford	VTrans	Green	Yes	Tomar
Route 5 at Highland Ave and Worcester Ave	Hartford	VTrans	Green	Yes	Tomar
Main St at Railroad Ave & Tracy St	Lebanon	Lebanon	Green	Yes	Opticom
Main Street at Bridge St & Dana St	Lebanon	Lebanon	Green	Yes	Opticom
Route 10A at Route 5 & I-91 SB	Norwich	VTrans	Green	No	
Route 10A at I-91 NB	Norwich	VTrans	Green	No	
Route 10A at River Road	Norwich	VTrans	Green	No	

Traffic Controller Capabilities

Both the McCain controllers and Naztec controllers at the intersections of Route 120 at I-89 NB, I-89 SB and Heater Road are capable of providing both Early Return to Green and Green Extend TSP operations. The remaining controllers have varied capabilities to provide TSP.

Each of the controller manufacturers was contacted to determine what upgrades to the existing on-street signal hardware would be required to upgrade to a GPS based TSP system capable of providing both Green Extend and Early Return to Green functionality.

In order to provide full TSP functionality including Early Return to Green as well as the Green Extend feature, additional upgrades are required to the signal control.

Table 6 - Controller Needs

Location	Municipality	Jurisdiction	Bus Route	Controller Manufacturer	Controller Model #	Upgrades Required for Full TSP
Route 120 at Lebanon St and Co-Op Driveway	Hanover	Hanover	Blue	McCain	ATC eX NEMA	None
Route 120 at Summer St and Summer Ct	Hanover	Hanover	Blue	McCain	ATC eX NEMA	None
Lebanon St at Summer St	Hanover	Hanover	Blue	McCain	ATC eX NEMA	None
Main St at Lebanon St	Hanover	Hanover	Blue	McCain	ATC eX NEMA	None
Main St at Wheelock St	Hanover	Hanover	Green	McCain	ATC eX NEMA	None
Route 120 at Lyme Rd & Dewey Field Road	Hanover	Hanover	Blue	McCain	ATC eX NEMA	None
Route 120 at Wheelock St	Hanover	Hanover	Blue	McCain	LMD 9200	None
Route 120 at Heater Rd	Lebanon	NHDOT	Blue	Naztec	Series 900 ATC. 980-B230	Software/License
Route 120 at I-89 NB	Lebanon	NHDOT	Blue	Naztec	900 ATC. 980-B230	Software/License
Route 120 at I-89 SB	Lebanon	NHDOT	Blue	Naztec	900ATC. 980-A0300-1	Software/License
Mt. Supprt Rd at Lahaye Dr	Lebanon	Lebanon	Blue	Econolite	ASC/2S-2100	New Controller
Route 120 at Medical Center Dr	Hanover	NHDOT	Blue	Naztec	NT900-TX	New Controller
Route 120 at Greensboro Rd	Hanover	NHDOT	Blue	Naztec	NT900TXII/CL	New Controller
Maple St at Bridge St & Pine St	Hartford	VTrans	Green	Econolite	ASC/2-2109	New Controller
Maple St at Prospect St	Hartford	VTrans	Green	McCain	ATC eX NEMA	None
Hartford Ave at Maple St (Rte 4 at Rte 5)	Hartford	VTrans	Green	Naztec	980-A0200-1	Software/License
Route 5 at Highland Ave and Worcester Ave	Hartford	VTrans	Green	Naztec	981-A1200-1	Software/License
Main St at Railroad Ave & Tracy St	Lebanon	Lebanon	Green	Peek	LMD 8000	New Controller
Main Street at Bridge St & Dana St	Lebanon	Lebanon	Green	Peek	LMD 8000	New Controller
Route 10A at Route 5 & I-91 SB	Norwich	VTrans	Green	Econolite	ASC/2-2100	New Controller
Route 10A at I-91 NB	Norwich	VTrans	Green	Econolite	ASC/2-2100	New Controller
Route 10A at River Road	Norwich	VTrans	Green	Econolite	ASC/2S-2100	New Controller

The majority of the signals along the Blue route are capable of providing a full TSP (both Green Extend and Early Return to Green functionality) operation. All the newer McCain controllers installed within the Town of Hanover, NH are capable of providing full TSP. Two of the controllers may require a firmware update, but in discussions with the manufacturer there is no cost associated with upgrading the McCain software in the controller.

The two Naztec NT900 controllers could be upgraded with firmware upgrades; however, the controllers are older legacy controllers and the manufacturer recommends replacement of the controllers if TSP was desired. The remaining Naztec 900 ATC, 980 and 981 series controllers require TSP licensing software and potentially a firmware update, but the controllers do not need to be replaced.

Along the Green route, the Econolite ASC/2 controller is no longer supported by Econolite for parts or software and while the ASC/2s is still supported for parts, it is no longer supported for software support. Therefore, while it is possible to upgrade the firmware in the ASC/2s controllers the manufacturer recommends replacing the controllers if TSP is desired.

The older Peek LMD 8000 controllers are legacy controllers and do not support Full TSP operations and therefore these controllers are recommended to be replaced.

Additional On-Street Signal Hardware Components

In addition to upgrading the traffic controllers, in order to implement a GPS based TSP system all intersections will require installing new GPS detection systems. These devices consist of a GPS radio receiver mounted externally to the traffic controller cabinet as well as a Priority Detector mounted within the controller cabinet. The priority detector is available as a GPS only unit or a dual function Optical/GPS unit that allows an existing Optical based emergency pre-emption system to remain functional while providing a new GPS based TSP system. This also allows existing Emergency Service providers to gradually transition their vehicle fleets from Optical to GPS based pre-emption while maintaining functionality. Finally, the traffic control strategy for the TSP functionality needs to be engineered and implemented.

Vehicle Requirements

In order to request TSP operations, each transit vehicle needs to be outfitted with a GPS based radio emitter. While the Advance Transit buses are equipped with GPS units, the current units do not provide location updates frequently enough to integrate into a TSP system. The current radios transmit a location update approximately once every 7-8 seconds. While this is suitable for tracking buses and reviewing schedules, it does not provide sufficient accuracy to determine the arrival of the bus to the signal.

Integration with Existing AVL Systems

Advance Transit utilizes a custom AVL System. The system does not transmit ridership data; however it does predict the arrival time to each stop based on bus positions. Working with the AVL system integrator, and the TSP manufacturer, this predictive algorithm could be modified to integrate a schedule adherence priority and provide Conditional Service for TSP to provide additional system efficiency.

SECTION 4 – ANALYSIS

Introduction

Transit Signal Priority (TSP) can improve bus service and operating efficiency without significantly impacting general traffic operations or delay. Retiming or optimizing the signals prior to implementing TSP aids in minimizing the impact of TSP on overall traffic conditions. To determine the existing condition and operating efficiency of the signals and bus routes, existing data was collected at all major intersections along the Green and Blue bus routes. The data collection consisted of:

- Vehicle volumes and class
- Pedestrian volumes
- Signal timings and settings
- Roadway geometry
- Vehicle travel time
- Bus routes, stops and travel time

Data Collection

Existing traffic conditions at the study area intersections were developed by conducting manual-turning movement counts (TMCs) in the spring (April and May) and summer (July) of 2016. The scope of the study focused on the critical morning peak hours where the AT buses are experiencing the greatest delays, therefore the TMCs were performed during the weekday AM peak period (7:00 to 9:00 AM). Traffic-volumes are typically adjusted to peak-month conditions. Based on a review of historic traffic counts collected by NHDOT at permanent count stations in the area, traffic volumes in April are 4.8 percent lower than peak-month conditions. The April TMCs were increased by 4.8 percent. To provide a conservative (worst case) analysis condition, the counts from May and July are typically higher than April volumes, therefore May and July volumes were also increased by 4.8 percent. The seasonally adjusted volume networks were then balanced between intersections where appropriate.

The seasonally adjusted and balanced TMC networks are provided in the Appendix B.

Actual traffic signal timing and operations were collected as part of the signal inventory and manual travel time runs were conducted during the AM peak hours for each of the selected portions of the Green and Blue bus routes. A stop watch and personal vehicle were used to drive the bus routes and measure the time from beginning to multiple checkpoints along each route. Multiple runs were conducted and the average was taken to present more accurate data. The Advance Transit bus route web interface was used to collect bus travel time and bus stop dwell time data. Multiple runs were collected and the average was taken to present more accurate data.

Analysis Methodology

The signalized intersection capacity and queue analyses were conducted using methodology from the *Highway Capacity Manual (HCM) 2000*[2] due to the restrictions posed on signalized intersection analysis using Synchro 8.0 by the more recently published *HCM 2010*. This includes the inability of HCM 2010 to analyze non-NEMA signal phasing and exclusive pedestrian phases. To remain consistent throughout the study, GPI conducted all signalized intersection capacity and queue analyses using *HCM 2000* methodology, as it represents the most previous state and federally accepted methodology for analyzing capacity, delay, and queues.

Capacity analyses provide an indication of how well the intersection accommodates the traffic demand placed upon it. A primary result of capacity analysis is the assignment of levels of service to traffic facilities under various traffic flow conditions. The concept of level of service (LOS) is defined as a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers. A level-of-service definition provides an index to quality of traffic flow in terms of such factors as speed, travel time, freedom to maneuver, traffic interruptions, comfort, convenience, and safety.

Six levels of service are defined for each type of facility. They are given letter designations from A to F, with LOS A representing the optimal operating conditions and LOS F the least desirable operating conditions. Since the level of service of a traffic facility is a function of the traffic flows placed upon it, such a facility may operate at a wide range of levels of service, depending on the time of day, day of week, or period of year. A description of the operating condition under each level of service is provided below:

- *LOS A* describes conditions with little to no delay to motorists.
- *LOS B* represents a desirable level with relatively low delay to motorists.
- *LOS C* describes conditions with average delays to motorists.
- *LOS D* describes operations where the influence of congestion becomes more noticeable. Delays are still within an acceptable range.
- *LOS E* represents operating conditions with high delay values. This level is considered by many agencies to be the limit of acceptable delay.
- *LOS F* is considered to be unacceptable to most drivers with high delay values that often occur, when arrival flow rates exceed the capacity of the intersection.

LOS D or better is generally considered an acceptable operating condition. Thresholds for vehicular LOS criteria for signalized intersections are shown in Table 7.

[2] *Highway Capacity Manual 2000*, Transportation Research Board; Washington, D.C.; 2000.

Table 7 - Level of Service Criteria

Level of Service	Signalized Intersection Control Delay Ranges (Seconds)
A	≤10
B	>10 and ≤20
C	>20 and ≤35
D	>35 and ≤55
E	>55 and ≤80
F	>80

Source: *Highway Capacity Manual 2000*, **Transportation Research Board; Washington, D.C.; 2000.**

Control delay is the primary performance measure for signalized intersections. Control delay is the portion of total delay credited to traffic signals. Control delay includes the effects of initial deceleration delay approaching a STOP sign or signal, stopped delay, queue move-up time, and final acceleration delay from a stopped condition. For signalized intersections, the analysis considers the operation of each lane group entering the intersection and the overall condition at the intersection. Control delay coupled with the respective volume-to-capacity ratio characterized the LOS of that lane group entering the intersection. Volume to capacity ratio quantifies the degree to which a phase's capacity is utilized by the lane group.

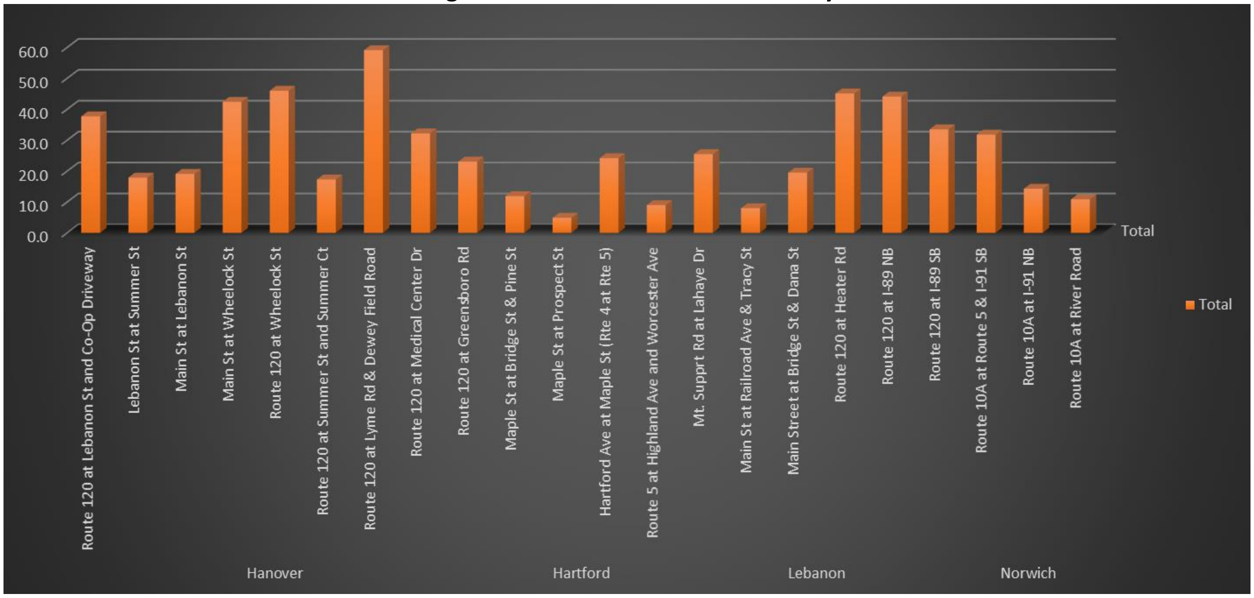
Baseline Operating Conditions

Base operating conditions were determined utilizing traffic modeling software programs Synchro and Aimsun. First, a base condition was established in Synchro to determine the operating condition of the signals. Vehicle volumes and class, pedestrian volumes, signal timing and settings and roadway geometry data were used to create a network of roadways and signals. Synchro is a macroscopic simulation program that models traffic flow as a whole, simulating traffic based on equations of the traffic flow process which predicts conditions at an intersection. Once the base condition was established, the intersections were analyzed to determine the locations along the bus routes with the most congestion and delay. Table 8 provides a summary of the overall level of service for each of the signalized intersections along the Blue and Green Routes. Figure 7 illustrates the overall intersection delays under existing conditions for all signalized intersections along the Blue and Green Routes

Table 8 - Baseline Level of Service

Location	LOS
Hanover	
Route 120 at Lebanon St and Co-Op Driveway	D
Lebanon St at Summer St	B
Main St at Lebanon St	B
Main St at Wheelock St	D
Route 120 at Wheelock St	D
Route 120 at Summer St and Summer Ct	B
Route 120 at Lyme Rd & Dewey Field Road	E
Route 120 at Medical Center Dr	C
Route 120 at Greensboro Rd	C
Hartford	
Maple St at Bridge St & Pine St	B
Maple St at Prospect St	A
Hartford Ave at Maple St (Rte 4 at Rte 5)	C
Route 5 at Highland Ave and Worcester Ave	A
Lebanon	
Mt. Supprt Rd at Lahaye Dr	C
Main St at Railroad Ave & Tracy St	A
Main Street at Bridge St & Dana St	B
Route 120 at Heater Rd	D
Route 120 at I-89 NB	D
Route 120 at I-89 SB	C
Norwich	
Route 10A at Route 5 & I-91 SB	C
Route 10A at I-91 NB	B
Route 10A at River Road	B

Figure 7 - Baseline Intersection Delay



A detailed breakdown of the intersection operations for the existing and optimized scenarios can be found in the LOS tables in the Appendix C.

Project Area and Route Selection

In order to evaluate areas that would benefit most from potential TSP installation, the PAC developed a criteria based on signal density, signal spacing and overall intersection operations. Table 8 illustrates the signal density per mile along the various segments of the Blue and Green routes.

Table 9 - AT Route Summary

Blue Route	Distance (miles)	Signals	Density (sig/mile)
I89 SB-Heater Road	0.5	3	6.0
Heater Road - Lebanon at South Park	5.5	5	0.9
Hanover Loop	2.9	7	2.4
Green Route			
I91 SB (Norwich) - North Main at E. Wheelock (Hanover)	1.5	4	2.7
Route 5 (I91 SB- Route 4)	6.2	3	0.5
Route 4 Loop	1.3	5	3.8

Based on the spacing of the signals it became clear that the segment along Route 120 in Lebanon in the vicinity of the I89 interchange had a high signal density with 3 major signalized intersections within approximately ½ mile.

The section of the Blue route between Route 120 and Lebanon at South Park Street was approximately 5.5 miles in length with only 3 signals within the corridor (5 inclusive of the two signals at each end). With signal spacing between more than ½ a mile up to over 2 miles, the signal density along this corridor would not benefit from TSP operations.

Similarly the 6.2 mile section along Route 5 between Route 4 and the I91 SB interchange was also eliminated for from further consideration for TSP.

The remaining sections (Blue Hanover Loop, Green route from Norwich into Hanover and the Green Route along Route 4) has similar signal densities and were examined further for consideration of TSP implementation.

The signal density was compared against the operational characteristics of the intersections during the morning peak hours and the following four segments were determined by the PAC to warrant further analysis to determine the benefits associated with implementing a TSP system:

- Blue Route - Route 120 at the I89 interchanges and Heater Road
- Blue Route - Hanover, NH Loop
- Green Route – Route 4 Corridor
- Green Route – Route 10 at I91 and River Road into Hanover

TSP Analysis

In order to evaluate the operations of the transit vehicles, a base condition was established utilizing the Aimsun software. Vehicle volumes and class, pedestrian volumes, signal timing and settings, roadway geometry and bus route and stop data were used to create a network of roadways, signals and bus routes and stops. Aimsun is a Microscopic simulation program that models individual vehicles that move along the network according to assigned speed, accelerations and interaction parameters. The randomly assigned driver characteristics allow these models to simulate traffic that reflects real world processes. The base model, or 'Existing Scenario' was then calibrated to have the vehicle and bus travel times in the model match the manually observed vehicle and bus travel time data to most accurately reflect existing conditions.

The signals within the model were then optimized based on Synchro's optimized signal timings to produce a scenario without TSP implemented, but with optimized signal operations. The resulting travel times for the buses were then determined and compared to existing conditions. This 'Optimized Scenario' was used as a base to determine the operational benefits of TSP for the bus routes, independent of the operational benefits from the signal optimization.

TSP parameters were then added to the signals within the model. Consideration was given to the effects of the TSP implementation on the conflicting vehicles (vehicles not benefiting from TSP) and to the *degree* of benefit to the bus travel times. The timing and phasing of some signals did not allow for TSP to be implemented without significant impacts to overall intersection operations. In addition, in certain circumstances, the optimized signal timings were adjust slightly to offset the TSP effects on the overall signal operations where TSP was implemented. The resulting travel times for the buses were then determined for this 'TSP Scenario.'

Note: The analysis was completed for the morning peak hours only and conditions may vary during the afternoon peak period and TSP may be necessary at additional intersections.

TSP Analysis Results

Section of Blue Route in Hanover, NH

Figure 8 illustrates this section of the Blue route. This section in Hanover, NH travels along Route 120 northbound through the Lebanon St intersection, continuing on Route 120 northbound straight through the Summer Street and Wheelock Street intersections. The bus then makes a left at the Lyme Road/College Street/Dewey Field Road intersection onto College Street, leaving Route 120. The bus then makes a right turn onto Maynard Street and a left turn onto Main Street, both stop controlled intersections. The bus continues southbound on Main Street straight through the Wheelock Street intersection, and then turns left at the Lebanon Street intersection. The bus continues on Lebanon Street through the Summer Street intersection, where it returns to the Route 120 at Lebanon intersection traveling straight onto Route 120 southbound. This portion of the Blue bus route is 2.27 miles long and includes seven signalized intersection, and two unsignalized intersections. The two unsignalized intersections were unchanged for the optimized and TSP scenarios.

Table 10 summarizes the overall intersection Level of Service under the existing conditions as well as the Level of Service that can be achieved by optimizing the signal timing.

Figure 8 - Blue Route - Hanover, NH

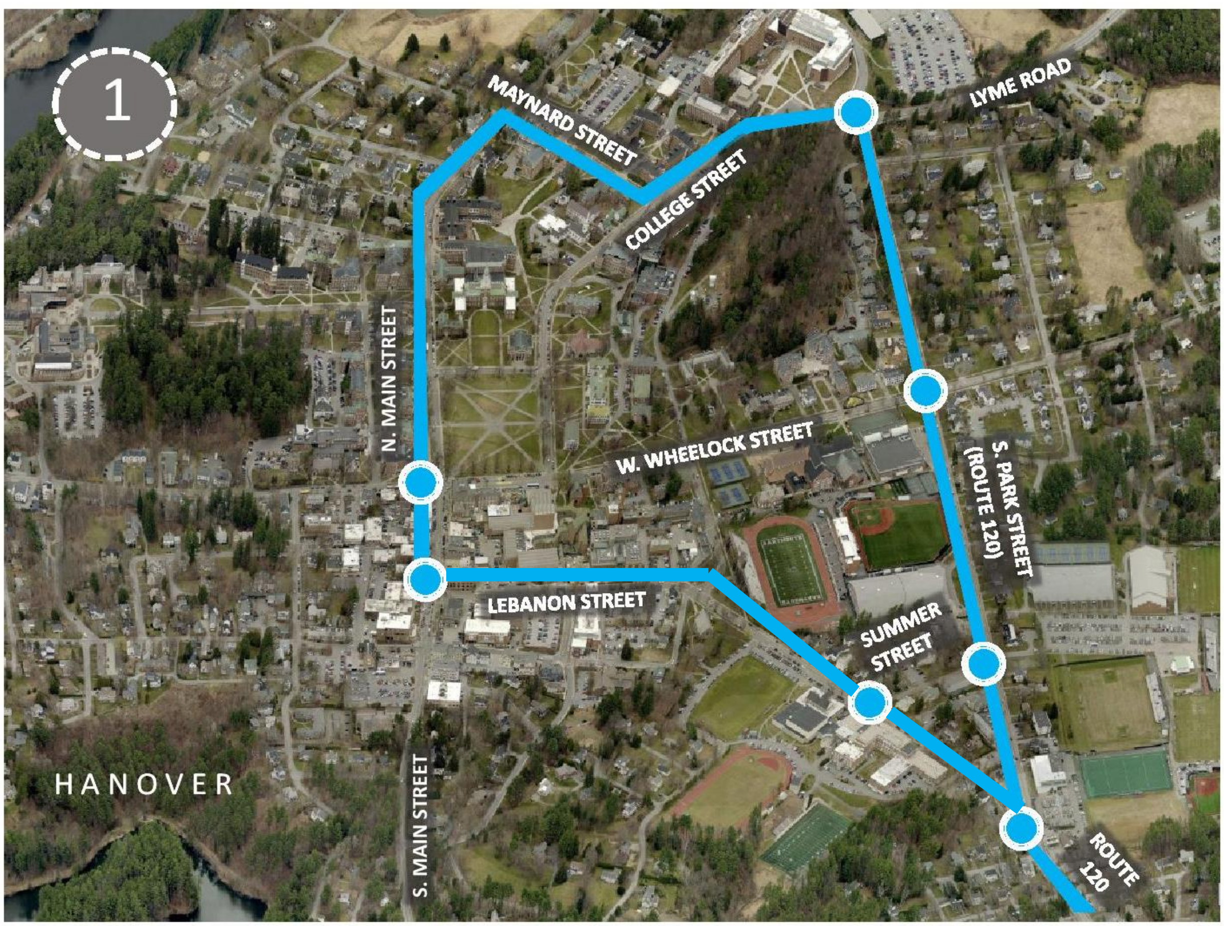


Table 10 - Hanover Blue Route LOS Summary

Hanover Blue Route LOS Summary	Existing LOS	Optimized LOS
Hanover		
Route 120 at Lebanon St and Co-Op Driveway	D	C
Route 120 at Summer St and Summer Ct	B	B
Route 120 at Wheelock St	D	D
Route 120 at Lyme Rd & Dewey Field Road	E	D
Main St at Wheelock St	D	D
Main St at Lebanon St	B	B
Lebanon St at Summer St	B	B

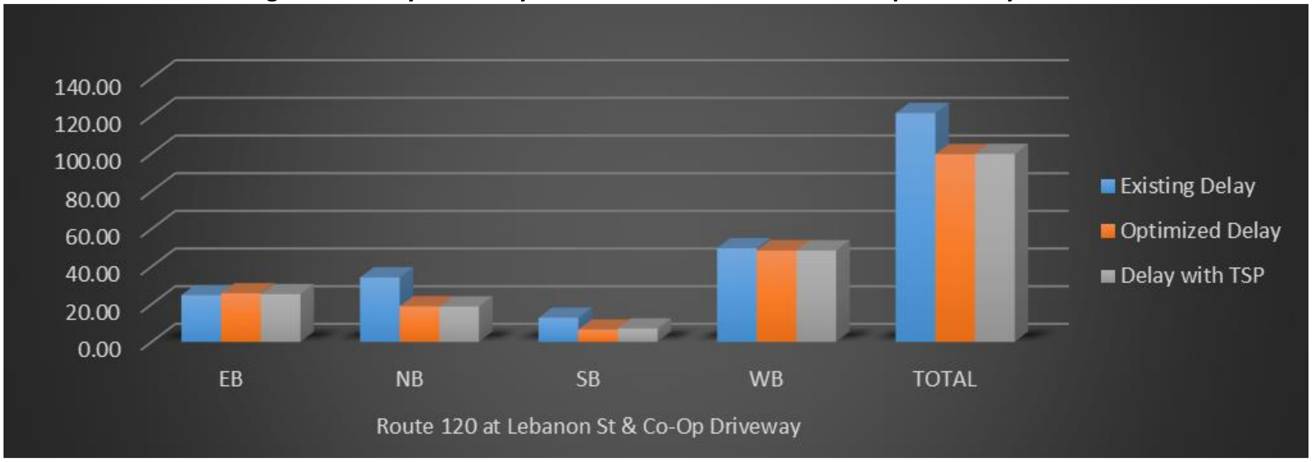
Table 11 below compares the approach delay and total intersection delay under existing conditions, signal operations with optimized timing and no TSP and finally the signal operations with TSP deployed at each signalized intersection along the Blue Route in Hanover.

Table 11 - Blue Route Hanover - Delay Comparison

Intersection	Existing Total Delay	Optimized Total Delay	Total Delay with TSP
Hanover			
Route 120 at Lebanon St & Co-Op Driveway	121.46	99.65	99.75
Route 120 at Summer St & Court St	139.87	83.89	74.94
Route 120 at Wheelock St	237.77	195.83	206.14
Route 120 at Lyme Rd & Dewey Field Rd	51.79	21.77	22.06
Main St at Wheelock St	162.79	154.13	154.05
Main St at Lebanon St	69.80	62.81	62.78
Lebanon St at Summer St	91.65	55.59	54.38

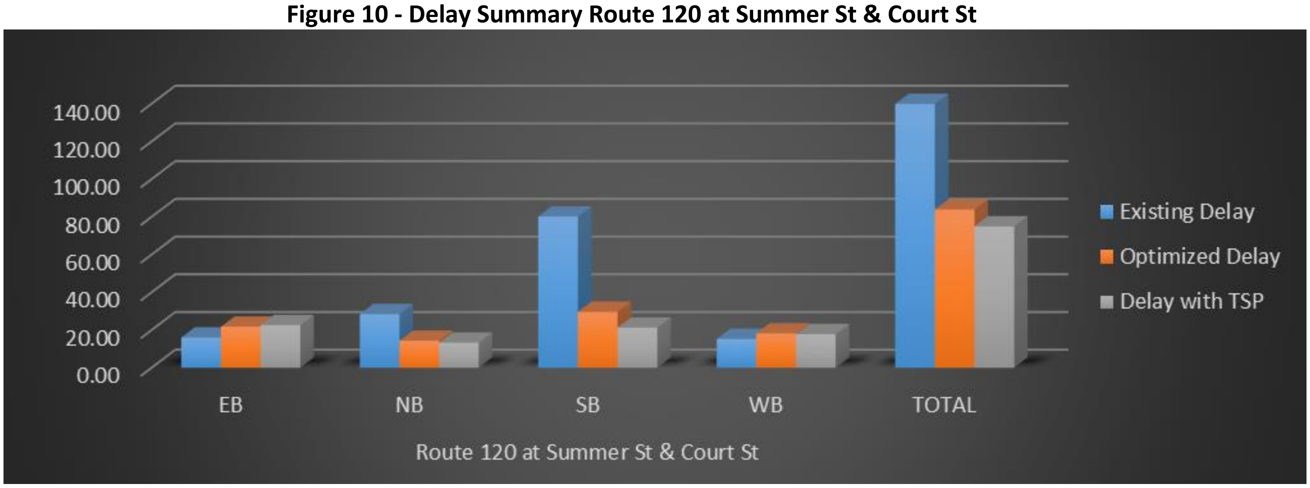
The intersection of **Route 120 at Lebanon Street and the Co-Op Driveway** operates at an overall Level of Service (LOS) ‘D’ during the morning peak hour under existing conditions. The bus movements of Route 120 northbound through and Lebanon Street southbound through operate at a LOS ‘C’ and ‘D’ respectively. Under optimized conditions, the intersection improves operations to an overall LOS ‘C’, with LOS ‘B’ and ‘D’ for the Route 120 northbound and Lebanon Street southbound bus movements respectively. TSP capabilities were utilized at this intersection for the Lebanon Street southbound through movement under the TSP Scenario. Figure 9 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 9 - Delay Summary Route 120 at Lebanon St & Co-Op Driveway



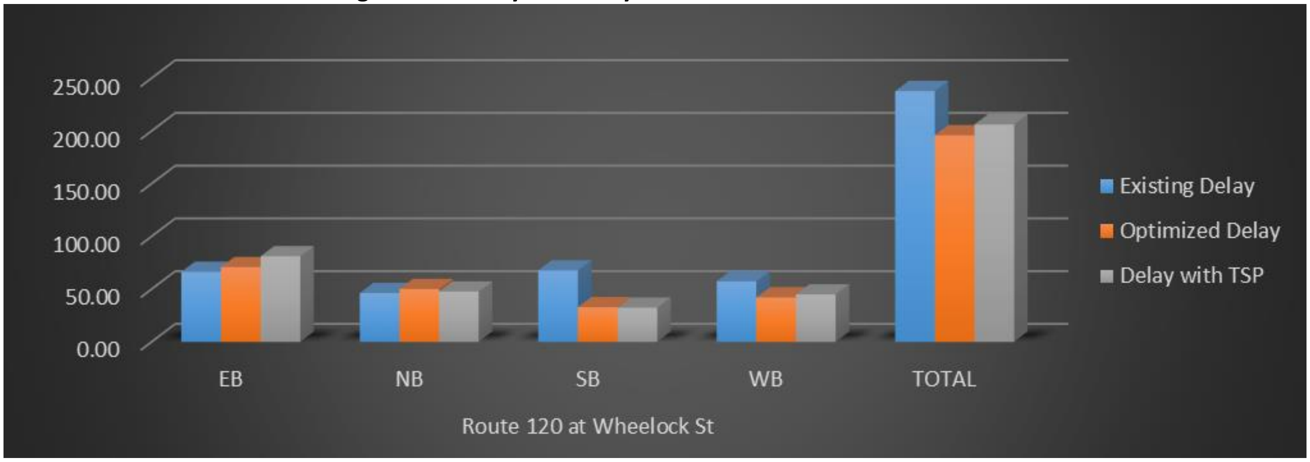
The intersection of **Route 120 at Summer Street and Summer Court** operates at an overall LOS 'B' during the morning peak hour under existing conditions. The bus movement of Route 120 northbound through operates at a LOS 'B'. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings are necessary. Under optimized conditions, the intersection remains at an overall LOS 'B', with LOS 'B' for the Route 120 northbound bus movement. TSP capabilities were utilized at this intersection for the northbound through movement under the TSP Scenario. Figure 14 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 10 - Delay Summary Route 120 at Summer St & Court St



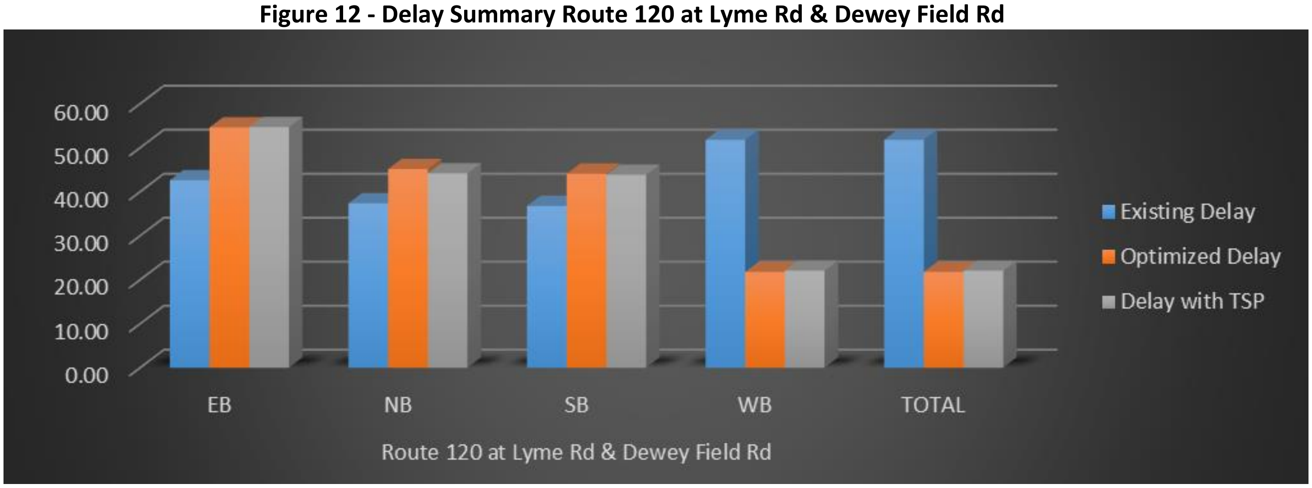
The intersection of **Route 120 at Wheelock Street** operates at an overall LOS 'D' during the morning peak hour under existing conditions. The bus movements of Route 120 northbound through operates at a LOS 'C'. Under optimized conditions, the intersection operations improve slightly remaining an overall LOS 'D', with LOS 'C' for the Route 120 northbound a bus movement. TSP capabilities were utilized at this intersection for the northbound through movement under the TSP Scenario. Figure 13 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 11 - Delay Summary Route 120 at Wheelock St



The intersection of **Route 120 at Lyme Road and Dewey Field Road** operates at an overall LOS 'E' during the morning peak hour under existing conditions. The Lyme Road westbound left movement operates at a LOS 'F' and the bus movements of Route 120 northbound left operates at a LOS 'D'. Under optimized conditions, the intersection operations improve to an overall LOS 'D', with LOS 'D' for the Lyme Road westbound left turn and a LOS 'E' for the Route 120 northbound left bus movement. TSP capabilities were utilized at this intersection for the northbound left turn movement under the TSP Scenario. Figure 15 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 12 - Delay Summary Route 120 at Lyme Rd & Dewey Field Rd

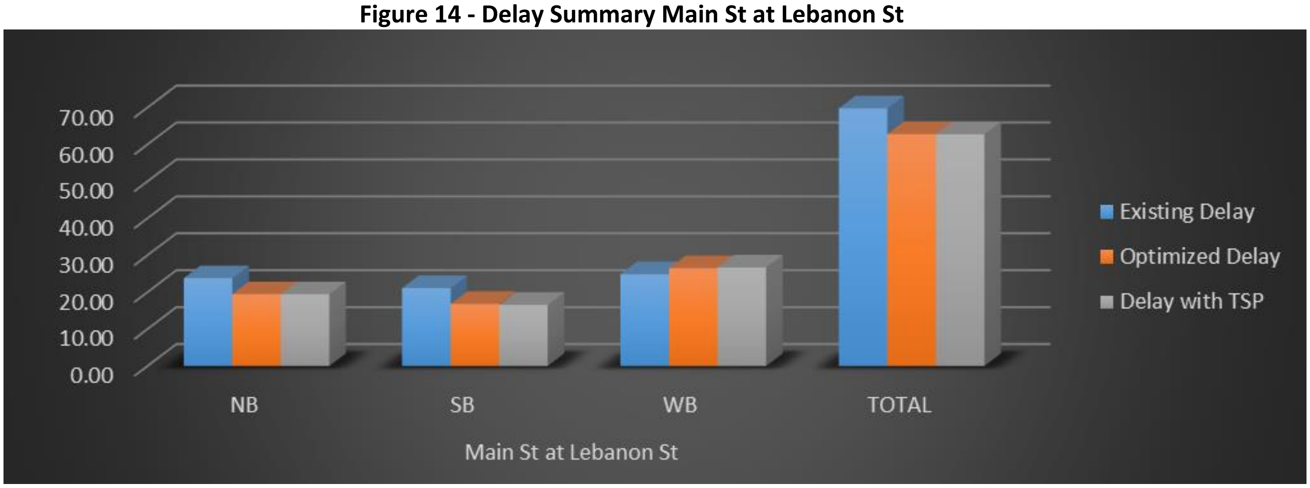


The intersection of **Main Street and Wheelock Street** operates at an overall LOS 'D' during the morning peak hour under existing conditions. The Main Street southbound through movement operates at a LOS 'D'. Under optimized conditions, the intersection operations improve slightly remaining an overall LOS 'D', with LOS 'D' for the Main Street southbound through bus movement. TSP capabilities were not utilized at this location due to minimal bus movement improvements. Figure 12 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 13 - Delay Summary Main Street at Wheelock St

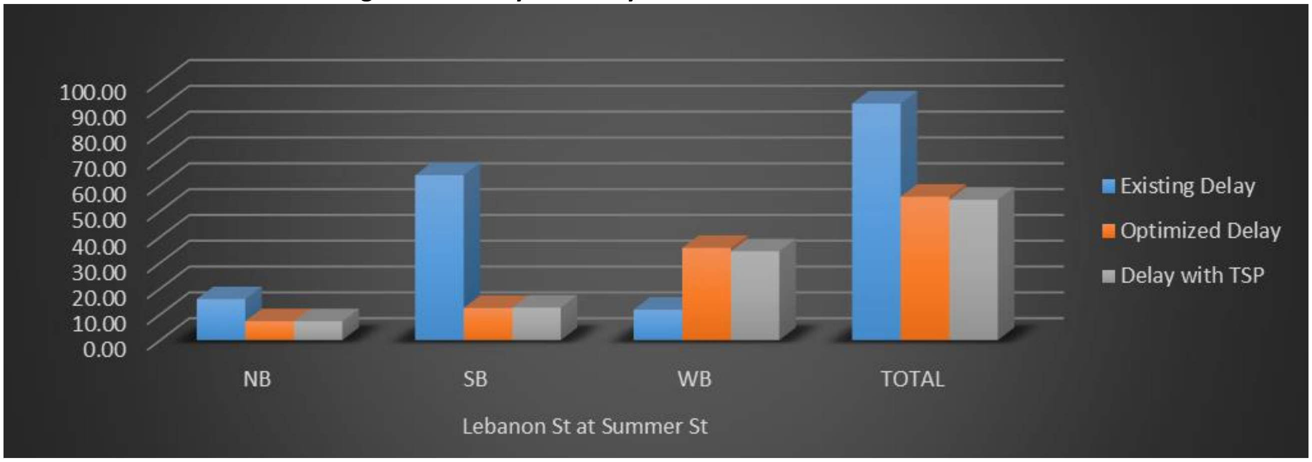
The intersection of **Main Street and Lebanon Street** operates at an overall LOS 'B' during the morning peak hour under existing conditions. The Main Street southbound left turn movement operates at a LOS 'B'. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings are necessary. Under optimized conditions, the intersection remains at an overall LOS 'B', with LOS 'B' for the Main Street southbound left turn bus movement. TSP capabilities were not utilized at this location due to impacts on conflicting movement delay and minimal bus movement improvements. Figure 11 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 14 - Delay Summary Main St at Lebanon St



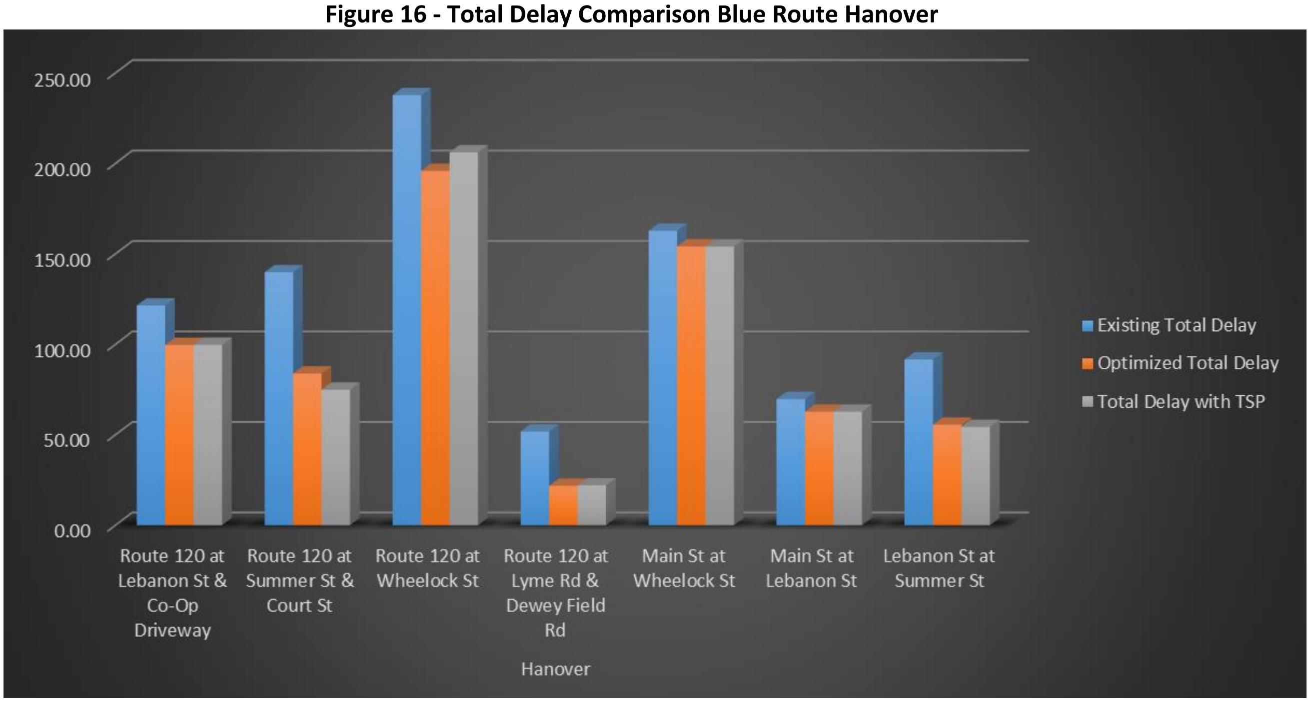
The intersection of **Lebanon Street and Summer Street** operates at an overall LOS 'B' during the morning peak hour under existing conditions. The Lebanon Street southbound through movement operates at a LOS 'A'. Under optimized conditions, the intersection operations improve to an overall LOS 'B', with LOS 'A' for the Lebanon Street southbound through bus movement. TSP capabilities were utilized at this intersection for the southbound through movement under the TSP Scenario. Figure 10 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 15 - Delay Summary Lebanon St at Summer St



Overall total intersection delay is reduced at the signalized intersections with an optimized signal timing plan and implementation of a TSP system. Figure 16 illustrates the reduction in delay associated with all signalized intersection along the Blue Route in Hanover.

Figure 16 - Total Delay Comparison Blue Route Hanover



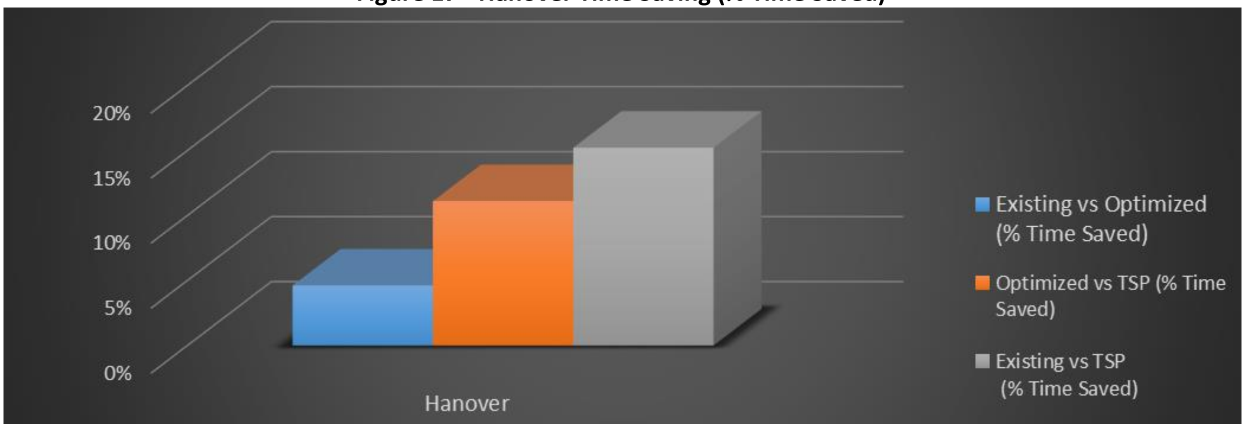
The bus travel time for the existing scenario is approximately 14 minutes 4 seconds. Under the optimized scenario, the bus travel time improves to 13 minutes 25 seconds. This is an improvement of 39 seconds, or 5 percent from existing conditions. Under the TSP scenario, the bus travel time improves 11 minutes 56 seconds. This is an improvement of 89 seconds, or 11 percent from the optimized scenario.

As illustrated in Table 12 and Figure 17, this section of the Blue Route through Hanover experiences a reduction in travel time of 2 minutes 4 seconds or 15 percent with the implementation of optimized signal timings and a TSP system.

Table 12 - Hanover Blue Route Time Savings

Route Segment	Route Time Existing Conditions (min)	Route Time with Optimized Signals (min)	Route Time with Optimization and TSP (min)	Total Time Saved with TSP & Optimization	Total % Time Saved with TSP & Optimization
Hanover	14.07	13.42	11.93	2.14	15.21%

Figure 17 - Hanover Time Saving (% Time Saved)



Section of Blue Route in Lebanon, NH

Figure 18 illustrates this section of the Blue route. This section in Lebanon, NH travels along Route 120 northbound bearing right at the unsignalized Hanover Street intersection, continuing on Route 120 northbound straight through the I-89 northbound and southbound intersections. The bus then makes a left at the Heater Road intersection continuing on towards Hanover. The Blue bus route was also modeled in the southbound direction, following the above route in the reverse order. The portion of the Blue bus route that was modeled in the northbound direction is 0.79 between the stop south of I-89 and north of Heater Road. The southbound route I 1.14 miles between the stop north of Heater Road and south of I-89.The northbound and southbound corridors with three signalized intersection, and one unsignalized intersections were analyzed. The unsignalized intersection was unchanged for the optimized and TSP scenarios. The three signals are currently running the Synchro Green adaptive signal technology, continually changing the signal times to meet the current traffic demands at any given time. Thus, the existing signal times are considered optimized for analysis purposes.

Table 13 summarizes the overall intersection Level of Service under the existing conditions as well as the Level of Service that can be achieved by optimizing the signal timing.

Figure 18 - Blue Route - Lebanon, NH

Table 13 - Lebanon Blue Route LOS Summary

Lebanon Blue Route LOS Summary	Existing LOS	Optimized LOS
Lebanon		
Route 120 at Heater Rd	D	D
Route 120 at I-89 NB	D	D
Route 120 at I-89 SB	C	C

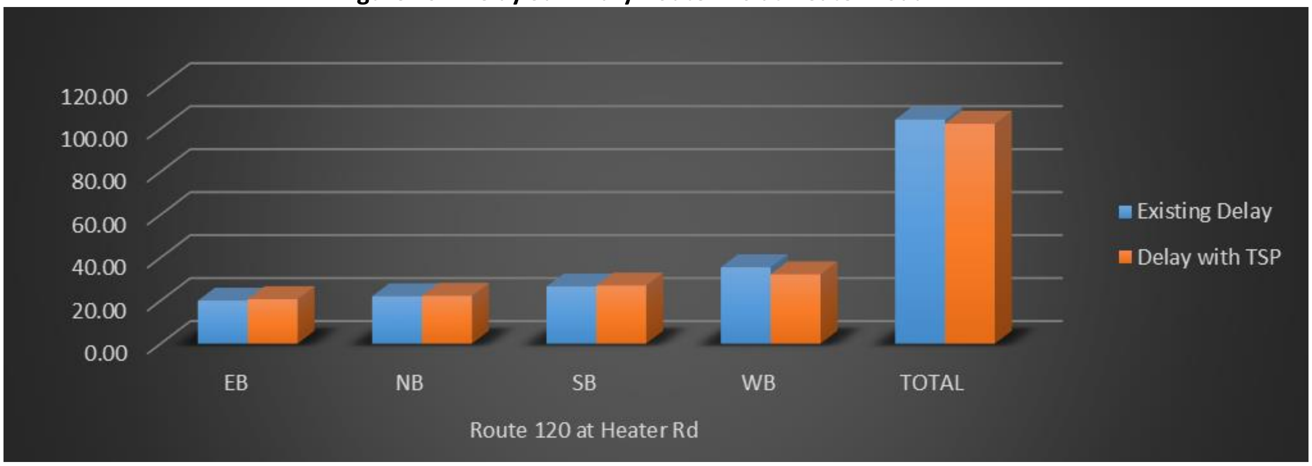
Table 14 below compares the approach delay and total intersection delay under existing conditions, signal operations with optimized timing and no TSP and finally the signal operations with TSP deployed at each signalized intersection along the Blue Route in Lebanon.

Table 14 - Blue Route Lebanon - Delay Comparison

Intersection	Existing Total Delay	Total Delay with TSP
Lebanon		
Route 120 at Heater Rd	104.28	102.35
Route 120 at I-89 NB	27.87	27.31
Route 120 at I-89 SB	108.21	105.49

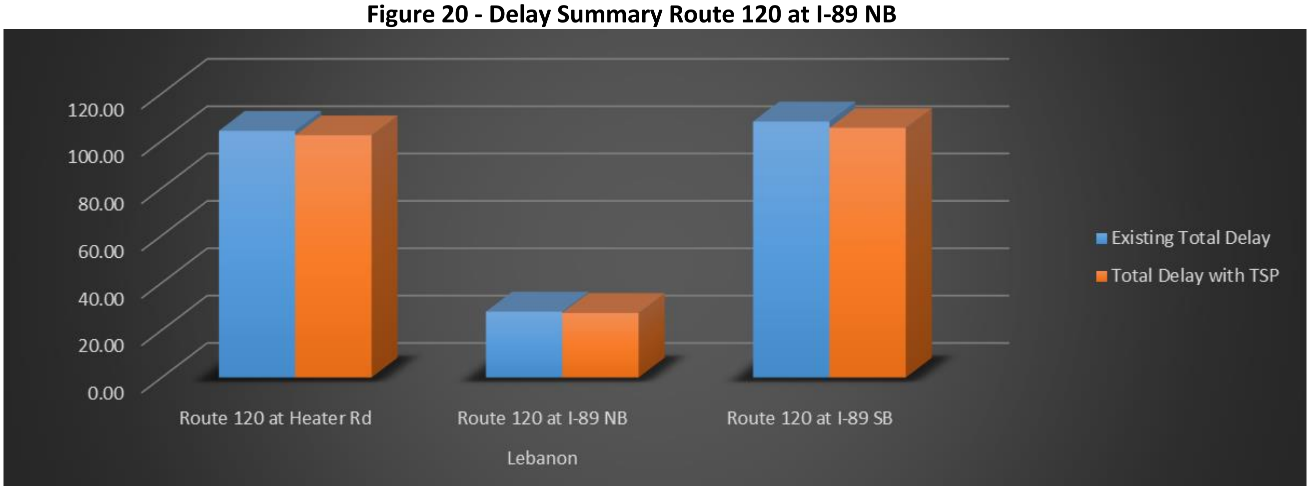
The intersection of **Route 120 at Heater Road** operates at an overall LOS 'D' during the morning peak hour under existing conditions. The bus movements of Route 120 northbound left and Heater Road eastbound right operate at a LOS 'D' and 'C' respectively. TSP capabilities were utilized at this intersection for the bus movement of Route 120 northbound left under the TSP Scenario. Figure 19 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 19 - Delay Summary Route 120 at Heater Road



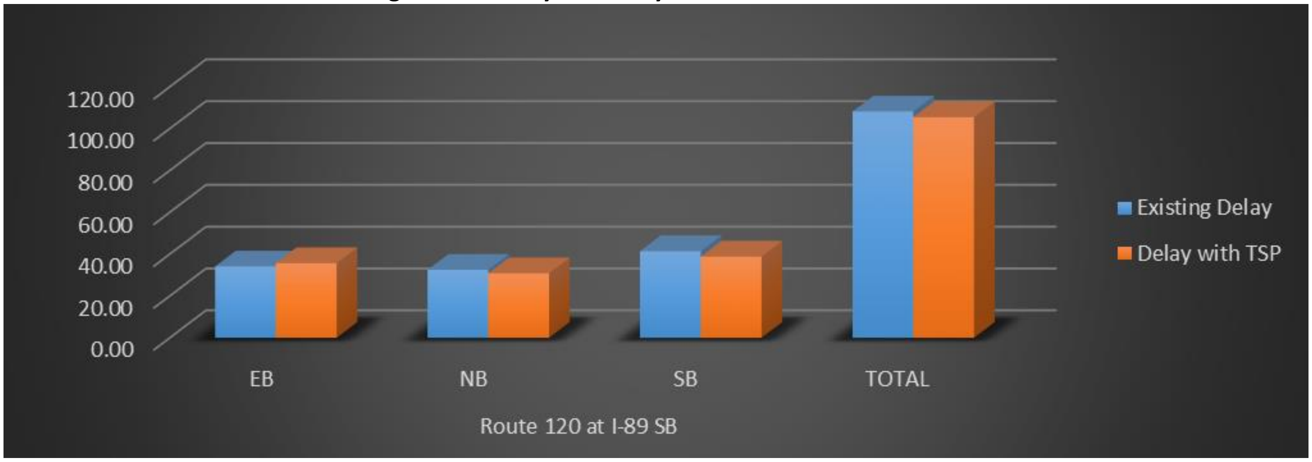
The intersection of **Route 120 at I-89 Northbound Ramps** operates at an overall LOS 'D' during the morning peak hour under existing conditions. The bus movements of Route 120 northbound and southbound through operate at a LOS 'C' and 'B' respectively. The I-89 northbound Off-Ramp operates at a LOS 'F' during the morning peak hour. TSP capabilities were utilized at this intersection for the bus movement of Route 120 northbound and southbound through under the TSP Scenario. Figure 20 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 20 - Delay Summary Route 120 at I-89 NB



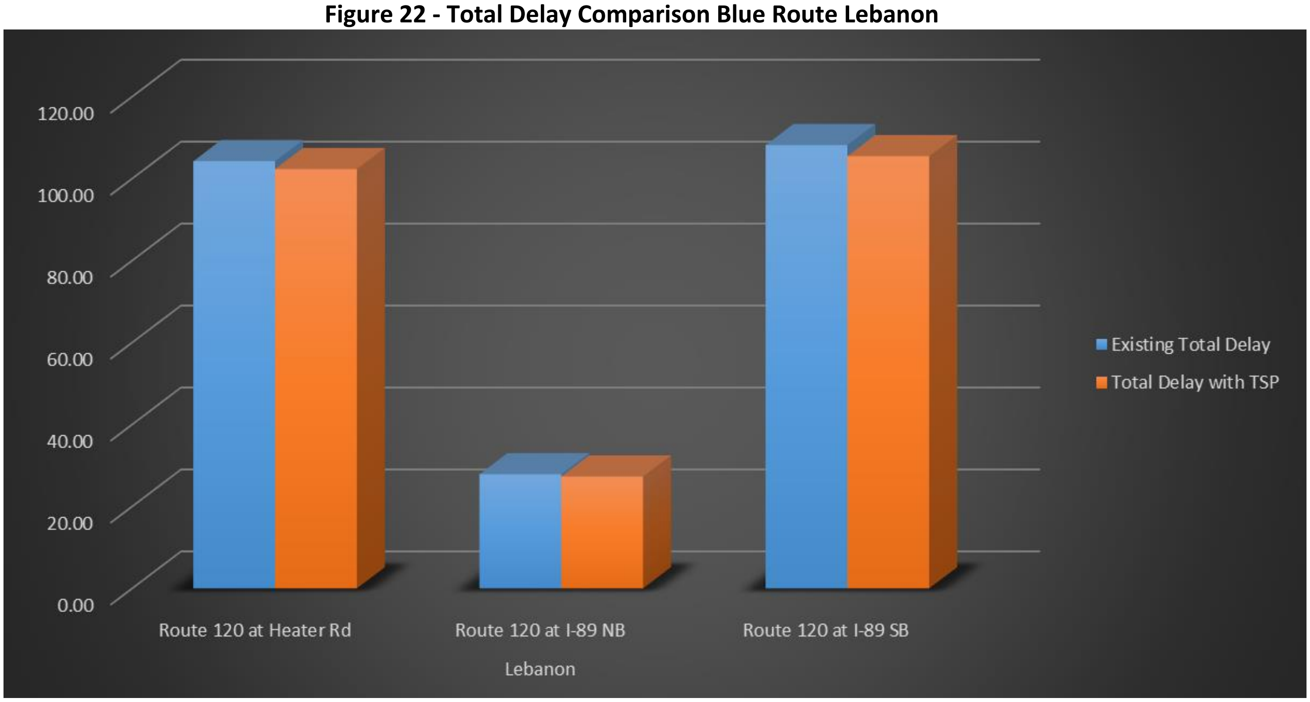
The intersection of **Route 120 at I-89 Southbound Ramps** operates at an overall LOS 'C' during the morning peak hour under existing conditions. The bus movements of Route 120 northbound and southbound through operate at a LOS 'D' and 'C' respectively. TSP capabilities were utilized at this intersection for the bus movement of Route 120 northbound and southbound through under the TSP Scenario. Figure 21 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 21 - Delay Summary Route 120 at I-89 SB



Overall total intersection delay is reduced at the signalized intersections with an optimized signal timing plan and implementation of a TSP system. Figure 22 illustrates the reduction in delay associated with all signalized intersection along the Blue Route in Lebanon.

Figure 22 - Total Delay Comparison Blue Route Lebanon



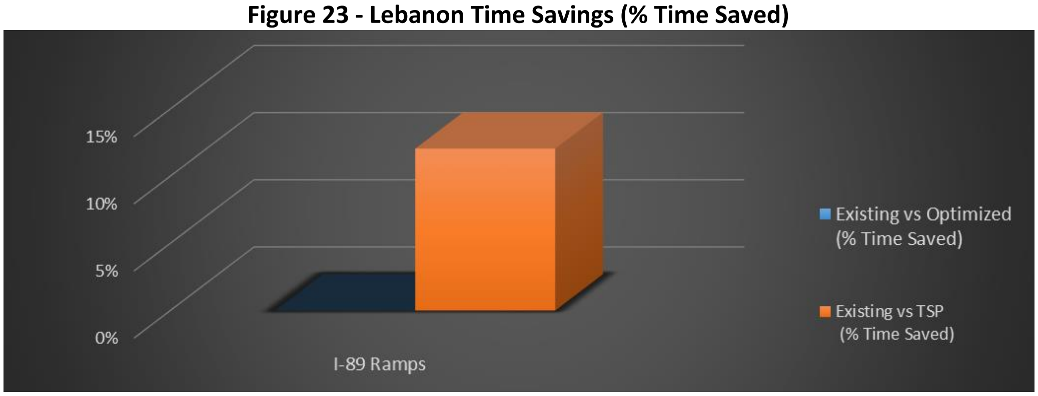
The bus travels both northbound and southbound through this section. The combined northbound/southbound time spent passing through these three intersections is approximately 10 minutes 12. Under the TSP scenario, the bus travel time improves to 8 minutes 59 seconds. This is an improvement of 73 seconds, or 12 percent from the existing/optimized scenario

As illustrated in Table 15 and Figure 23, this section of the Blue Route through Lebanon experiences a reduction in travel time of 1 minute 13 seconds or 12 percent with the implementation of optimized signal timings and a TSP system.

Table 15 - Lebanon Blue Route Time Savings

Route Segment	Route Time Existing Conditions (min)	Route Time with Optimization and TSP (min)	Total Time Saved with TSP & Optimization	Total % Time Saved with TSP & Optimization
I-89 Ramps	10.21	8.98	1.23	12.05%

Figure 23 - Lebanon Time Savings (% Time Saved)



Section of Green Route in Hartford, VT & Lebanon, NH

Figure 24 illustrates this section of the Green route. This section in Hartford, VT and Lebanon, NH travels along Hartford Avenue southbound turning left at the Maple Street intersection, continuing on Maple Street eastbound straight through the Bridge Street and Prospect Street intersections. The bus then travels over the Connecticut River into Lebanon on Bridge Street straight through the Main Street intersection. The bus turns right at the Dana Street at Maple Street intersection, and then right again at the Maple Street at Tracy Street intersection, stopping at the Kilton Public Library for a mandatory 10 minute stop. After the mandatory 10 minute stop, the bus heads north on Main Street and turns left at the Bridge Street intersection, continuing in the reverse order through Prospect Street, Bridge Street and turning right at Hartford Avenue towards Norwich. This portion of the Green bus route is 1.52 miles long and includes five signalized intersection, and one unsignalized intersections that were analyzed. The unsignalized intersection was unchanged for the optimized and TSP scenarios.

Figure 24 - Section of Green Route in Hartford, VT & Lebanon, NH

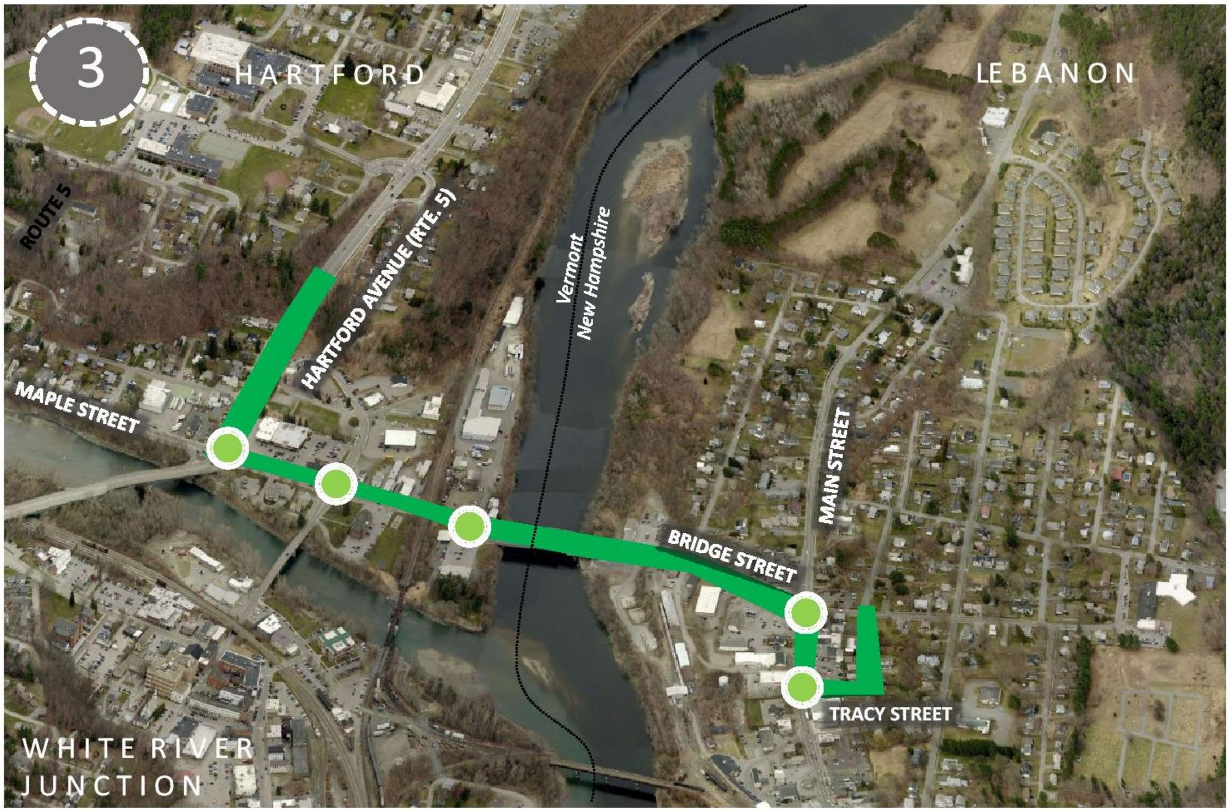


Table 16 summarizes the overall intersection Level of Service under the existing conditions as well as the Level of Service that can be achieved by optimizing the signal timing

Table 16 - Hartford, VT and Lebanon, NH Green Route LOS Summary

Hartford, VT & Lebanon, NH Green Route LOS Summary	Existing LOS	Optimized LOS
Hartford		
Hartford Ave at Maple St (Rte 4 at Rte 5)	C	C
Maple St at Bridge St & Pine St	B	B
Maple St at Prospect St	A	A
Lebanon		
Main Street at Bridge St & Dana St	B	B
Main St at Railroad Ave & Tracy St	A	A

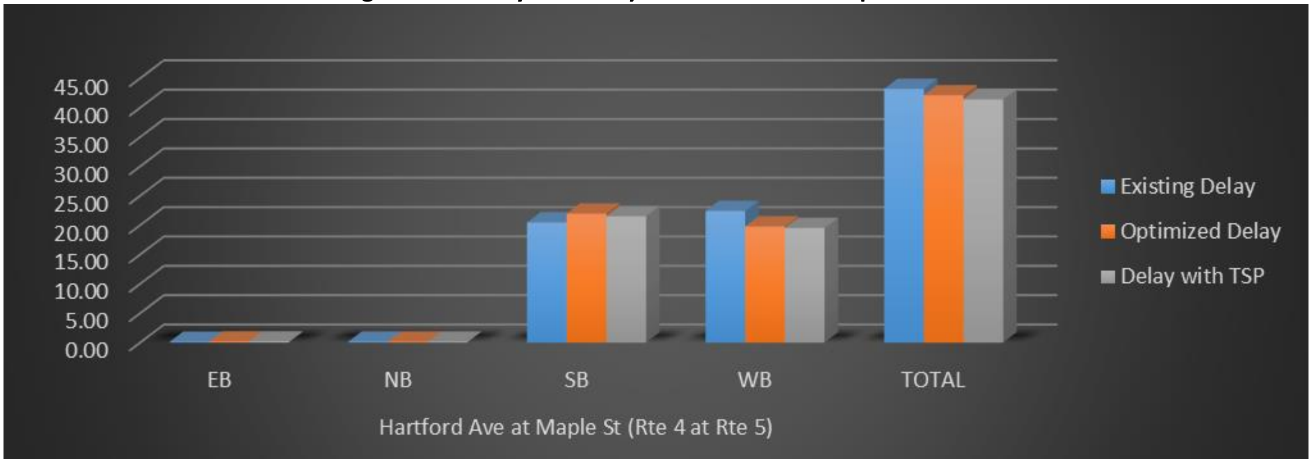
Table 17 compares the approach delay and total intersection delay under existing conditions, signal operations with optimized timing and no TSP and finally the signal operations with TSP deployed at each signalized intersection along the Blue Route in Hanover.

Table 17 - Green Route Lebanon, NH & Hartford, VT - Delay Comparison

Intersection	Existing Total Delay	Optimized Total Delay	Total Delay with TSP
Hartford			
Hartford Ave at Maple St (Rte 4 at Rte 5)	43.19	42.11	41.42
Maple St at Bridge St & Pine St	40.32	50.39	50.16
Maple St at Prospect St	50.55	48.72	48.38
Lebanon			
Main St at Bridge St & Dana St	50.10	39.01	39.17
Main St at Railroad Ave & Tracy St	86.24	84.41	80.90

The intersection of **Hartford Avenue at Maple Street** operates at an overall LOS 'C' during the morning peak hour under existing conditions. The bus movement of Hartford Avenue southbound left and Maple Street westbound right operate at a LOS 'C' and 'B' respectively. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings are necessary. Under optimized conditions, the intersection remains at an overall LOS 'C', with LOS 'C' and 'B' for the Hartford Avenue southbound left and Maple Street westbound right bus movements respectively. TSP capabilities were utilized at this intersection for the southbound left movement under the TSP Scenario. Figure 25 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 25 - Delay Summary Hartford Ave at Maple St

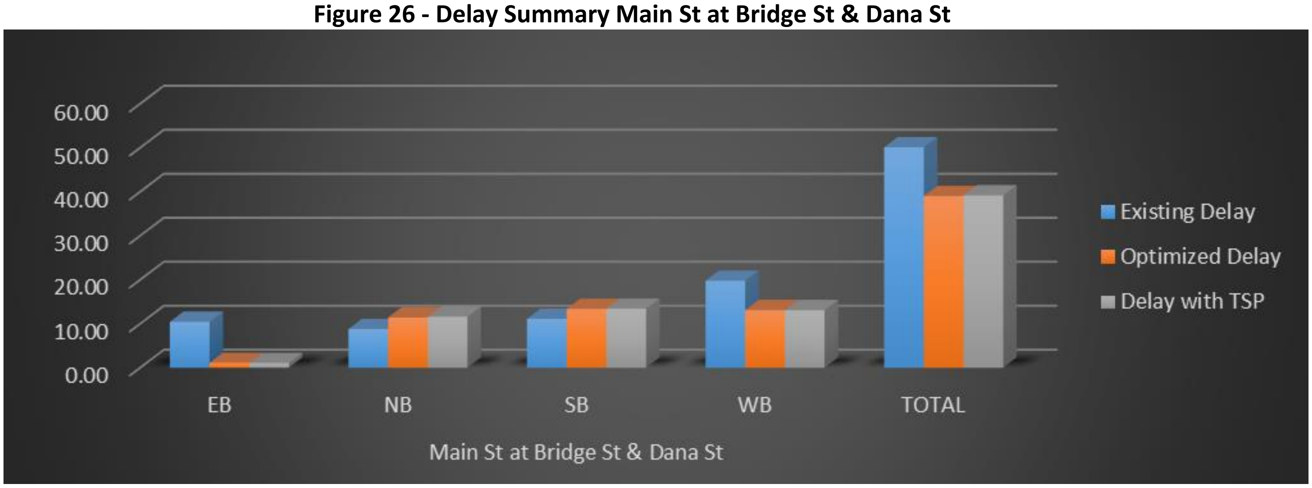


The intersection of **Maple Street at Bridge Street and Pine Street** operates at an overall LOS 'C' during the morning peak hour under existing conditions. The bus movement of Maple Street eastbound and westbound through operate at a LOS 'C' and 'B' respectively. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings were made and the optimized operations remained as above. TSP capabilities were not utilized at this intersection due to limited available side street green time.

The intersection of **Maple Street at Prospect Street** operates at an overall LOS 'B' during the morning peak hour under existing conditions. The bus movement of Maple Street eastbound and westbound through operate at a LOS 'B' and 'A' respectively. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings were made and the optimized operations remain as above. TSP capabilities were not utilized at this intersection due to limited available side street green time.

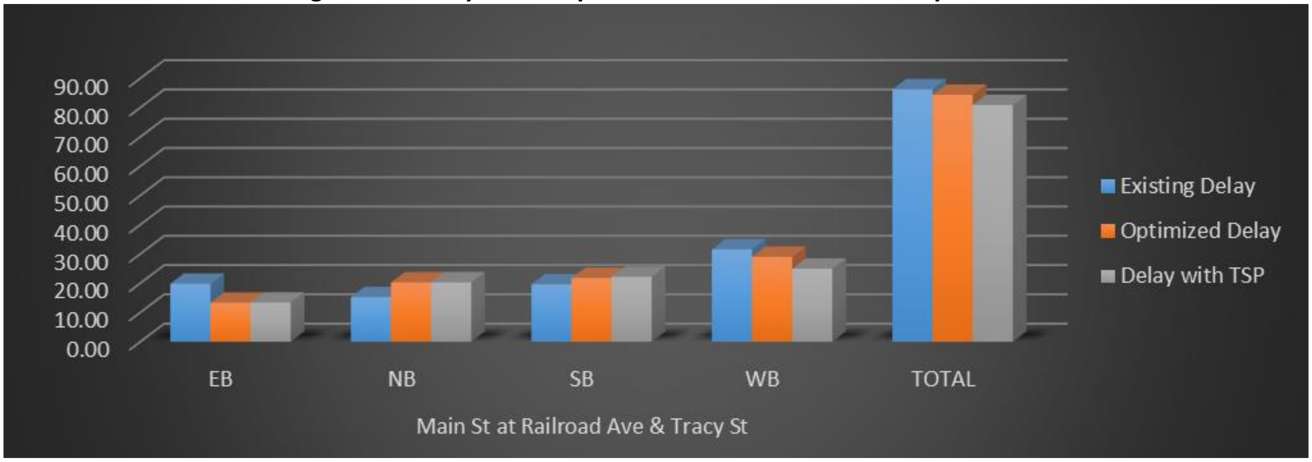
The intersection of **Main Street at Bridge Street and Dana Street** in Lebanon, NH operates at an overall LOS 'B' during the morning peak hour under existing conditions. The bus movement of Bridge Street eastbound through and Main Street northbound left operate at a LOS 'E' and 'B' respectively. Under optimized conditions, the intersection operates at an overall LOS 'B', with LOS 'B' for the Main Street northbound left turn. The Bridge Street eastbound through bus movements improves greatly to a LOS 'C'. TSP capabilities were utilized at this intersection for the northbound left turn under the TSP Scenario. Figure 26 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 26 - Delay Summary Main St at Bridge St & Dana St



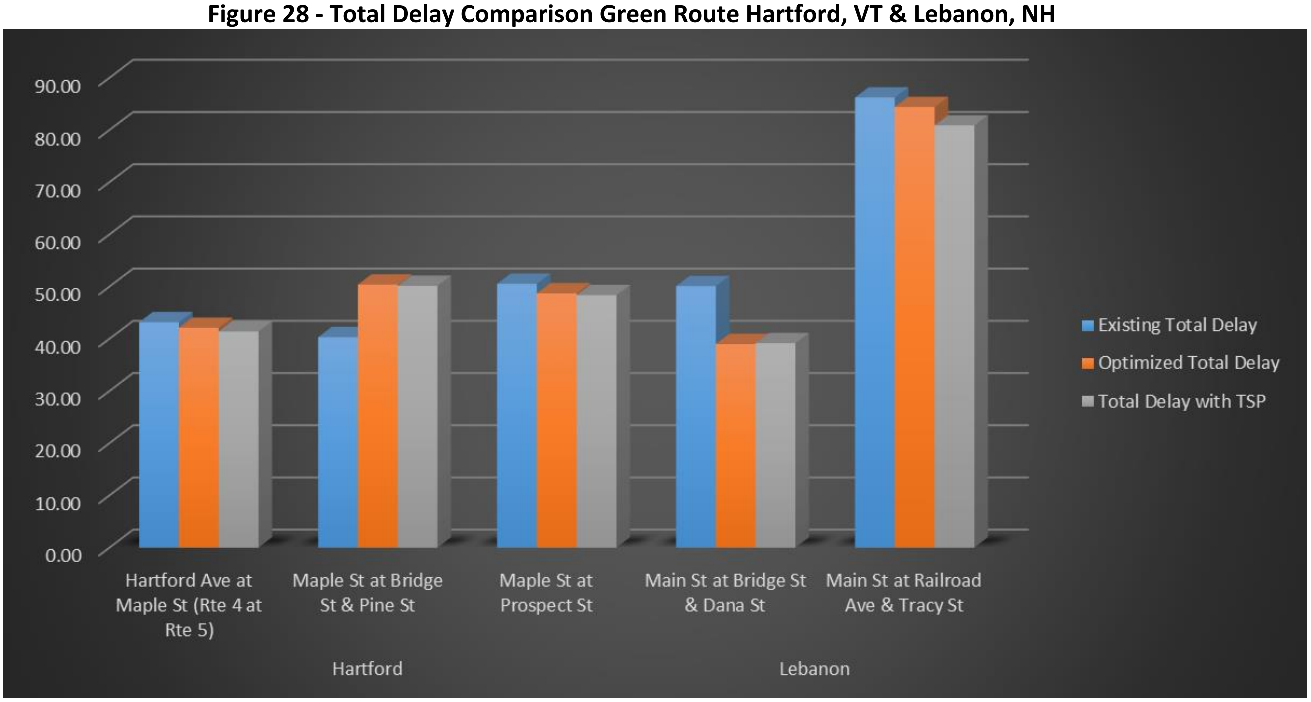
The intersection of **Main Street at Railroad Avenue and Tracy Street** operates at an overall LOS 'A' during the morning peak hour under existing conditions. The bus movement of Tracy Street westbound right operates at a LOS 'C'. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings were made and the optimized operations remain as above. TSP capabilities were utilized at this intersection for the westbound right turn under the TSP Scenario. Figure 27 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 27 - Delay Summary Main St at Railroad Ave & Tracy St



Overall total intersection delay is reduced at the signalized intersections with an optimized signal timing plan and implementation of a TSP system. Figure 28 illustrates the reduction in delay associated with all signalized intersection along the Green Route in Hartford, VT and Lebanon, NH.

Figure 28 - Total Delay Comparison Green Route Hartford, VT & Lebanon, NH

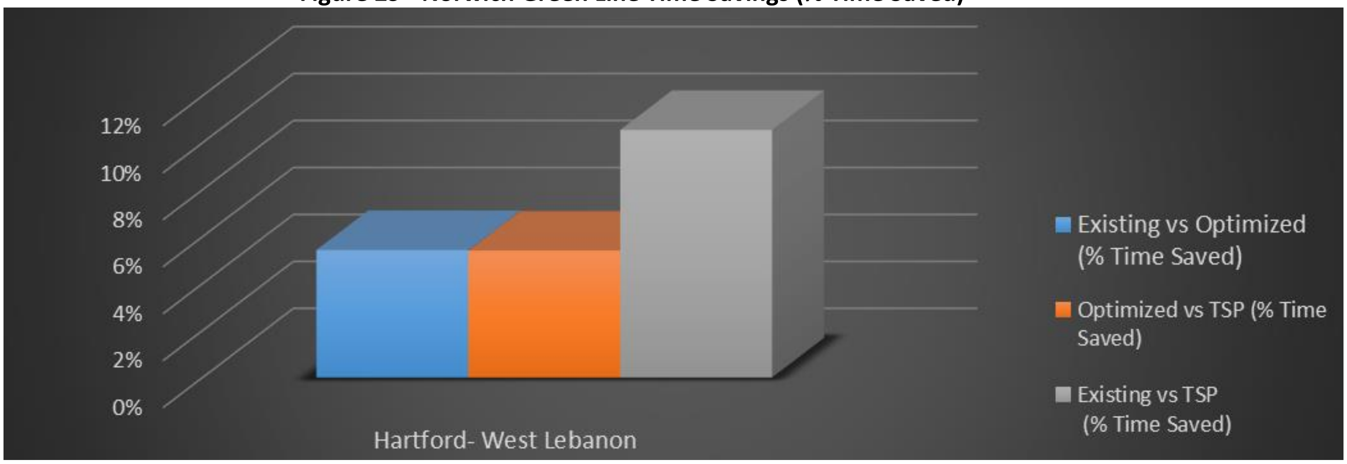


As illustrated in Table 18 and Figure 29, this section of the Green Route through Hartford, VT and Lebanon, NH experiences a reduction in travel time of nearly 1 minute or 10 percent with the implementation of optimized signal timings and a TSP system.

Table 18 – Hartford - Lebanon Green Route Time Savings

Route Segment	Route Time Existing Conditions (min)	Route Time with Optimized Signals (min)	Route Time with Optimization and TSP (min)	Total Time Saved with TSP & Optimization	Total % Time Saved with TSP & Optimization
Hartford- West Lebanon	9.2	8.7	8.23	0.97	10.54%

Figure 29 - Norwich Green Line Time Savings (% Time Saved)



Section of Green Route in Norwich, VT

Figure 30 illustrates this section of the Green route. This section in Norwich, VT and Hanover, NH travels along Route 5 northbound and bears right at the Main Street and I-91 southbound ramps intersection. The bus continues on Main Street straight through the I-91 northbound ramps and River Road intersections. The bus then travels over the Connecticut River into Hanover on W. Wheelock Street straight through the Main Street intersection. This portion of the Green bus route is 1.36 miles long and includes four signalized intersections that were analyzed.

Figure 30 - Section of Green Route in Norwich, VT & Hanover, NH

Table 19 summarizes the overall intersection Level of Service under the existing conditions as well as the Level of Service that can be achieved by optimizing the signal timing

Table 19 - Norwich Green Route LOS

Norwich, VT & Hanover, NH Green Route LOS Summary	Existing LOS	Optimized LOS
Norwich		
Route 10A at Route 5 & I-91 SB	C	C
Route 10A at I-91 NB	B	B
Route 10A at River Road	B	B
Hanover		
Main St at Wheelock St	D	D

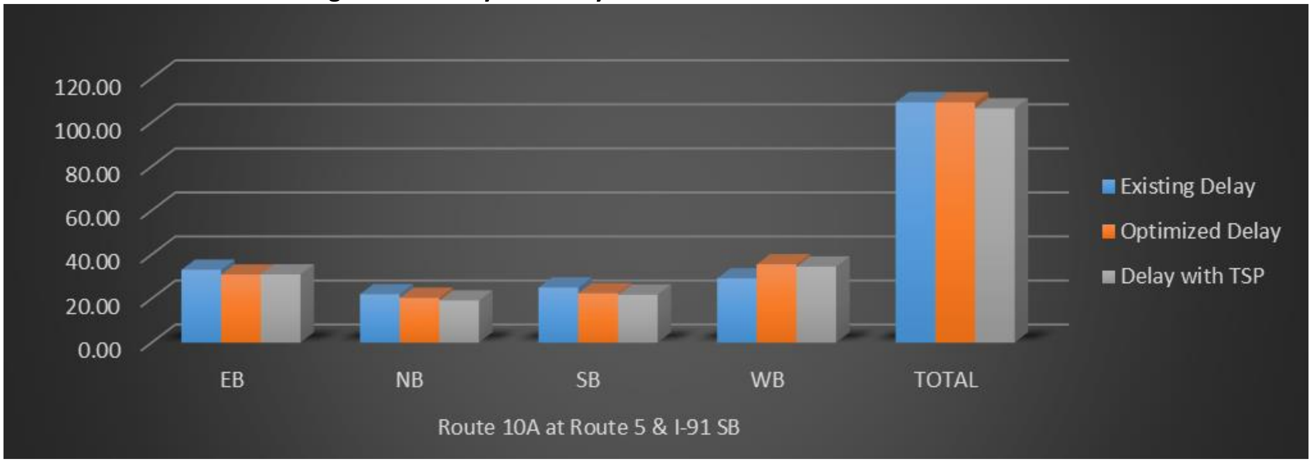
Table 20 compares the approach delay and total intersection delay under existing conditions, signal operations with optimized timing and no TSP and finally the signal operations with TSP deployed at each signalized intersection along the Green Route in Norwich.

Table 20 - Green Route Norwich - Delay Comparison

Intersection	Existing Total Delay	Optimized Total Delay	Total Delay with TSP
Norwich			
Route 10A at I-91 NB	60.96	56.77	55.96
Route 10A at River Rd	63.96	49.25	49.26
Route 10A at Route 5 & I-91 SB	109.13	109.10	106.34
Hanover			
Main St at Lebanon St	69.80	62.81	62.78

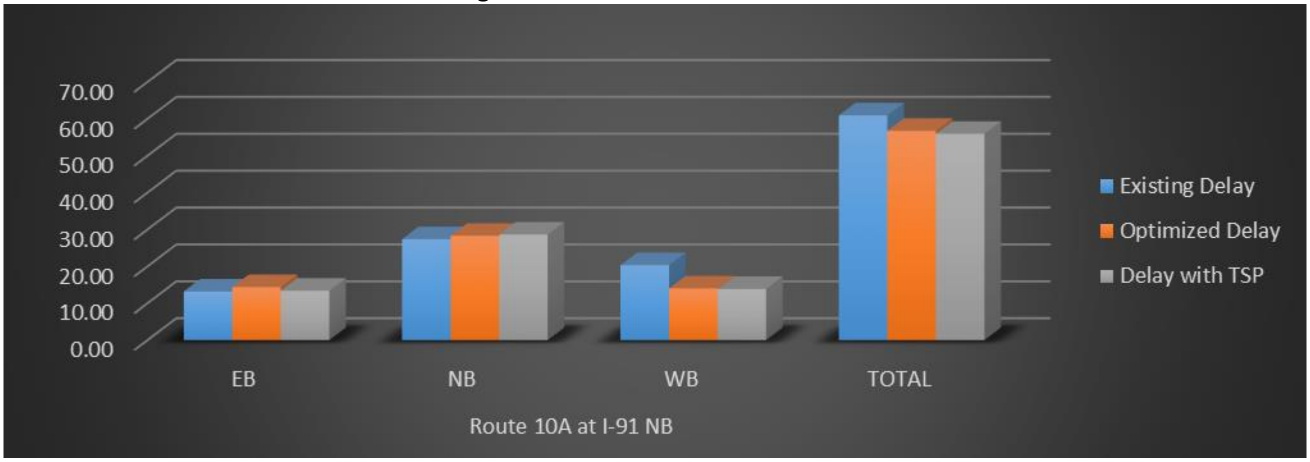
The intersection of **Route 10A at Route 5 & I-91 SB** operates at an overall LOS 'C' during the morning peak hour under existing conditions. The bus movement of Route 5 northbound right operates at a LOS 'C'. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings were made and the optimized operations remain as above. TSP capabilities were utilized at this intersection for the northbound right turn under the TSP Scenario. Figure 31 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 31 - Delay Summary Route 10A at Route 5 & I-91 SB



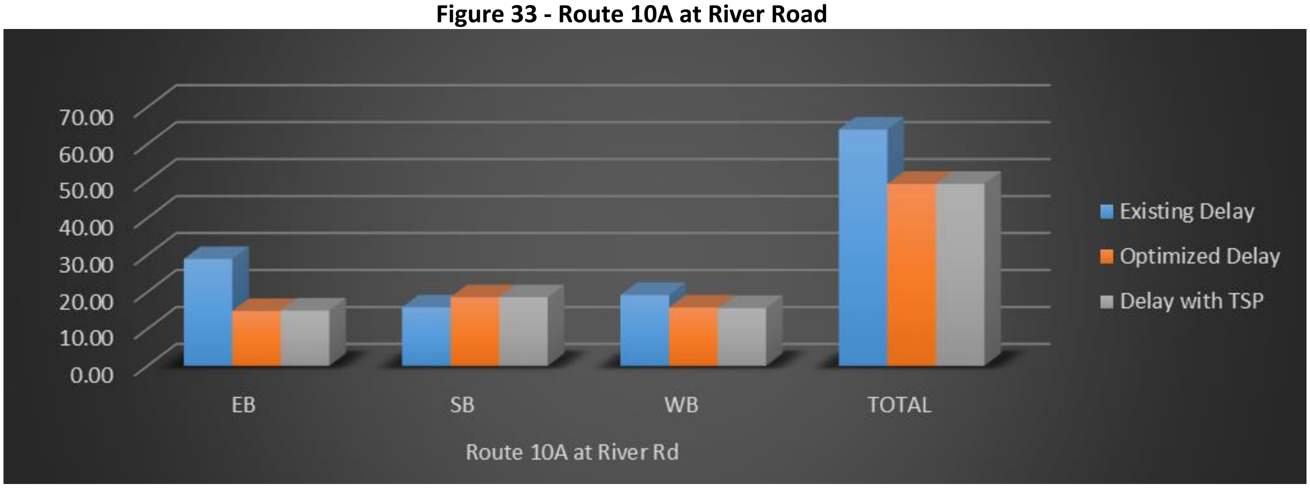
The intersection of **Route 10A at I-91 NB** operates at an overall LOS 'B' during the morning peak hour under existing conditions. The bus movement of Route 10A southbound through operates at a LOS 'A'. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings were made and the optimized operations remain as above. TSP capabilities were utilized at this intersection for the southbound through movement under the TSP Scenario. Figure 32 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 32- Route 10A at I-91 NB



The intersection of **Route 10A at River Road** operates at an overall LOS 'B' during the morning peak hour under existing conditions. The bus movement of Route 10A southbound through operates at a LOS 'A'. The existing timings have the intersection operating close to optimized timings. Thus, few or no changes to this signals timings were made and the optimized operations remain as above. TSP capabilities were not utilized at this intersection due to limited available side street green time. Figure 33 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 33 - Route 10A at River Road

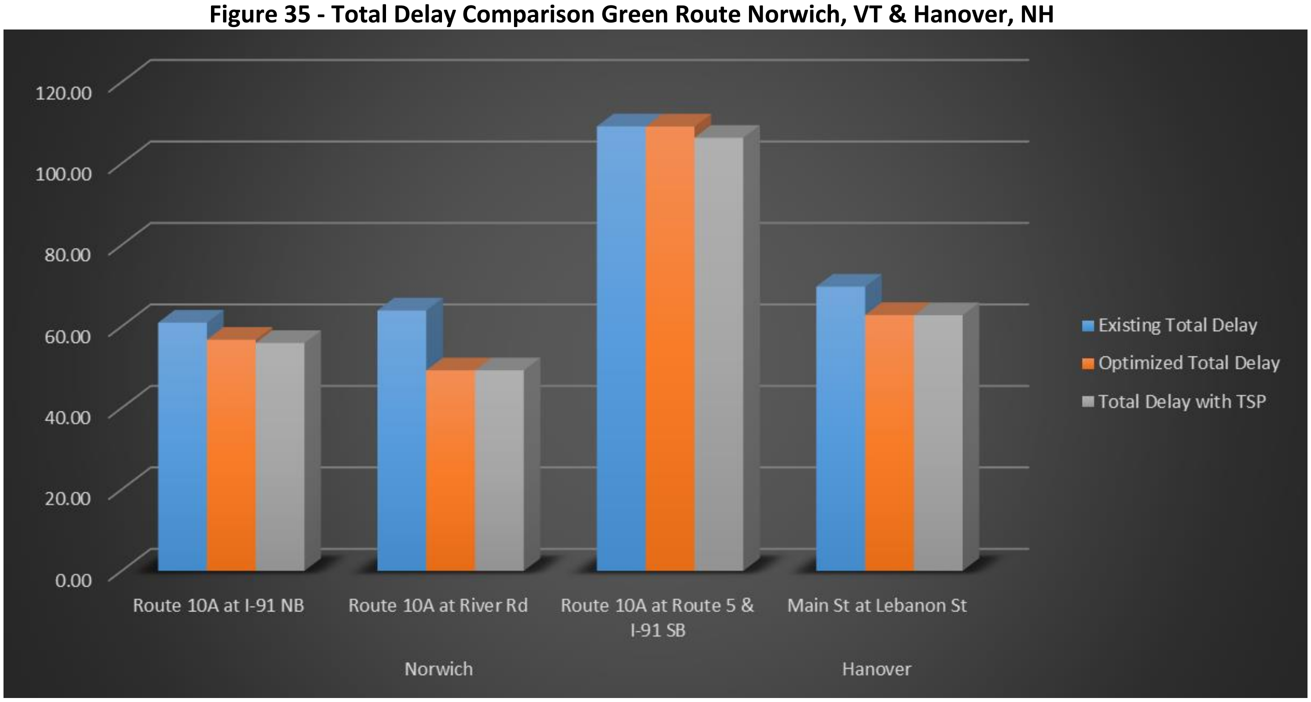


The intersection of **Main Street and Wheelock Street** operates at an overall LOS 'D' during the morning peak hour under existing conditions. The Wheelock Street eastbound through movement operates at a LOS 'E'. Under optimized conditions, the intersection operations improve slightly remaining an overall LOS 'D', with LOS 'E' for the Wheelock Street eastbound through bus movement. TSP capabilities were utilized at this location for the Wheelock Street eastbound through movement under the TSP scenario. Figure 34 provides a comparison of the approach and total intersection delay under the existing conditions, operations with optimized signal timings and finally with a TSP system implemented.

Figure 34 - Delay Summary Main St at Wheelock St

Overall total intersection delay is reduced at the signalized intersections with an optimized signal timing plan and implementation of a TSP system. Figure 35 illustrates the reduction in delay associated with all signalized intersection along the Green Route in Norwich, VT and Hanover, NH.

Figure 35 - Total Delay Comparison Green Route Norwich, VT & Hanover, NH

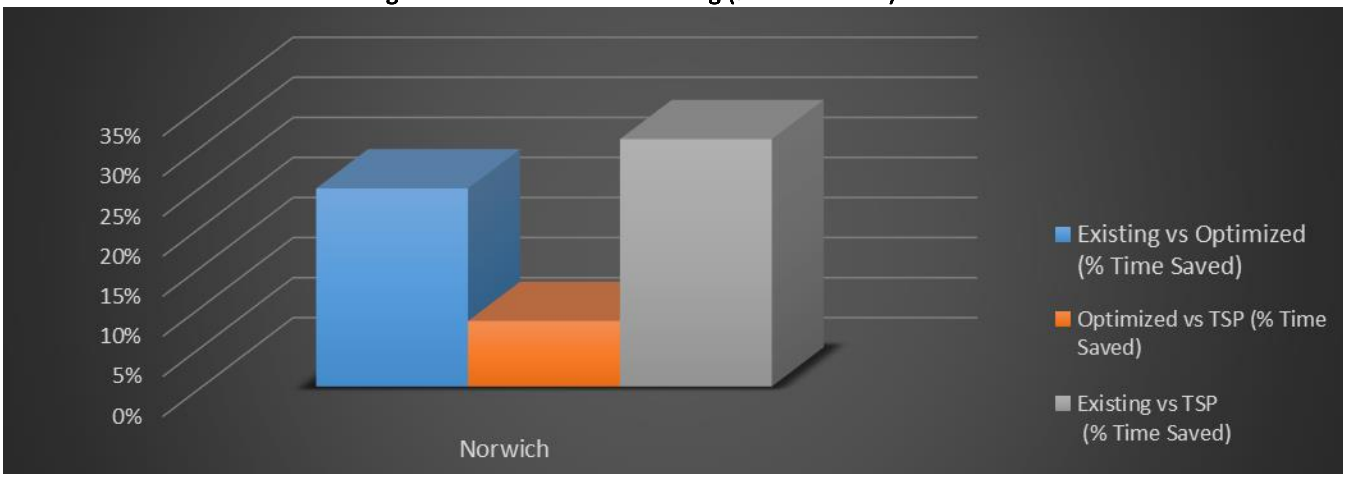


As illustrated in Table 21 and Figure 35, this section of the Green Route through Norwich, VT and entering Hanover, NH experiences a reduction in travel time of 2 min 33 sec or 31 percent with the implementation of optimized signal timings and a TSP system.

Table 21 - Norwich Green Route Time Savings

Route Segment	Route Time Existing Conditions (min)	Route Time with Optimized Signals (min)	Route Time with Optimization and TSP (min)	Total Time Saved with TSP & Optimization	Total % Time Saved with TSP & Optimization
Norwich	8.29	6.24	5.73	2.56	30.88%

Figure 36 - Norwich Time Saving (% Time Saved)



Overall Improvements

The installation of a TSP system at the signalized intersections along the four corridors analyzed results in a significant time savings.

As illustrated in Table 22, the total improvement in bus travel time during the morning peak hour for the Blue bus route is 3 minutes and 23 seconds or 14% and the total improvement in bus travel time during the morning peak hour for the Green bus route is 3 minutes and 32 seconds or 20%. Combined the effect of TSP on the segments of the Blue and Green Routes analyzed is a savings of nearly 7 minutes or 17% in transit vehicle delay.

Table 22 - Time Savings by Route

Route Segment	Route Time Existing Conditions (min)	Route Time with Optimization and TSP (min)	Total Time Saved with TSP & Optimization	Total % Time Saved with TSP & Optimization
TOTAL BLUE ROUTE	24.27	20.88	3.39	14%
TOTAL GREEN ROUTE	17.49	13.96	3.53	20%
TOTAL GREEN AND BLUE COMBINED	41.76	34.84	6.92	17%

The Aimsun delay and travel time results can be found in the Appendix D.

SECTION 5 - IMPLEMENTATION

To implement a TSP system for Advance Transit's Green and Blue Routes, several issues need to be reviewed and evaluated. These include:

- Projected Implementation Costs
  - Transit Equipment Costs
  - Construction Costs
  - Maintenance Costs
- Prioritization Plan
  - Costs vs Time Savings
- Lead Agency
- Conformance with Existing ITS Infrastructure

Projected Costs for Implementation

There are three major costs associated with the implementation of a TSP system. These include:

1. On-Street Hardware Costs
2. Vehicle Costs
3. Central Management System Costs

For the purposes of this study, it is assumed that a Central Management System is not part of the current project. However, Advance Transit may explore this option further in the future.

Vehicle costs are a fixed cost per transit vehicle expected to service a route with TSP. The cost is associated with outfitting the vehicle with a GPS receiver to provide communications between the transit vehicle and the on-street signal hardware. This cost is approximately $4000-$5000 inclusive of installation. The cost may be impacted by the complexity of the installation (i.e. if the AVL route adherence needs to activate the TSP request remotely.)

The Table 23 illustrates the approximate costs anticipated per location to provide full GPS based TSP throughout the entire Green and Blue routes. These costs include any required updates or replacement of the traffic controller as well as the installation of GPS receivers. The vehicle costs have initially been established based on the five (5) buses currently servicing the Green and Blue Routes. However, AT may choose to outfit all buses to allow any bus to service the Green or Blue Route and provide for future TSP integration along the Red and/or Orange Routes

Other costs include design, permitting and system integration costs.

It is noted that for the four (4) sections examined TSP is recommended to be installed at all locations. While the analysis indicated that some intersections were not modeled with TSP in place due to impacts to overall traffic at the intersection or limited available green times to allocate to the TSP phasing, the model was examined during the morning peak hours only. Differences in time of day signal plans, differing traffic levels and potentially different optimized timing plans during the afternoon may indicate additional benefits from TSP. In addition, with the investment in updated infrastructure to provide TSP at these closely spaced intersections, it would not be cost effective to eliminate those locations.

Table 23 - Implementation Costs

Jurisdiction	GPS Cost	Controller Upgrade Cost	Total Signal Cost	Design Costs	Total Implementation Cost
Hanover	**$35,000**	**$0**	**$35,000**	**$14,000**	**$49,000**
Route 120 at Lebanon St and Co-Op Driveway	$5,000	$0	$5,000	$2,000	$7,000
Lebanon St at Summer St	$5,000	$0	$5,000	$2,000	$7,000
Main St at Lebanon St	$5,000	$0	$5,000	$2,000	$7,000
Main St at Wheelock St	$5,000	$0	$5,000	$2,000	$7,000
Route 120 at Wheelock St	$5,000	$0	$5,000	$2,000	$7,000
Route 120 at Summer St and Summer Ct	$5,000	$0	$5,000	$2,000	$7,000
Route 120 at Lyme Rd & Dewey Field Road	$5,000	$0	$5,000	$2,000	$7,000
Lebanon	**$10,000**	**$14,000**	**$24,000**	**$9,600**	**$33,600**
Main St at Railroad Ave & Tracy St	$5,000	$7,000	$12,000	$4,800	$16,800
Main Street at Bridge St & Dana St	$5,000	$7,000	$12,000	$4,800	$16,800
NHDOT	**$15,000**	**$9,000**	**$24,000**	**$9,600**	**$33,600**
Route 120 at Heater Rd	$5,000	$3,000	$8,000	$3,200	$11,200
Route 120 at I-89 NB	$5,000	$3,000	$8,000	$3,200	$11,200
Route 120 at I-89 SB	$5,000	$3,000	$8,000	$3,200	$11,200
VTrans	**$30,000**	**$31,000**	**$61,000**	**$24,400**	**$85,400**
Maple St at Bridge St & Pine St	$5,000	$7,000	$12,000	$4,800	$16,800
Maple St at Prospect St	$5,000	$0	$5,000	$2,000	$7,000
Hartford Ave at Maple St (Rte 4 at Rte 5)	$5,000	$3,000	$8,000	$3,200	$11,200
Route 10A at Route 5 & I-91 SB	$5,000	$7,000	$12,000	$4,800	$16,800
Route 10A at I-91 NB	$5,000	$7,000	$12,000	$4,800	$16,800
Route 10A at River Road	$5,000	$7,000	$12,000	$4,800	$16,800
Total	**$90,000**	**$54,000**	**$144,000**	**$57,600**	**$201,600**

	Number of Buses	Cost Per Bus (GPS)	Total Bus Infrastructure Cost
	5	$4,000	$20,000
Total Implementation Cost			$221,600

As discussed in the previous sections, four areas have been identified as benefiting most from a TSP installation. Cost for the individual segments are reflected below in Table 24 through Table 27. It should be noted that the intersection of Main Street at Wheelock Street in Hanover, NH is part of both the Green Route and Blue Route. In the total implementation cost table (Table 23) it is included once. However, it is part of the individual segment costs for both the Blue Route in Hanover and the Green Route in Norwich, VT and Hanover, NH.

Table 24 - Implementation Costs Blue Route Hanover, NH

Jurisdiction	GPS Cost	Controller Upgrade Cost	Total Signal Cost	Design Costs	Total Implementation Cost
Hanover	**$35,000**	**$0**	**$35,000**	**$14,000**	**$49,000**
Route 120 at Lebanon St and Co-Op Driveway	$5,000	$0	$5,000	$2,000	$7,000
Lebanon St at Summer St	$5,000	$0	$5,000	$2,000	$7,000
Main St at Lebanon St	$5,000	$0	$5,000	$2,000	$7,000
Main St at Wheelock St	$5,000	$0	$5,000	$2,000	$7,000
Route 120 at Wheelock St	$5,000	$0	$5,000	$2,000	$7,000
Route 120 at Summer St and Summer Ct	$5,000	$0	$5,000	$2,000	$7,000
Route 120 at Lyme Rd & Dewey Field Road	$5,000	$0	$5,000	$2,000	$7,000
Total	**$35,000**	**$0**	**$35,000**	**$14,000**	**$49,000**

Table 25 - Implementation Costs Blue Route Lebanon, NH

Jurisdiction	GPS Cost	Controller Upgrade Cost	Total Signal Cost	Design Costs	Total Implementation Cost
NHDOT	**$15,000**	**$9,000**	**$24,000**	**$9,600**	**$33,600**
Route 120 at Heater Rd	$5,000	$3,000	$8,000	$3,200	$11,200
Route 120 at I-89 NB	$5,000	$3,000	$8,000	$3,200	$11,200
Route 120 at I-89 SB	$5,000	$3,000	$8,000	$3,200	$11,200
Total	**$15,000**	**$9,000**	**$24,000**	**$9,600**	**$33,600**

Table 26 - Implementation Costs Green Route Lebanon, NH and Hartford, VT

Jurisdiction	GPS Cost	Controller Upgrade Cost	Total Signal Cost	Design Costs	Total Implementation Cost
Lebanon	**$10,000**	**$14,000**	**$24,000**	**$9,600**	**$33,600**
Main St at Railroad Ave & Tracy St	$5,000	$7,000	$12,000	$4,800	$16,800
Main Street at Bridge St & Dana St	$5,000	$7,000	$12,000	$4,800	$16,800
VTrans	**$15,000**	**$10,000**	**$25,000**	**$10,000**	**$35,000**
Maple St at Bridge St & Pine St	$5,000	$7,000	$12,000	$4,800	$16,800
Maple St at Prospect St	$5,000	$0	$5,000	$2,000	$7,000
Hartford Ave at Maple St (Rte 4 at Rte 5)	$5,000	$3,000	$8,000	$3,200	$11,200
Total	**$25,000**	**$24,000**	**$49,000**	**$19,600**	**$68,600**

Table 27 - Implementation Costs Green Route Norwich, VT

Jurisdiction	GPS Cost	Controller Upgrade Cost	Total Signal Cost	Design Costs	Total Implementation Cost
Hanover	**$5,000**	**$0**	**$5,000**	**$2,000**	**$7,000**
Main St at Wheelock St	$5,000	$0	$5,000	$2,000	$7,000
VTrans	**$15,000**	**$21,000**	**$36,000**	**$14,400**	**$50,400**
Route 10A at Route 5 & I-91 SB	$5,000	$7,000	$12,000	$4,800	$16,800
Route 10A at I-91 NB	$5,000	$7,000	$12,000	$4,800	$16,800
Route 10A at River Road	$5,000	$7,000	$12,000	$4,800	$16,800
Total	**$20,000**	**$21,000**	**$41,000**	**$16,400**	**$57,400**

Maintenance Costs/Operations

A GPS based TSP system is very low maintenance. However, since the signalized intersections are under various jurisdictions maintenance agreements may be necessary between Advance Transit and each jurisdiction. Depending on the jurisdiction, the on-street components of TSP system may be maintained as part of the intersection/signal maintenance or AT may be responsible for the equipment maintenance. Operational parameters will likely fall under the jurisdiction of the municipality or state DOT, as operations of the TSP (i.e. timing, phasing, etc.) will impact regional traffic operations.

Cost vs Benefit

The Federal Highway Authority (FHWA) *Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2* was utilized to assess the potential benefits to Travel Time and Speed, Throughput, Energy and Efficiency. Based on the historical data compiled and maintained by the FHWA, Table 28 summarizes the benefits that can be expected from TSP installation.

Table 28 - FHWA TOPS-BC Expected Benefits

Transit Signal Priority Expected Benefits	
Travel Time and Speed	Expected travel time percent decreases by 5%-25% Expected passenger-delay decreased by 5%-14% Expected bus-delay decreased by 5%-20% Expected bus speed increased by 5%-15%
Throughput	Expected 0%-10% reduction in bus stoppage time
Energy	Expected fuel consumption rates decreased by 0%-10%
Efficiency	Expected travel time reliability improvement rated between 30%-40%

There is the increased value and attractiveness of a service that will run on time more often due to the time gained particularly during the peak periods. In addition, the expected improvement in efficiency and schedule adherence could delay the need and costs to provide additional vehicles along the routes to maintain headway and schedules.

Based on the analysis completed in reviewing the critical signalized intersections along the Blue and Green Routes, travel times are anticipated to be reduced by approximately 14% and 20%, respectfully during the morning peak hours consistent with the FHWA findings.

In order to prioritize the four segments, an analysis of the implementation costs associated with each segment was weighed against the length of the segment, number of traffic signals and the time savings expected along each corridor resulting from TSP. The results were factored on a scale of 1-10 with a rating of 10 providing the largest benefit to cost ratio. The results are highlighted in Table 29.

Table 29 - Benefit/Cost Prioritization

Route Section	Implementation Cost	Distance (miles)	Number of Signals	Sum of Time Saved (min)	Benefit/Cost Ratio	Time Save per mile (min)
Blue Route - Hanover	$49,000	2.27	7	2.07	10.00	0.91
Blue Route - Lebanon (NB/SB)	$33,600	1.93	3	1.27	3.26	0.66
Green Route - Hartford	$68,600	1.52	5	0.97	1.60	0.64
Green Route - Norwich	$50,400	1.36	4	2.55	4.11	1.88

Lead Agency

It is anticipated that Advance Transit will be the lead agency and work with NHDOT, VTrans and the local municipalities to coordinate the implementation of TSP along the Blue and Green Transit Routes. AT will review potential funding/grant options and coordinate efforts with local municipal emergency services providers.

ITS Architecture

Transit Signal Priority is part of an Intelligent Transportation System (ITS). Both the State of New Hampshire Department of Transportation and the Vermont Transportation Agency have an ITS Architecture established. The following items were reviewed to determine if TSP is consistent with the statewide ITS Architecture plans:

- NHDOT, 5-Year Strategic Plan – Transportation Systems, Management & Operations (TSM&O), July 2014
- NHDOT, Statewide ITS Architecture and Strategic Plan, Version 1.0, February 3, 2006
- VTrans, Vermont Statewide ITS Architecture, (website)
    - http://www.consystec.com/vermont/web/index.htm
- US Department of Transportation, Developing Traffic Control Systems Using the National ITS Architecture, February 1998

TSP is consistent with the goals of both agencies ITS plans. Table 30 identifies the regional ITS Architecture elements that would be implemented as part of advancing a TSP system to serve the Advance Transit routes.

Table 30 - ITS Architecture

PROJECT ELEMENTS	NHDOT ITS ARCHITECTURE ELEMENT	VTRANS ITS ARCHITECTURE ELEMENT	NATIONAL ITS ARCHITECTURE SUBSYSTEM
Transit Signal Priority	APTS2 Transit Fixed Route Operations	APTS09 Transit Signal Priorty - Municipal	APTS7 - Multmodal Coordination
	APTS7 Multimodal Coordination	APTS09 Transit Signal Priorty - VTRANS	

Figures 37-39 depict the specific ITS project elements against a "sausage diagram" of the VTrans ITS Architecture.

Figure 37 - VTrans ITS Architecture -AT/UVLS Regional TOC

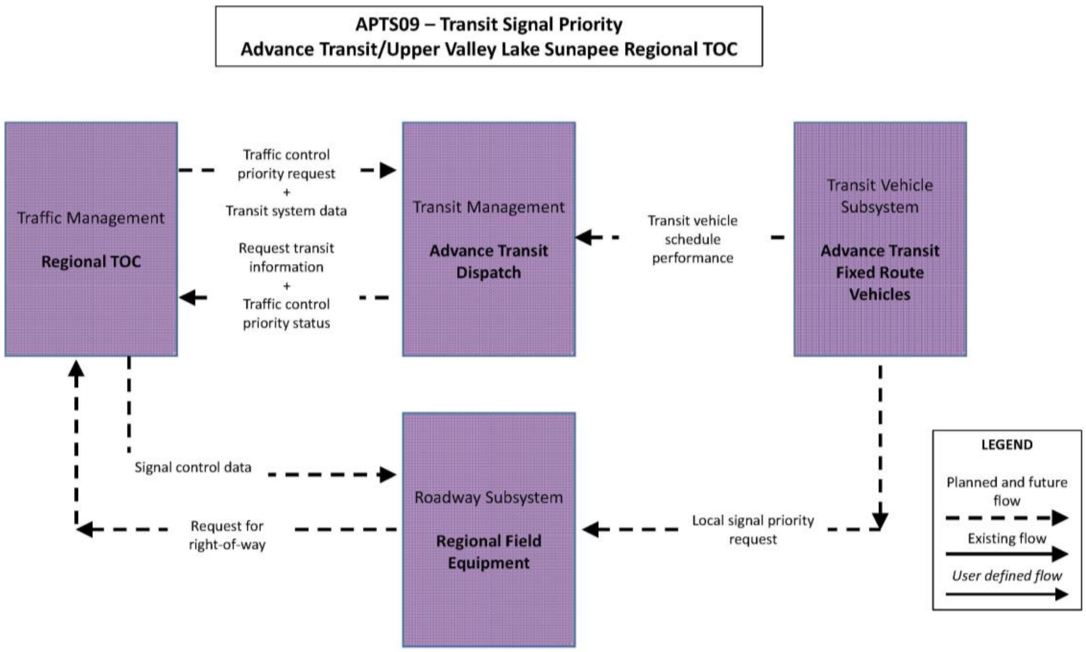


Figure 38 - VTrans ITS Architecture AT/VTrans

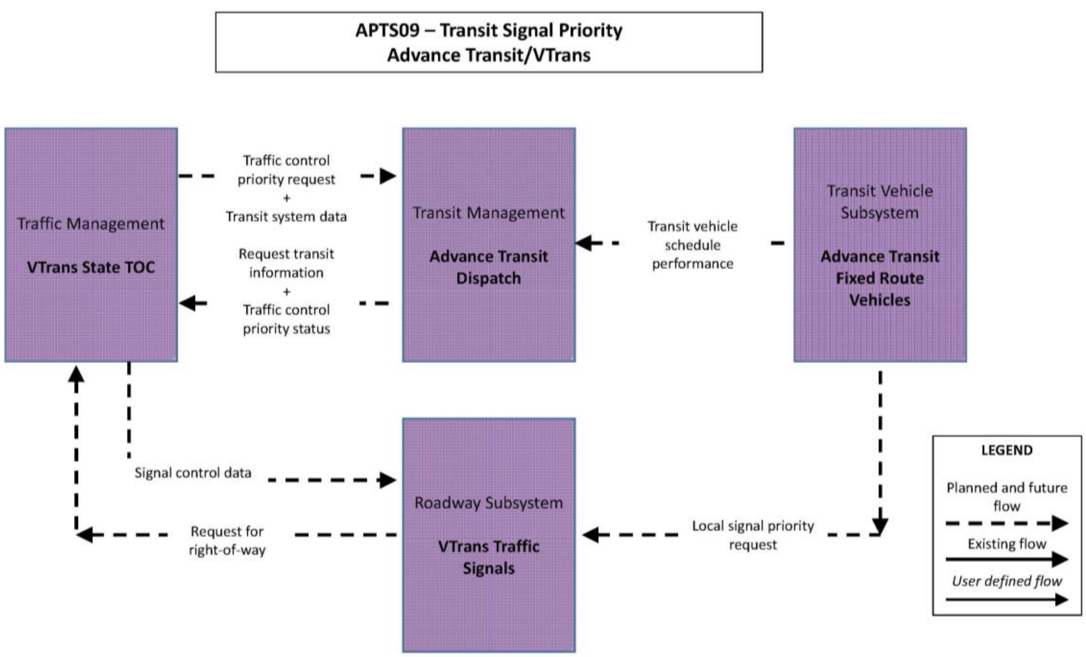


Figure 39 - VTrans ITS Architecture AT/Municipal

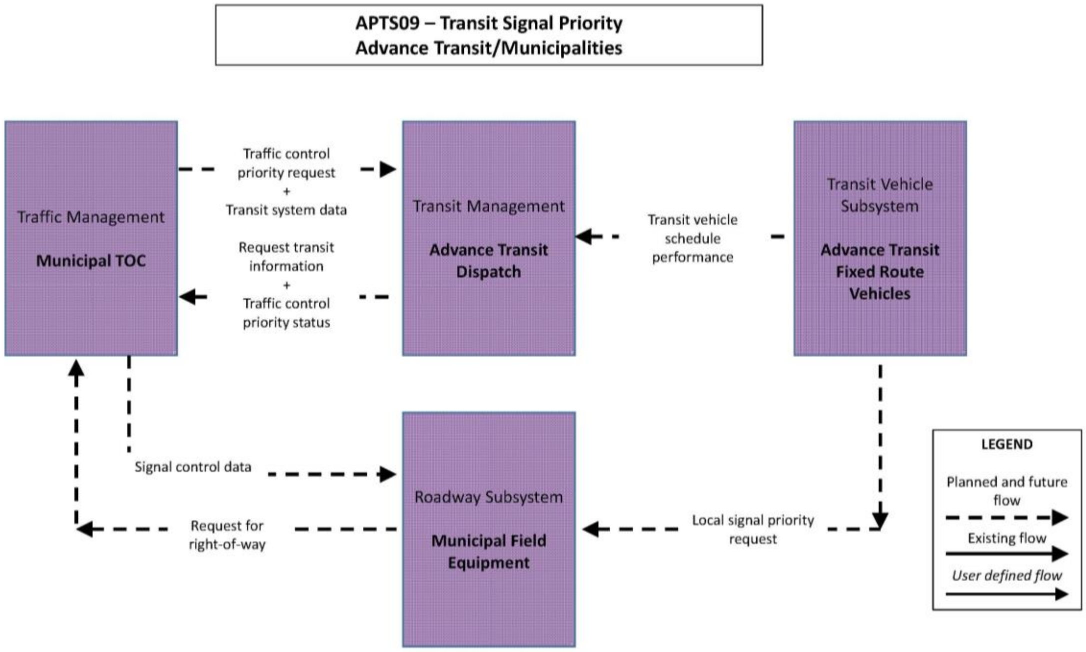
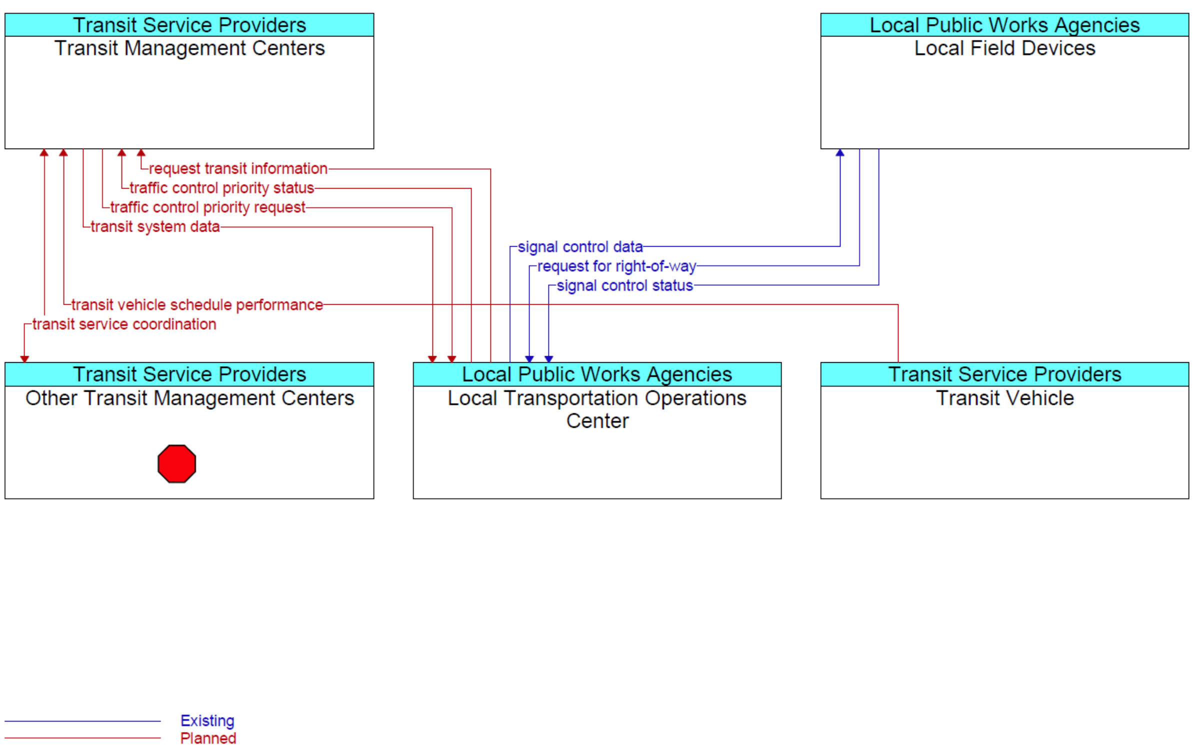


Figure 40 depicts the NHDOT ITS Architecture as it relates to TSP operations.

Figure 40 - NHITS Architecture
Multi-Modal Coordination (APTS07)



SECTION 6 – STANDARDS AND POLICIES

Vehicle to Intersection Communications
To be provided by GPS based vehicle to intersection communications

TSP Operations
Full TSP Functionality including Early Return to Green, Green Extension and Conditional Service (Schedule Adherence with system integration)

Compatibility with NEMA Controllers
TSP system shall be able to interface with any manufacturers NEMA Controller

Compatibility with Emergency Services
TSP shall be backwards compatible to provide continued integration with optical infrared based pre-emption systems and provide dual detection (GPS/Infrared) as well as coded and uncoded detection. System shall distinguish between pre-emption and priority service calls.

Scaled Operations and Integration with AT AVL
The TSP system shall be capable of future expansion and or modification of AT's AVL system.

APPENDIX A – TRAFFIC SIGNAL INVENTORY

GPI Signal Inventory

Intersection:	West Park @ South Park &	**Phase 1:**	Hanover St EB - W. Park WB
City/Town:	Lebanon, NH	**Phase 2:**	Fire Preemption
Date:	4/5/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	Ped
		Phase 5:	
Controller:	TCT LMD 8000	**Phase 6:**	
Firmware:	9-17-93 Rev 8f.	**OL A:**	Phase 2
	Prog # 0807170	**OL B:**	
		OLC:	

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	15	10		15					
EXT	5	1		5					
MAX 1	45	30		30					
MAX 2									
YEL	4	3		5					
RED	5	5		0					
WALK	0	0		15					
FDW	0	0		10					
DUAL ENTRY									
RECALL (Veh & PED)									
NON LOCK									

Special Event Programming

Hours of Operation	Dial	Split	Offset

Preemption

Preempt #	Phase Called

Ring Structure

1	2	4	

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset

Remarks

No Detection
No Opticom/Preemption
Fire Preemption from Fire Station
ime Clock Off: 06:27 3/20/16 operating at 10:54 4/5/16

GPI Signal Inventory

Intersection:	Mt. Support Rd @ Lahaye Drive	**Phase 1:**	
City/Town:	Lebanon, NH	**Phase 2:**	Lahaye Dr WB
Date:	4/5/2016	**Phase 3:**	Mt Support Rd SB LT
Recorded By:	JWD	**Phase 4:**	Mt. Support Rd NB
		Phase 5:	
Controller:	Econolite ASC/2S-2100	**Phase 6:**	Lahaye Dr EB
Firmware:	See Notes:	**Phase 7:**	Dynamic NTOR Sign
		Phase 8:	Mt Support Rd SB TH
		Phase 9:	

Timing

	PHASE											
	1	2	3	4	5	6	7	8	9	10	11	12
MIN		5	5	5		5		5	5	5	5	5
EXT		3	3	3		3		3	5	5	5	5
MAX 1		38	10	5		38		55	35	35	35	35
MAX 2		57	20	5		57		36	40	40	40	40
YEL		3	3	3		3		3	3			
RED		2	2	2		2		2	2			
WALK		10		10						10		10
FDW		16		16		16	14	16		16		16
DUAL ENTRY		X		X		X		X		X		X
RECALL (Veh & PED)		SOFT				SOFT						
Non Act I		X				X3						
Non Act II				X				X				
COND SERV	X		X		X		X		X		X	

Special Event Programming (Local/Master)

Hours of Operation	Dial	Split	Offset
M-F 0700-0900		7/0/1	
M-F 0900-1530 M-F 0830-1530 (from Master)		FREE	
M-F 1530-1800		7/0/2 FREE FROM MASTER	
M-F 1800-0700		FREE	
SAT- SUN		FREE	

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
3	2	30/10	2&6
4	6	30/10	2&6
5	4	30/10	4&8
6	3&8	30/10	4&8

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Coord Pattern 1 - C/O/S 701		49	11	45		49		56		105	21
Coord Pattern 2 - C/O/S 702		72	11	22		72		33		105	57

Remarks

Time of Day Program Incorrect:
13:32 on 4/5/16 at 14:32 4/5/16 (Loks like Daylught Savings Time issue)
Dynamic NTOR Signs w/WALK Indication NB

Ring Structure

1	2	3	4	7
5	6		8	

GPI Signal Inventory

Intersection:	Route 10 at Route 4 & Dana St	**Phase 1:**	NB Main St LT
City/Town:	Lebanon, NH	**Phase 2:**	Main St SB
Date:	4/5/2016	**Phase 3:**	PED
Recorded By:	JWD	**Phase 4:**	Bridge and Dana EB/WB
		Phase 5:	
Controller:	PEEK LMD 8000	**Phase 6:**	
Firmware:	0807170 Rev. 8L	**Phase 7:**	
		Phase 8:	
		OL A:	Phase 4

Timing

	PHASE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	9
MIN	6	6	0	5	6	6	6	6	
EXT	3	4	3	3	3	4	3	3	
MAX 1	22	14	0	8	22	16	0	16	
MAX 2	25	16	0	8	25	16	0	16	
YEL	4	4	4	4	4	4	4	4	
RED	1	1	1	1	1	1	1	1	
WALK	0	0	7	0	0	0	0	0	
FDW	0	0	15	0	0	0	0	0	
DUAL ENTRY									
RECALL (Veh & PED)									
Non Act I									
Non Act II									
COND SERV									

Special Event Programming **(Local)**

Hours of Operation	Dial	Split	Offset
M-F 1500-1830		MAX II	
M-F 18:30-1500		MAX I	
SAT- SUN 1000-1600		MAX II	
SAT-SUN 1600-1000		MAX I	

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
1	2		
2	1&6		
3	4	Inh OL A	

PREEMPTION SPLIT

	Phase # - Splits (in seconds)								
Cycle/Split/Offset	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Remarks

Time of Day Program Incorrect:
0:27 5/14/85 on 12:18 4/5/16

Simultaneous Gap Out -Psg Can Reset

Ring Structure

1	2	3	4	

GPI Signal Inventory

Intersection: North Main at Tracy and Railroad
City/Town: Lebanon, NH
Date: 4/5/2016
Recorded By: JWD

Controller: Peek LMD8000
Firmware: 0807798 Rev: 7.4.17

Phase 1: Main Street NB-SB
Phase 2: PED
Phase 3: Railroad
Phase 4: Tracy
Phase 5:
Phase 6:
Phase 7:
Phase 8:
OL A: Phase 1

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	10	0	5	25					
EXT	1	0	3	0					
MAX 1	40	22	10	26					
MAX 2	40	22	10	26					
YEL	4	3	4	3					
RED	3	0	2	3					
WALK		7							
FDW		10							
DUAL ENTRY									
RECALL (Veh & PED)									
Non Act I									
Non Act II									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
1	1	10	
2	1	10	
3	4	25	

PREEMPTION SPLIT

	Phase # - Splits (in seconds)								
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9

Remarks

Time of Day Program Incorrect:
02:34 at 12:06
Date is correct

Ring Structure

1	2	3	4	

GPI Signal Inventory

Intersection:	Route 120 at I89 SB Ramp	**Phase 1:**	
City/Town:	Lebanon, NH	**Phase 2:**	Route 120 SB
Date:	4/5/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	
		Phase 5:	Route 120 SB LT
Controller:	900ATC. 980-A0300-1	**Phase 6:**	Route 120 NB
Firmware:	76.13 M. Local, Sync Green	**Phase 7:**	
		Phase 8:	EB Off- Ramp
		OL A:	

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN		10			5	10		5	
EXT		3			2	2		3	
MAX 1		60			25	60		40	
MAX 2		45			40	45		40	
YEL		4			3	4		4	
RED		2			2	2		2	
WALK									
FDW									
DUAL ENTRY		X				X			
RECALL (Veh & PED)		Soft				Soft			
Non Lock		X			X	X		X	
Sim Gap		X			X	X		X	
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
M-F			
000-0645	FREE		
0645-930	Pattern 1		
0930-1530	FREE		
1530-1800	Pattern 2		
1800-000	FREE		
Sat-Sun			
000-0645	FREE		
0645-0930	Pattern 1		
0930-1530	FREE		
1530-1800	Pattern 2		
1800-000	FREE		

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
1	2 & 5	120/10	2&6
2	6	120/10	2&6
3	8	120/10	2&6

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1		42			16	26*		68		110	0
Pattern 2		70*			35	35		40		110	10
Pattern 3 (not used)		84			55	29*		45		129	
*** Coord Phase/Max Mode**											
Short - 10											
Long - 24											

Remarks

Communication via Ethernet over copper
Encom wireless to Wavetronix detector on ramp (queue detector) - appears to be disconnected
Running Synchro Green Adaptive Software

COORD DATA
Opp Mode: 0
Force Off: Fixed
Corr: Short/Long
MAX Mode: Inhibit
Flash Mode: Chan

Ring Structure

	2			
5	6		8	

GPI Signal Inventory

Intersection: Route 120 at I-89 NB Ramps
City/Town: Lebanon, NH
Date: 4/5/2016
Recorded By: JWD

Controller: Naztec 900 ATC. 980-B230
Firmware: 76.13M. Synchro Green

Phase 1: Route 120 NB LT
Phase 2: Route 120 SB
Phase 3:
Phase 4: I-89 NB Off-Ramp WB
Phase 5:
Phase 6: Route 120 NB
Phase 7:
Phase 8:
Phase 9:

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	5	10		5		10			
EXT	2	3		2		3			
MAX 1	20	60		20		60			
MAX 2	20	60		25		50			
YEL	4	4		4		4			
RED	2	2		2		2			
WALK									
FDW									
DUAL ENTRY		X				X			
RECALL (Veh & PED)		SOFT				SOFT			
Non Lock	X	X		X		X			
Sim Gap									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
M-F			
000-0645	FREE		
0645-930	Pattern 1		
0930-1530	FREE		
1530-1800	Pattern 2		
1800-000	FREE		
Sat-Sun			
000-0645	FREE		
0645-0830	Pattern 1		
0830-1530	FREE		
1530-1800	Pattern 2		
1800-000	FREE		

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases

Ring Structure

1	2		4	
	6			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1	16	48		46		64*				110	70
Pattern 2	16	58**		36		74				110	0
** Coord Phase/Max Mode											
* Coord Phase/Non Mode											
Short - 10											
Long - 24											

Remarks

Running Synchro Green Adaptive Software

COORD DATA
Opp Mode: 0
Force Off: Fixed
Corr: Short/Long
MAX Mode: Inhibit
Flash Mode: Chan

Communication via ethernet over copper
ENCOM wireless to wavetronix detector on ramp (queue detector) - NOT CONNECTED

	Pre Empt Number					
	1	2	3	4	5	6
Time Delay						
Min Duration	10	10	10			
Max Presence	120	120	120			
Min Green	10	10	10			
Min Walk						
Ped Clear						
Track Green						
Min Dwell	10	10	10			
Dwell	1+6	2	4			
Exit	2+6	2+6	2+6			

GPI Signal Inventory

Intersection: Route 120 @ Greensboro Rd
City/Town: Hanover, NH
Date: 4/27/2016
Recorded By: JWD

Controller: Naztec NT900TXII/CL
Firmware: V14.16

Phase 1: Route 120 SB LT
Phase 2: Route 120 NB
Phase 3: Greensboro WB
Phase 4:
Phase 5:
Phase 6: Route 120 SB
Phase 7:
Phase 8:
Phase 9:

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	5	8	4			8			
EXT	4	6	4			6			
MAX 1	25	35	25			35			
MAX 2	25	40	25			40			
YEL	4	5	4			5			
RED	2	2	2			2			
WALK	4	4	4			4			
FDW	14	14	14			14			
DUAL ENTRY									
RECALL (Veh & PED)	NONE	MIN	NONE			MIN			
Memory	ON		OFF						
Sim Gap									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
NONE			

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
NONE			

Ring Structure

1	2	3	
	6		

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
NONE											

Remarks

Clock set to 2-15-16, 03:33 (checked at 11:03 on 4/27/16)
Dalight Savings set to 4-1 and 10-5

Location	**S. Park St at Lebanon St - Hanover NH**								
Phase	1	2	3	4	5	6	7	8	9
MG	4	5	5	5	5	5	NU	NU	XPEd
Pas	4	4	4	4	4	4			
MX1	30	40	20	20	20	40			
Yellow	4	4	4	4	4	4			
Red	2	2	2	2	2	2			2
Walk									7
PED CLR									12

PE Channel		1	2	3	4
Phase		Did Not Retrieve PE Data			

Phase	1	2	3	4	5	6	7	8
Movement	Park NB Left Turn	Park SB Thru	Coop Site Res. Dr.					

GPI Signal Inventory

Intersection:	N/S Park St (Rte 120) @ E	**Phase 1:**	Route 120 SB LT
City/Town:	Hanover, NH	**Phase 2:**	Route 120 NB
Date:	4/27/2016	**Phase 3:**	Wheelock WB LT
Recorded By:	JWD	**Phase 4:**	Wheelock EB
		Phase 5:	Route 120 NB LT
Controller:	PEEK LMD 9200	**Phase 6:**	Route 120 SB
Firmware:	Rev 4B	**Phase 7:**	Wheelock EB LT
		Phase 8:	Wheelock WB
		Phase 9:	

Timing

	PHASE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	9
MIN	6	7	6	7	6	7	7	6	
EXT	3	4	3	3	3	4	3	3	
MAX 1	10	35	20	25	25	35	30	25	
MAX 2	8	45	20	35	35	40	35	30	
YEL	4	4	4	4	4	4	4	3	
RED	2	2	2	2	2	2	2	2	
WALK	7								
FDW	15								
DUAL ENTRY									
RECALL (Veh & PED)	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	
LOCK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	
Sim Gap									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
MON-FRI, 3AM-6AM	DAY 1 - MAX2		
SAT-SUN, 3AM-6AM	DAY 2 - MAX2		
ALL ELSE FREE			

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
1	1+6		
2	2+5		
3	3+8		
4	4+7		

Ring Structure

1	2	3	4
5	6	7	8
	9		

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Cycle**	**Offset**
NONE											

Remarks

MAX 2 should run from 3-6 PM, not 0300-0600

	Pre Empt Number					
	1	2	3	4	5	6
Run Enable						
Railroad						
PE Input Lock						
Early Pre Empt Out						
Max Intervals						
Flash Overide						
Go To Higher Priority						
NEMA Priority						
Hold Only						
User Priority						
Duration						
Preempt Delay						
Reserve (sec)						
Fal Max (minutes)						
Green	5	5	5	5		
Valid Phase						
Dwell						
Fixed						
Phase(s) called						
Walk		1	1	1		
Ped Clr	OFF	7	7	7		
Yellow						
Red						
O/L Yel		4	4	4		
O/L Red		2	2	2		

Location	**Park St at Lyme Rd - Hanover NH**								
Phase	1	2	3	4	5	6	7	8	9
MG	5	10 NU		5	5	10 NU		5 XPED	
Pass	3	3		2	3	3			
MX1	25	25		25	25	25		20	
Yellow	4	4		4	4	4		4	
Red	2	2		2	2	2		2	2
Walk									6
PED CLR									12

PE Channel	1	2	3	4
Phase	1&6	2&5	4	8

Phase	1	2	3	4	5	6	7	8
Movement	Lyme WB Left Turn	Lyme EB Thru	NU	Park NB	Lyme EB Left Turn	Lyme WB Thru		Parking Lot SB

Location	**Main St at Wheelock St - Hanover NH**								
Phase	1	2	3	4	5	6	7	8	9
MG	5	7	NU	10	NU	7	NU	5	
Pass	3	3		3		3		3	
MX1	10	35		25		35		25	
Yellow	4	4		4		4		4	
Red	1	2		2		2		2	1
Walk									9
PED CLR									11
PE Channel	1	2	3	4					
Phase									
Phase	1	2	3	4	5	6	7	8	
Movement	Wheelock WB Left Turn	Wheelock EB	NU	Main NB	NU	Wheelock WB	NU	Main SB	

Location	**Main St at Lebanon St - Hanover NH**								
Phase	1	2	3	4	5	6	7	8	9
MG	4	4	NU	4	NU	4	NU	NU	XPED
Pass	1.5	2		2		2			
MX1	25	30		20		25			
MX2	30	30		20		30			
Yellow	4	4		4		4			
Red	2	2		2		2			0
Walk									7
PED CLR									13

PE Channel	1	2	3	4
Phase				

Phase	1	2	3	4	5	6	7	8
Movement	Main SB Left Turn	Main NB	NU	Lebanon WB	NU	Main SB	NU	NU

GPI Signal Inventory

Intersection:	Main St (Rte 10A) at River Rd	**Phase 1:**	
City/Town:	Norwich, VT	**Phase 2:**	Main SB
Date:	4/27/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	River WB
		Phase 5:	Main SB LT
Controller:	Econolite ASC/2S-2100	**Phase 6:**	Main NB
Firmware:	1.79.34556	**Phase 7:**	
	Year 1992	**Phase 8:**	
		Phase 9:	

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN		8		8	5	8			
EXT		2		2	0	2			
MAX 1		37		16	5	26			
MAX 2		72		16	5	61			
MAX 3		37		16	5	26			
YEL		4		4	4	4			
RED		2.0		2.0	2.0	2.0			
WALK						10			
FDW						7			
DUAL ENTRY		X				X			
MAX RECALL									
Non Lock									
Inhibit Sim Gap									
Ped Clr Thru Yel									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
Sun-Sat			
1800-600	Max 3		
600-900	MAX 1		
900-1500	MAX 3		
1500-0000	MAX 2		
0000-1800	MAX 1		

Preemption

Preempt #	Phase Called	Min/Ped	Exit to Phases
none			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
none											

Remarks

Rest on phase 2+6

Ring Structure

	2		4
5	6		

GPI Signal Inventory

Intersection:	Main St (Rte 10A) at I-91 NB Ramps	**Phase 1:**	
City/Town:	Norwich, VT	**Phase 2:**	Main SB
Date:	4/6/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	
		Phase 5:	Main SB LT
Controller:	Econolite ASC/2-2100	**Phase 6:**	Main NB
Firmware:	1.30.32787	**Phase 7:**	
	Year 1992	**Phase 8:**	I-91 NB Off-Ramp EB
		Phase 9:	

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN		8			5	8		5	
EXT		4			2	4		4	
MAX 1		44			7	30		18	
MAX 2		40			7	26		26	
MAX 3		40			5	29		14	
YEL		4			4	4		4	
RED		2.0			2.0	2.0		2.0	
WALK						7			
FDW		7				10		7	
DUAL ENTRY		X				X			
MAX RECALL		X				X			
Non Lock									
Inhibit Sim Gap									
Ped Clr Thru Yel									

Special Event Programming (Local)

Hours of Operation	Dial / Split / Offset
Mon-Fri	
0000-0600	FREE
0600-0930	2/1/1
0930-1430	1/1/1
1430-1800	3/1/1
1800-2200	1/1/1
2200-0000	FREE
Sat-Sun	
0000-0600	FREE
0600-2200	1/1/1
2200-0000	FREE

Preemption

Preempt #	Phase Called	Min/Ped	Exit to Phases
none			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1		50			14	36		24		74	0
Pattern 2		42			22	20		26		78	0
Pattern 3		46			11	35		20		66	0

Remarks

Hardwire Interconnect to I-91 SB Ramps

Master Controller Settings SAT-SUN=Day 2
MON-FRI=Day 1

Step	Program	Time	COS	Sp Funct	Maint Call
1	1	600	2/1/1		
2	1	930	1/1/1		
3	1	1430	3/1/1		
4	1	1800	1/1/1		
5	1	2200	FREE	X	
6	2	600	1/1/1		
7	2	2200	FREE	X	
8	0	0000	CLR		

MIDNIGHT TO 6AM - FLASH

Ring Structure

	2		
5	6		8

GPI Signal Inventory

Intersection:	Main St (Rte 10A) at Rte 5 and I-91 SB Ramp	**Phase 1:**	Main NB LT
City/Town:	Norwich, VT	**Phase 2:**	Main SB
Date:	4/6/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	I-91 WB
		Phase 5:	Main SB LT
Controller:	Econolite ASC/2-2100	**Phase 6:**	Main NB
Firmware:	1.74.32787	**Phase 7:**	
	Year 1992	**Phase 8:**	Route 5 EB
		Phase 9:	

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	5	8		5	5	8		5	
EXT	2	2		2	3	2		2	
MAX 1	12	28		16	12	28		16	
MAX 2	10	23		27	12	23		27	
MAX 3	19	12		12	12	24		12	
YEL	4	4		4	4	4		4	
RED	2	2		2	2	2		2	
WALK						7			
FDW		7		7		16		7	
DUAL ENTRY	X	X		X	X	X		X	
RECALL to MAX		X				X			
Non Lock									
Inhibit Sim Gap									
Ped Clr Thru Yel									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
Mon-Fri			
0000-0600	FREE		
0600-0930	2/1/1		
0930-1430	1/1/1		
1430-1800	3/1/1		
1800-2200	1/1/1		
2200-0000	FREE		
Sat-Sun			
0000-0600	FREE		
0600-2200	1/1/1		
2200-0000	FREE		

Preemption

Preempt #	Phase Called	Min/Ped	Exit to Phases
none			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1	18	34		22	16	34		22		74	31
Pattern 2	16	29		33	16	29		33		78	75
Pattern 3	25	23		18	18	30		18		66	45

Remarks

Coordinated with I-91 NB Ramps via hardware - coordination options not set
No preemption

Ring Structure

1	2		4
5	6		8

GPI Signal Inventory

Intersection: Hartford Ave (Rte 5) at Worcester Ave/Highland Ave
City/Town: Hartford, VT
Date: 4/6/2016
Recorded By: JWD

Controller: Naztec 981 A1200-1
Firmware: V61.49
Year 2007

Phase 1:
Phase 2: Hartford NB
Phase 3:
Phase 4: Highland EB
Phase 5:
Phase 6: Hartford SB
Phase 7:
Phase 8: Worcester WB
Phase 9: Pedestrian

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN		12		6		12		6	
EXT		2		3		2		3	
MAX 1		35		31		35		31	
MAX 2		0		0		0		0	
YEL		4		4		4		4	3
RED		2.0		2.0		2.0		2.0	0
WALK									8
FDW									25
DUAL ENTRY		X		X		X		X	
RECALL (Veh & PED)		SOFT		NONE		SOFT		NONE	
Non Lock									
Inhibit Sim Gap		X		X		X		X	X
Ped Clr Thru Yel									X

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
All Days			
000-0600		54	
0600-900		54	
900-1400		54	
1400-1600		54	
1600-1800		54	
1800-000		54	

Preemption

Preempt #	Phase Called	Min/Ped	Exit to Phases
3	6	20/5	0
4	2	20/5	0
5	8	20/5	0
6	4	20/5	0

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1		38*		37		38*		37	33	75	0
Pattern 2		41*		34		41*		34	33	75	0
Pattern 3		40*		35		40*		35	33	75	0
Pattern 4		39*		36		39*		36	33	75	0

*Coordinated phases in MAX mode

Remarks

Max Recall (Phase 5 - not used)
Coordination appears to be free 24/7
Premts have no exit phase, return to Phase 2+6
cannot access pattern 54

MASTER CONTROL SETTING:
Note: no time base schedules or plans programmed under CLP master
System Online
Master Sta ID: 6140
TYPE: Master
Min Change Time (minute): 15
Sample Accum: 15
Lock Sample Time (Minutes): 15
Tx Error Time (Minutes): 95

Coordinated Intersections:
6140 - Master and Local, Route 5 at Highland
6142 - Highland at School Drive
6143 - Route 5 at Route 4

Ring Structure

	2	3	4
	6	7	8

	Pre Empt Number					
	1	2	3	4	5	6
Dwell	4	8	4+7	3+8	2+5	1+6
Exit	4+8	4+8	4+8	4+8	4+8	4+8
Min Duration	20	20	20	20	20	20
Ped Clear	5	5	5	5	5	5
Max Presence	0	0	0	0	0	0
Min Green	0	0	0	0	0	0
Min Walk	0	0	0	0	0	0
Track Green	0	0	0	0	0	0
Min Dwell	0	0	0	0	0	0

GPI Signal Inventory

Intersection:	Maple St (Rte 14) at Hartford Ave	**Phase 1:**	
City/Town:	Hartford, VT	**Phase 2:**	Hartford SB
Date:	4/6/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	Maple WB
		Phase 5:	Hartford SB LT
Controller:	Naztec 980 A0200-1	**Phase 6:**	Hartford NB
Firmware:	V61.49	**Phase 7:**	Maple St WB LT
	Year 2007	**Phase 8:**	Maple St EB
		Phase 9:	Pedestrian

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN		5		5	5	5	5	5	
EXT		2		2	2	2	2	2	
MAX 1		30		32	14	10	14	12	
MAX 2		0		0	0	0	0	0	
YEL		3.7		4.1	3.7	3.7	4.1	4.1	3
RED		1.9		3.0	1.9	1.9	3.0	1.9	0
WALK									7
FDW									33
DUAL ENTRY		X		X		X		X	
RECALL (Veh & PED)		SOFT				SOFT			
Non Lock									
Inhibit Sim Gap		X		X	X	X	X	X	X
Ped Clr Thru Yel									X

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
All Days			
000-0600	FREE		
0600-1000	Pattern 2		
1000-1500	Pattern 1		
1500-1800	Pattern 3		
1800-000	Pattern 1		

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
see next pg			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1		36		39	20	16	21	18	40	75	6
Pattern 2		38		37	22	16	20	17	40	75	20
Pattern 3		35		40	19	16	22	18	40	75	14
Pattern 4		30		45	17	13	16	29	33	75	12

Remarks

Phase 7 Maple St WB LT detectors faulting
Split 1, 2 and 3 set to NON with no coordination phase set
Split 4 has Phse 2 in MAX and set as coordinated phase

COORD DATA
Force Off: Float
Corr: Short/Long
MAX Mode: Inhibit
Flash Mode: Phase 1 OL

Ring Structure

	2	3	4
	6	7	8

	Pre Empt Number					
	1	2	3	4	5	6
Dwell	4	8	4+7	3+8	2+5	1+6
Exit	4+8	4+8	4+8	4+8	4+8	4+8
Min Duration	20	20	20	20	20	20
Ped Clear	5	5	5	5	5	5
Max Presence	0	0	0	0	0	0
Min Green	0	0	0	0	0	0
Min Walk	0	0	0	0	0	0
Track Green	0	0	0	0	0	0
Min Dwell	0	0	0	0	0	0

GPI Signal Inventory

Intersection:	Maple St (Rte 4) at Pine St/Bridge St	**Phase 1:**	
City/Town:	Hartford, VT	**Phase 2:**	Bridge St NB
Date:	4/6/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	Maple St EB
		Phase 5:	
Controller:	Econolite ASC/2-2109	**Phase 6:**	Pine St SB
Firmware:	32787 Ver. 1.64	**Phase 7:**	
	Year 1992	**Phase 8:**	Maple St WB
		Phase 9:	Pedestrian

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN		7		28		7		28	
EXT		2		0		2		0	
MAX 1		15		28		15		28	
MAX 2									
YEL		4		4		4		4	
RED		2		2		2		2	
WALK									7
FDW									18
DUAL ENTRY									
RECALL (Veh & PED)		NONE		MAX		NONE		MAX	
Non Act I				X				X	
Non Act II									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
none			

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
none			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
1/1/1		20		30		20		30	30	100	12

Remarks

No time of day programmed
no communication to other locations
appears to run Max 1 24/7
no preemption used
no detection working on Route 4 (Maple St)

Software/Version
BOOT/32783, 1.27
MAIN/32787, 1.64
HELP/32789, 1.5
CONFIG/32790, C8033

Ring Structure

	2		4
	6		8

GPI Signal Inventory

Intersection:	Route 120 at Heater Road	**Phase 1:**	Route 120 NB LT
City/Town:	Lebanon	**Phase 2:**	Route 120 SB
Date:	4/5/2016	**Phase 3:**	Heater WB
Recorded By:	JWD	**Phase 4:**	Heater EB
		Phase 5:	Route 120 SB LT
Controller:	Naztec 900 ATC. 980-B230	**Phase 6:**	Route 120 NB
Firmware:	76.13M. Synchro Green	**OL A:**	Phase 3 + 5
	Build 4732	**OL B:**	Phase 1 + 4
		Phase 9:	Pedestrian

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	4	6	4	4	4	6		4	
EXT	2	3	2	2	2	3		2	
MAX 1	15	60	15	15	15	60		0	
MAX 2	15	60	10	10	10	60		0	
YEL	3	4	4	4	3	4		4	3
RED	2	2	2	2	2	2		2	0
WALK									4
FDW									23
DUAL ENTRY									
RECALL (Veh & PED)	OFF	MIN	OFF	OFF	OFF	MIN			
Non Lock									
Sim Gap									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
M-F			
000-0645	FREE		
0645-930	Pattern 1		
0930-1530	FREE		
1530-1800	Pattern 2		
1800-000	FREE		
Sat-Sun			
000-0645	FREE		
0645-0830	Pattern 1		
0830-1530	FREE		
1530-1800	Pattern 2		
1800-000	FREE		

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
Pattern 1	28	30	20	20	15	43**	0	40	12	110	0
Pattern 2	15	43**	20	20	23	35	0	40	12	110	90
**** Coord Phase/Max Mode**											
*** Coord Phase/Non Mode**											
Short - 10											
Long - 24											

Remarks

Running Synchro Green Adaptive Software

COORD DATA
Opp Mode: 0
Force Off: Fixed
Corr: Short/Long
MAX Mode: Inhibit
Flash Mode: Chan
Stop in Walk: On
Walk Rec: No Recylce

Ring Structure

1	2		4	
	6			

	Pre Empt Number					
	1	2	3	4	5	6
Time Delay			0	0	0	0
Min Duration			10	10	10	10
Max Presence			120	120	120	120
Min Green			10	10	10	10
Min Walk			0	0	0	0
Ped Clear			255	255	255	255
Track Green			0	0	0	0
Min Dwell			10	10	10	10
Dwell			1+6	2+5	3	4
Exit			2+6	2+6	2+6	2+6
Lock Inh			ON	ON	ON	ON
Or Higher			NO	NO	NO	NO

GPI Signal Inventory

Intersection: Route 120 at Medical Center Dr
City/Town: Hanover
Date: 4/5/2016
Recorded By: JWD

Controller: Naztec NT900-TX
Firmware: V14.16

Phase 1: Route 120 NB LT
Phase 2: Route 120 SB
Phase 3:
Phase 4:
Phase 5: Route 120 SB LT
Phase 6: Route 120 NB
Phase 7:
Phase 8: Medical Ctr/Rest EB/WB
Phase 9:

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	5	6	5	6				4	
EXT	4	6	4	6				4	
MAX 1	30	40	30	40				30	
MAX 2	30	40	30	40				30	
YEL	4	4	4	4				4	
RED	2	2	2	2				2	
WALK	6								
FDW	24								
DUAL ENTRY									
RECALL (Veh & PED)	OFF	MIN	OFF	MIN				OFF	
Non Lock									
Sim Gap									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
NONE			

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
NONE			

Ring Structure

1	2		
5	6		8
	9		

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
NONE											

Remarks

GPI Signal Inventory

Intersection:	Maple St (Rte 4) at Prospect St	**Phase 1:**	
City/Town:	Hartford, VT	**Phase 2:**	Maple St WB
Date:	4/6/2016	**Phase 3:**	
Recorded By:	JWD	**Phase 4:**	Prospect St SB
		Phase 5:	
Controller:	McCain ATC eX	**Phase 6:**	Maple St EB
Firmware:	Rev. 1.6.3	**Phase 7:**	
		Phase 8:	Driveway NB
		Phase 9:	Pedestrian

Timing

	PHASE								
	1	2	3	4	5	6	7	8	9
MIN	4	8	4	5	4	8	4	5	4
EXT	2	4	2	3	2	4	2	3	2
MAX 1	15	51	15	14	15	51	15	14	15
MAX 2	15	45	15	45	15	45	15	45	15
YEL	3	4	3	4	3	4	3	4	3
RED	1	2	1	2	1	2	1	2	1
WALK		7		7		7		7	4
FDW		15		15		15		15	20
DUAL ENTRY									
RECALL (Veh & PED)									
Red revert	2	2	2	2	2	2	2	2	2
Non Act II									
COND SERV									

Special Event Programming (Local)

Hours of Operation	Dial	Split	Offset
none			

Preemption

Preempt #	Phase Called	MAX/Min	Exit to Phases
none			

PREEMPTION SPLIT

	Phase # - Splits (in seconds)										
Cycle/Split/Offset	1	2	3	4	5	6	7	8	9	Cycle	Offset
none											

Remarks

Verify operations after signal is turned on
no preemption set
only phases 2, 4, 6, 8 and 9 used.

Ring Structure

	2		4
	6		8
	9		

Location	**Park St at Summer St - Hanover NH**								
Phase	1	2	3	4	5	6	7	8	9
MG	NU	15	NU	6	NU	15	NU	8	XPED
Pas		5		4		5		4	
MX1		35		20		35		25	
Yellow		4		4		4		4	
Red		2		2		2		2	2
Walk									6
PED CLR									12
PE Channel		1	2	3	4				
Phase		2	6	8	4				
Phase	1	2	3	4	5	6	7	8	
Movement		Park NB		Smmer EB		Park SB		Site Dr.	

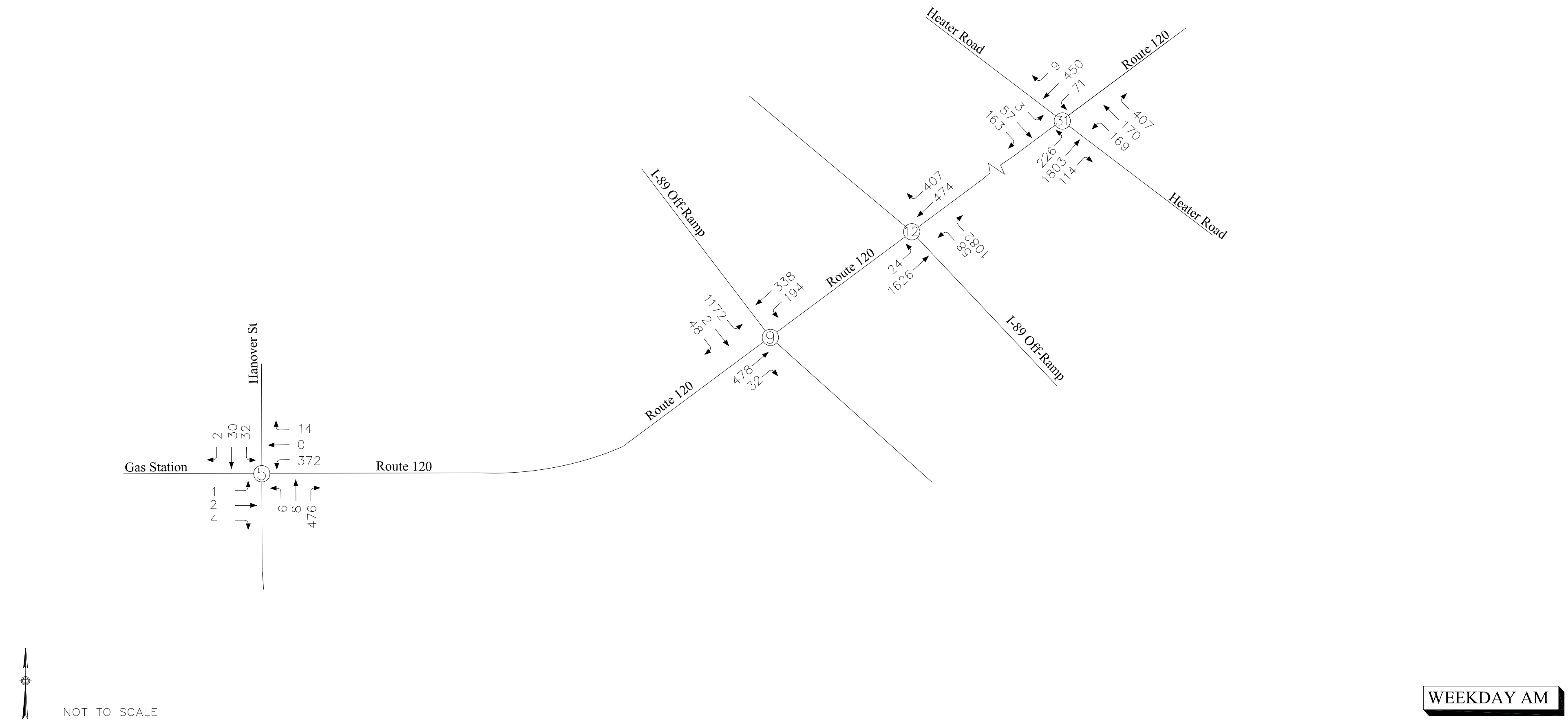
Location **Lebanon St at Summer St - Hanover NH**

Phase	1	2	3	4	5	6	7	8	9
MG	NU	4	NU	4	NU	4	NU	NU	XPED
Pas		3		2		3			
MX1		20		15		20			
MX2		45		45		45			
Yellow		4		4		4			
Red		2		2		2			
Walk									3
PED CLR									6

PE Channel								
Phase								

Phase	1	2	3	4	5	6	7	8
Movement		Lebanon NB		Summer WB		Lebanon SB		

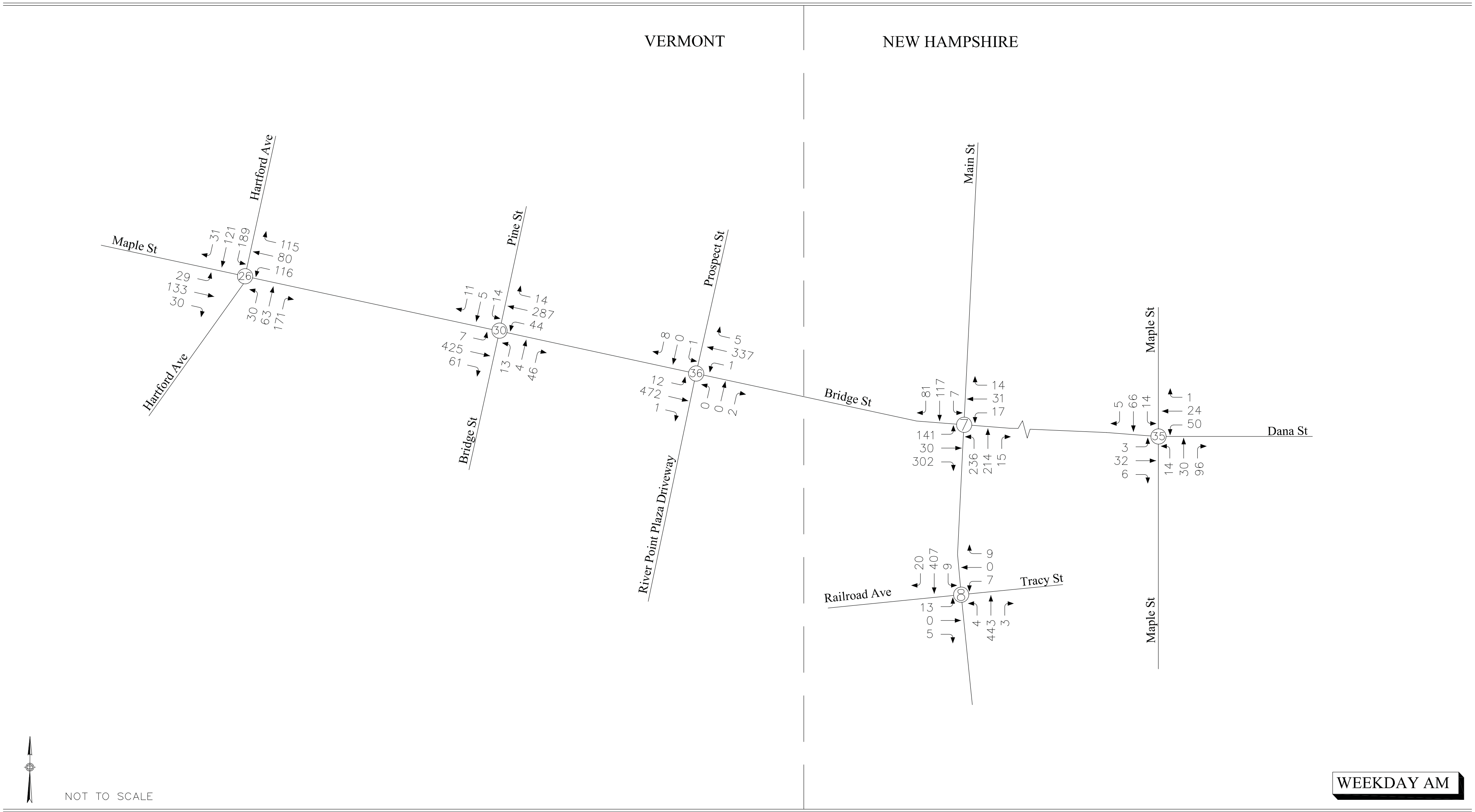
APPENDIX B – TRAFFIC DATA COLLECTION



GPI Greenman-Pedersen, Inc.
Engineering and Construction Services

Figure 01

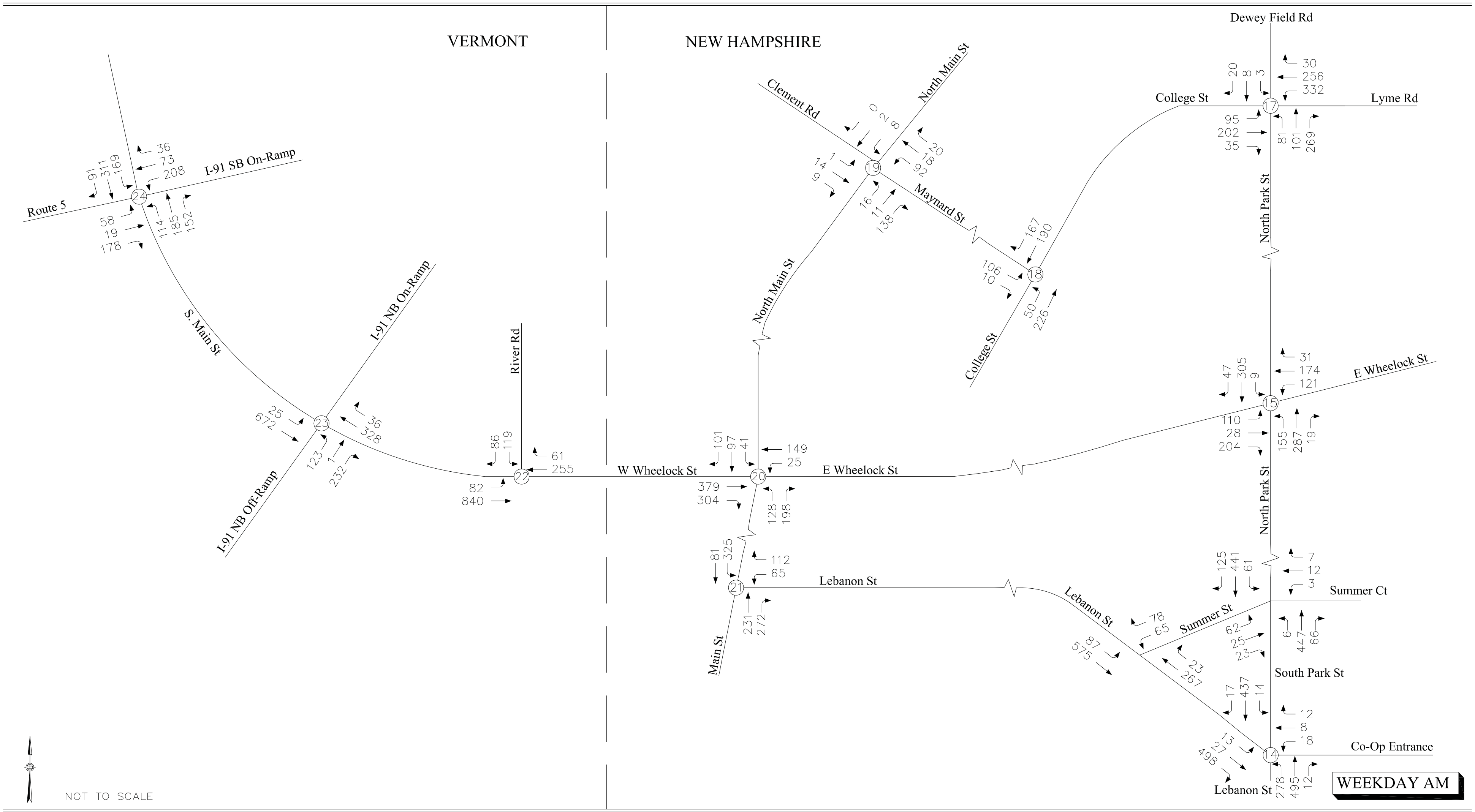
Peak Hour Traffic Volumes
Blue Bus Route
Lebanon, NH



Greenman-Pedersen, Inc.
Engineering and Construction Services

Figure 03

Peak Hour Traffic Volumes
Green Bus Route
Hartford, VT / Lebanon, NH



GPI Greenman-Pedersen, Inc.

Engineering and Construction Services

Figure 04

Peak Hour Traffic Volumes
Blue & Green Bus Routes
Norwich, VT / Hanover, NH

APPENDIX C – CAPACITY ANALYSIS

Blue Route – Hanover, NH

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
S. PARK STREET AT LEBANON STREET								
Weekday AM:								
Co-op Entrance WB left	0.29	56.9	E	25/38	0.47	55.9	E	<25/34
Co-op Entrance WB thru/right	0.37	58.3	E	29/42	0.59	65.5	E	25/38
Rte 120 NB left	0.37	65.8	E	<25/36	0.54	73.1	E	<25/33
Rte 120 NB thru	0.74	42.2	D	314/446	0.71	37.2	D	235/329
S. Park St (Rte 120) SB left	0.54	63.4	E	36/80	0.44	51.4	D	32/#88
S. Park St (Rte 120) SB thru	0.77	42.3	D	440/617	0.78	34.2	C	364/#575
Lebanon Street SEB thru	0.70	46.0	D	279/#406	0.68	38.0	D	221/306
Lebanon Street SEB right	0.62	20.5	C	277/496	0.61	17.5	B	198/326
Overall Intersection		**37.7**	**D**	--/--		**32.2**	**C**	--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95^{th} percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
S. PARK STREET AT SUMMER STREET								
Weekday AM:								
Summer St EB left/thru/right	0.56	35.2	D	48/98	0.58	35.4	D	47/97
Summer Ct. WB left/thru/right	0.08	28.9	C	<25/27	0.08	28.2	C	<25/27
S. Park St (Rte 120) NB right/thru/left	0.57	12.5	B	211/365	0.57	12.5	B	210/345
S. Park St (Rte 120) SB right/thru/left	0.76	17.7	B	299/#576	0.76	17.8	B	295/#546
Overall Intersection		**17.3**	**B**	**--/--**		**17.3**	**B**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing V/C [a]	2016 Existing Del. [b]	2016 Existing LOS [c]	2016 Existing Queue [d]	2016 Optimized V/C	2016 Optimized Del.	2016 Optimized LOS	2016 Optimized Queue
N./S. PARK STREET AT E. WHEELOCK STREET								
Weekday AM:								
E. Wheelock St EB left	0.52	42.2	D	87/136	0.60	37.9	D	78/120
E. Wheelock St EB thru/right	0.40	51.7	D	59/135	0.27	38.9	D	22/78
E. Wheelock St WB left	0.63	45.4	D	105/145	0.74	48.0	D	93/#133
E. Wheelock St WB thru/right	0.83	71.3	E	227/295	0.80	56.0	E	191/237
S. Park St NB left	0.52	26.8	C	102/158	0.55	22.3	C	89/137
S. Park St NB thru/right	0.47	30.7	C	223/361	0.48	25.2	C	194/320
N. Park St SB left	0.03	32.4	C	<25/<25	0.03	25.8	C	<25/<25
N. Park St SB thru/right	0.75	49.5	D	356/544	0.73	39.1	D	295/#399
Overall Intersection		**46.0**	**D**	**--/--**		**37.7**	**D**	**--/--**

[a] Volume-to-capacity ratio.
[b] Average control delay in seconds per vehicle.
[c] Level of service.
[d] Average/95[th] percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Existing Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
N. PARK STREET AT LYME ROAD								
Weekday AM:								
College St EB left	0.34	25.9	C	40/70	0.44	35.9	D	42/66
College St EB thru/right	0.79	47.5	D	182/256	0.86	65.1	E	223/#307
Lyme Rd WB left	1.13	103.9	F	~351/#338	0.95	53.0	D	~369/300
Lyme Rd WB thru/right	0.88	44.2	D	270/292	0.69	26.6	C	271/251
N. Park St NB thru/left	0.76	48.8	D	132/213	0.82	64.4	E	159/#251
N. Park St NB right	0.61	39.9	D	78/174	0.70	52.6	D	109/211
Dewey Field Rd. SB left	0.02	33.0	C	<25/<25	0.02	40.1	D	<25/<25
Dewey Field Rd. SB thru/right	0.04	33.1	C	<25/<25	0.05	40.2	D	<25/33
Overall Intersection		**59.1**	**E**	**--/--**		**48.7**	**D**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
N. MAIN STREET AT E. WHEELOCK STREET								
Weekday AM:								
W. Wheelock St. EB thru	0.89	59.1	E	346/#542	0.89	55.7	E	338/421
W. Wheelock St. EB right	0.24	21.9	C	<25/<25	0.24	21.3	C	<25/<25
E. Wheelock St. WB left	0.19	27.4	C	<25/36	0.21	26.8	C	<25/31
E. Wheelock St. WB thru	0.29	26.0	C	104/156	0.30	25.4	C	104/137
S. Main St. NB left	0.69	57.6	E	120/179	0.74	60.7	E	119/175
S. Main St. NB right	0.17	40.3	D	<25/<25	0.17	40.4	D	<25/28
N. Main St. SB left	0.26	46.8	D	40/69	0.26	44.1	D	39/66
N. Main St. SB thru	0.56	51.1	D	98/139	0.55	48.2	D	98/134
N. Main St. SB right	0.10	45.2	D	<25/27	0.10	42.6	D	<25/<25
Overall Intersection		**42.4**	**D**	**--/--**		**41.2**	**D**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
S. MAIN STREET AT LEBANON STREET								
Weekday AM:								
Lebanon St. WB left	0.44	31.8	C	45/83	0.53	30.6	C	44/70
Lebanon St. WB right	0.11	14.4	B	<25/<25	0.11	14.0	B	<25/<25
S. Main St. NB thru	0.64	28.3	C	130/223	0.68	27.6	C	123/182
S. Main St. NB right	0.21	16.9	B	0/20	0.21	16.7	B	<25/<25
S. Main St. SB left	0.71	15.8	B	120/189	0.75	17.5	B	113/166
S. Main St. SB thru	0.10	9.3	A	24/49	0.11	9.0	A	<25/44
Overall Intersection		**19.1**	**B**	**--/--**		**19.3**	**B**	**--/--**
				--/--				--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
LEBANON STREET AT SUMMER STREET								
Weekday AM:								
Summer St. WB left	0.43	22.9	C	<25/63	0.61	33.5	C	37/102
Lebanon St. NWB thru	0.34	8.4	A	66/138	0.30	7.8	A	70/125
Lebanon St. SEB thru	0.86	20.9	C	261/#481	0.76	14.6	B	239/415
Overall Intersection		**17.9**	**B**	**--/--**		**15.3**	**B**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

Blue Route – Lebanon, NH

INTERSECTION CAPACITY ANALYSIS SUMMARY

	2016 Existing/Optimized			
Intersection/Peak Hour/Lane Group	V/C [a]	Del. [b]	LOS [c]	Queue [d]
ROUTE 120 AT HEATER ROAD				
Weekday AM:				
Heater Rd. EB left	0.03	44.7	D	<25/<25
Heater Rd. EB thru	0.58	51.3	D	38/#117
Heater Rd. EB right	0.12	30.0	C	<25/36
Heater Rd. WB left	0.41	37.5	D	62/92
Heater Rd. WB thru	0.68	43.6	D	127/#240
Heater Rd. WB right	0.72	38.3	D	122/#172
Route 120 NB left	0.79	39.9	D	148/m134
Route 120 NB thru/right	1.06	53.6	D	~545/#523
Route 120 SB left	0.43	42.9	D	48/95
Route 120 SB thru/right	0.44	27.3	C	133/195
Overall Intersection		**45.1**	**D**	--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing/Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]
ROUTE 120 AT I-89 NB RAMPS				
Weekday AM:				
I-89 NB Off-Ramp WB left/thru	0.09	20.6	C	25/54
I-89 NB Off-Ramp WB right	1.08	83.4	F	~447/#592
Route 120 NB left	0.72	82.2	F	<25/<25
Route 120 NB thru	0.99	29.7	C	280/#751
Route 120 SB thru	0.24	10.9	B	<25/107
Route 120 SB right	0.28	36.6	D	<25/184
Overall Intersection		**44.1**	**D**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing/Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]
ROUTE 120 AT I-89 SB RAMPS				
Weekday AM:				
I-89 SB Off-Ramp EB left	0.86	32.6	C	364/501
I-89 SB Off-Ramp EB thru/left	0.86	32.9	C	365/502
I-89 SB Off-Ramp EB right	0.04	0.0	A	<25/<25
Route 120 NB thru	0.68	36.8	D	203/207
Route 120 NB right	0.03	27.2	C	<25/<25
Route 120 SB left	0.74	43.5	D	77/#107
Route 120 SB thru	0.30	30.2	C	128/167
Overall Intersection		**33.5**	**C**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

Green Route – Hartford, VT

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
MAIN STREET (ROUTE 10) AT TRACY STREET								
Weekday AM:								
Railroad Ave. EB left/thru	0.20	25.3	C	<25/<25	0.20	23.9	C	<25/<25
Railroad Ave. EB right	0.01	24.2	C	<25/<25	0.01	22.8	C	<25/<25
Tracy St. WB left/thru/right	0.02	24.2	C	<25/<25	0.02	22.9	C	<25/<25
Main St. (Route 10) NB left/thru/right	0.50	7.3	A	68/250	0.53	7.7	A	68/#259
Main St. (Route 10) SB left/thru/right	0.44	6.9	A	56/219	0.46	7.2	A	55/218
Overall Intersection		**8.0**	**A**	--/--		**8.3**	**A**	--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
MAIN STREET (ROUTE 10) AT BRIDGE STREET								
Weekday AM:								
Bridge St. EB left/thru	0.91	62.3	E	57/#253	0.63	25.6	C	56/#186
Bridge St. EB right	0.18	10.6	B	<25/43	0.19	9.6	A	<25/39
Dana St. WB left/thru/right	0.47	24.4	C	<25/60	0.26	19.9	B	<25/51
Main St. (Route 10) NB left	0.42	10.5	B	29/123	0.48	13.7	B	45/148
Main St. (Route 10) NB thru/right	0.28	7.1	A	27/115	0.32	9.7	A	42/139
Main St. (Route 10) SB left/thru	0.40	21.5	C	35/119	0.48	24.9	C	43/#133
Main St. (Route 10) SB right	0.06	19.2	B	<25/<25	0.06	21.7	C	<25/<25
Overall Intersection		**19.5**	**B**	--/--		**15.6**	**B**	--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
MAPLE STREET AT PROSPECT STREET								
Weekday AM:								
Maple St. EB left/thru/right	0.55	5.2	A	<25/134	0.53	4.9	A	<25/132
Maple St. WB left/thru/right	0.39	4.2	A	<25/86	0.37	4.0	A	<25/84
River Point Plaza Driveway NB right	0.00	12.5	B	<25/<25	0.00	13.1	B	<25/<25
Prospect St. SB left/thru/right	0.01	12.6	B	<25/<25	0.01	13.1	B	<25/<25
Overall Intersection		**4.9**	**A**	--/--		**4.6**	**A**	--/--

[a] Volume-to-capacity ratio.
[b] Average control delay in seconds per vehicle.
[c] Level of service.
[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
MAPLE STREET AT PINE STREET								
Weekday AM:								
Maple St. EB left	0.01	6.3	A	<25/<25	0.01	5.7	A	<25/<25
Maple St. EB thru/right	0.53	10.8	B	65/#374	0.50	9.7	A	65/315
Maple St. WB left/thru/right	0.24	7.5	A	<25/101	0.22	6.8	A	20/95
Bridge St. NB left/thru	0.25	28.0	C	<25/<25	0.27	30.8	C	<25/26
Bridge St. NB right	0.04	27.2	C	<25/<25	0.04	29.9	C	<25/<25
Pine St. SB left/thru/right	0.40	28.8	C	<25/<25	0.46	32.2	C	<25/26
Overall Intersection		**11.9**	**B**	--/--		**11.6**	**B**	--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
MAPLE STREET AT HARTFORD AVENUE								
Weekday AM:								
Maple St. EB left	0.20	26.1	C	<25/<25	0.17	25.6	C	<25/38
Maple St. EB thru/right	0.69	34.6	C	82/#157	0.60	30.6	C	83/143
Maple St. WB left	0.57	28.6	C	59/103	0.59	30.7	C	63/106
Maple St. WB thru	0.15	13.0	B	27/52	0.14	12.9	B	28/52
Maple St. WB right	0.10	12.7	B	<25/<25	0.10	12.7	B	<25/<25
Hartford Ave. NB left/thru/right	0.43	29.5	C	<25/57	0.44	31.0	C	<25/61
Hartford Ave. SB left	0.61	26.4	C	93/149	0.61	27.6	C	96/157
Hartford Ave. SB thru	0.20	13.3	B	41/68	0.20	14.2	B	43/74
Hartford Ave. SB right	0.03	12.3	B	<25/<25	0.03	13.1	B	<25/<25
Overall Intersection		**24.2**	**C**	--/--		**24.4**	**C**	--/--

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

Green Route – Norwich, VT

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
S. MAIN STREET AT ROUTE 5/I-91 SB RAMPS								
Weekday AM:								
US Route 5 EB left	0.18	15.7	B	<25/48	0.19	17.3	B	<25/47
US Route 5 EB thru/right	0.18	15.6	B	<25/39	0.18	17.2	B	<25/37
I-91 SB Ramps WB left/thru/right	0.84	35.5	D	146/#314	0.92	49.2	D	157/#307
S. Main St. NB left	0.66	38.7	D	51/#125	0.61	39.5	D	50/122
S. Main St. NB thru	0.61	32.1	C	103/114	0.56	28.0	C	106/99
S. Main St. NB right	0.11	33.8	C	<25/26	0.11	23.1	C	<25/<25
S. Main St. SB left	0.84	53.9	D	102/#192	0.79	48.1	D	102/#174
S. Main St. SB thru/right	0.53	27.3	C	104/119	0.50	26.2	C	108/132
Overall Intersection		**31.8**	**C**	**--/--**		**32.4**	**C**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
SOUTH MAIN STREET AT I-91 NB RAMPS								
Weekday AM:								
I-91 SB Ramps WB left/thru	0.47	30.2	C	64/97	0.48	31.2	C	66/100
I-91 SB Ramps WB right	0.48	30.4	C	48/97	0.47	31.3	C	47/97
S. Main St. NB thru/right	0.24	9.0	A	35/95	0.23	8.8	A	35/94
S. Main St. SB left	0.06	6.8	A	<25/<25	0.06	5.9	A	<25/<25
S. Main St. SB thru	0.37	9.5	A	125/188	0.36	8.2	A	127/187
Overall Intersection	**0.43**	**14.3**	**B**	**--/--**	**0.42**	**13.8**	**B**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing				2016 Optimized			
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
WEST WHEELOCK STREET AT RIVER ROAD								
Weekday AM:								
River Rd. WB left	0.53	20.0	B	35/85	0.60	21.2	C	33/84
River Rd. WB right	0.04	14.7	B	<25/<25	0.04	14.0	B	<25/<25
W. Wheelock St. NB thru/right	0.45	10.9	B	70/144	0.47	10.9	B	67/123
W. Wheelock St. SB left	0.16	4.5	A	<25/26	0.16	4.3	A	<25/<25
W. Wheelock St. SB thru	0.76	9.7	A	161/354	0.77	9.4	A	157/277
Overall Intersection		**10.9**	**B**	**--/--**		**10.8**	**B**	**--/--**

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

Other Intersection – not optimized

INTERSECTION CAPACITY ANALYSIS SUMMARY

	2016 Existing							
Intersection/Peak Hour/Lane Group	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
ROUTE 120 AT GREENSBORO ROAD								
Weekday AM:								
Greensboro Rd. WB left	0.58	30.3	C	87/123				
Greensboro Rd. WB right	0.15	25.3	C	0/18				
Route 120 NB thru	0.95	39.0	D	401/594				
Route 120 NB right	0.01	10.4	B	6/20				
Route 120 SB left	0.40	36.2	D	22/60				
Route 120 SB thru	0.45	7.5	A	110/194				
Overall Intersection		**23.1**	**C**	**--/--**				

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

	2016 Existing							
Intersection/Peak Hour/Lane Group	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
ROUTE 120 AT MEDICAL CENTER DRIVE								
Weekday AM:								
Medical Center Dr EB left	0.68	44.3	D	81/166				
Medical Center Dr EB thru/right	0.11	32.5	C	7/38				
Jesse's Restaurant Dr WB left	0.01	31.7	C	1/5				
Jesse's Restaurant Dr WB thru/right	0.10	32.6	C	8/19				
Route 120 NB left	0.45	44.0	D	34/86				
Route 120 NB thru/right	1.01	60.1	E	400/958				
Route 120 SB left	0.36	43.5	D	25/82				
Route 120 SB thru	0.34	17.6	B	87/251				
Route 120 SB right	0.38	0.7	A	0/0				
Overall Intersection		**32.2**	**C**	**--/--**				

[a] Volume-to-capacity ratio.
[b] Average control delay in seconds per vehicle.
[c] Level of service.
[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing							
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
MT SUPPORT ROAD AT LAHAYE DRIVE								
Weekday AM:								
Lahaye Dr EB left/thru/right	0.34	15.7	B	112/184				
Lahaye Dr WB left	0.03	12.5	B	4/14				
Lahaye Dr WB thru	0.74	24.7	C	310/456				
Lahaye Dr WB right	0.39	16.8	B	15/34				
Mt Support Rd NB left/thru	0.85	47.0	D	258/285				
Mt Support Rd NB right	0.04	24.8	C	0/17				
Mt Support Rd SB left	0.48	61.5	E	10/34				
Mt Support Rd SB thru/right	0.03	19.9	B	7/18				
Overall Intersection		**25.5**	**C**	**--/--**				

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

INTERSECTION CAPACITY ANALYSIS SUMMARY

Intersection/Peak Hour/Lane Group	2016 Existing							
	V/C [a]	Del. [b]	LOS [c]	Queue [d]	V/C	Del.	LOS	Queue
HARTFORD AVENUE AT HIGHLAND AVENUE								
Weekday AM:								
Highland Ave EB left/thru	0.24	19.4	B	5/35				
Highland Ave EB right	0.04	18.4	B	0/17				
Worcester Ave WB left/thru/right	0.23	19.3	B	6/47				
Hartford Ave NB thru	0.12	6.1	A	10/67				
Hartford Ave SB left	0.00	0.0	A	0/0				
Hartford Ave SB thru	0.36	7.1	A	35/223				
Hartford Ave SB right	0.02	5.8	A	0/12				
Overall Intersection		**9.0**	**A**	**--/--**				

[a] Volume-to-capacity ratio.

[b] Average control delay in seconds per vehicle.

[c] Level of service.

[d] Average/95th percentile queue length in feet per lane (assuming 25 feet per vehicle).

APPENDIX D – AIMSUN SIMULATION RESULTS

Aimsun Delay Results

Intersection	Route	Municipality	Jurisdiction	Direction	Existing*	Optimized*	TSP*
Route 120 at Wheelock St	Blue	Hanover	Hanover	NB	46.29	50.07	47.68
Route 120 at Wheelock St	Blue	Hanover	Hanover	SB	67.66	32.81	32.36
Route 120 at Wheelock St	Blue	Hanover	Hanover	EB	66.39	70.84	81.14
Route 120 at Wheelock St	Blue	Hanover	Hanover	WB	57.43	42.10	44.96
Route 120 at Wheelock St	Blue	Hanover	Hanover	TOTAL	237.77	195.83	206.14
Route 120 at Lyme Rd & Dewey Field Rd	Blue	Hanover	Hanover	NB	37.38	45.16	44.17
Route 120 at Lyme Rd & Dewey Field Rd	Blue	Hanover	Hanover	SB	36.78	44.08	43.84
Route 120 at Lyme Rd & Dewey Field Rd	Blue	Hanover	Hanover	EB	42.61	54.61	54.69
Route 120 at Lyme Rd & Dewey Field Rd	Blue	Hanover	Hanover	WB	51.79	21.77	22.06
Route 120 at Lyme Rd & Dewey Field Rd	Blue	Hanover	Hanover	TOTAL	51.79	21.77	22.06
Main St at Wheelock St	Blue	Hanover	Hanover	NB	36.74	47.39	47.38
Main St at Wheelock St	Blue	Hanover	Hanover	SB	50.09	53.51	53.58
Main St at Wheelock St	Blue	Hanover	Hanover	EB	42.79	26.41	26.41
Main St at Wheelock St	Blue	Hanover	Hanover	WB	33.17	26.83	26.69
Main St at Wheelock St	Blue	Hanover	Hanover	TOTAL	162.79	154.13	154.05
Main St at Lebanon St	Blue	Hanover	Hanover	NB	23.80	19.46	19.46
Main St at Lebanon St	Blue	Hanover	Hanover	SB	21.12	16.83	16.58
Main St at Lebanon St	Blue	Hanover	Hanover	WB	24.88	26.51	26.74
Main St at Lebanon St	Blue	Hanover	Hanover	TOTAL	69.80	62.81	62.78
Route 120 at Summer St & Court St	Blue	Hanover	Hanover	NB	28.43	14.30	13.26
Route 120 at Summer St & Court St	Blue	Hanover	Hanover	SB	80.14	29.62	21.26
Route 120 at Summer St & Court St	Blue	Hanover	Hanover	EB	16.02	21.76	22.59
Route 120 at Summer St & Court St	Blue	Hanover	Hanover	WB	15.27	18.22	17.81
Route 120 at Summer St & Court St	Blue	Hanover	Hanover	TOTAL	139.87	83.89	74.94
Lebanon St at Summer St	Blue	Hanover	Hanover	NB	15.92	7.34	7.33
Lebanon St at Summer St	Blue	Hanover	Hanover	SB	63.92	12.50	12.63
Lebanon St at Summer St	Blue	Hanover	Hanover	WB	11.82	35.75	34.43
Lebanon St at Summer St	Blue	Hanover	Hanover	TOTAL	91.65	55.59	54.38
Route 120 at Lebanon St & Co-Op Driveway	Blue	Hanover	Hanover	NB	34.19	18.82	18.75
Route 120 at Lebanon St & Co-Op Driveway	Blue	Hanover	Hanover	SB	12.76	6.49	7.10
Route 120 at Lebanon St & Co-Op Driveway	Blue	Hanover	Hanover	EB	24.84	25.78	25.34
Route 120 at Lebanon St & Co-Op Driveway	Blue	Hanover	Hanover	WB	49.67	48.56	48.56
Route 120 at Lebanon St & Co-Op Driveway	Blue	Hanover	Hanover	TOTAL	121.46	99.65	99.75
Route 120 at I-89 SB	Blue	Lebanon	NHDOT	NB	32.56		30.90
Route 120 at I-89 SB	Blue	Lebanon	NHDOT	SB	41.47		38.86
Route 120 at I-89 SB	Blue	Lebanon	NHDOT	EB	34.18		35.73
Route 120 at I-89 SB	Blue	Lebanon	NHDOT	TOTAL	108.21	0.00	105.49

* Results given in Seconds of Delay

Aimsun Delay Results

Intersection	Route	Municipality	Jurisdiction	Direction	Existing*	Optimized*	TSP*
Route 120 at I-89 NB	Blue	Lebanon	NHDOT	NB	26.86		26.29
Route 120 at I-89 NB	Blue	Lebanon	NHDOT	SB	1.00		1.01
Route 120 at I-89 NB	Blue	Lebanon	NHDOT	WB	0.02		0.02
Route 120 at I-89 NB	Blue	Lebanon	NHDOT	TOTAL	27.87	0.00	27.31
Route 120 at Heater Rd	Blue	Lebanon	NHDOT	NB	22.09		22.27
Route 120 at Heater Rd	Blue	Lebanon	NHDOT	SB	26.59		27.09
Route 120 at Heater Rd	Blue	Lebanon	NHDOT	EB	20.05		20.71
Route 120 at Heater Rd	Blue	Lebanon	NHDOT	WB	35.55		32.28
Route 120 at Heater Rd	Blue	Lebanon	NHDOT	TOTAL	104.28	0.00	102.35
Main St at Bridge St & Dana St	Green	Lebanon	Lebanon	NB	8.78	11.42	11.61
Main St at Bridge St & Dana St	Green	Lebanon	Lebanon	SB	11.12	13.38	13.40
Main St at Bridge St & Dana St	Green	Lebanon	Lebanon	EB	10.44	1.12	1.08
Main St at Bridge St & Dana St	Green	Lebanon	Lebanon	WB	19.76	13.10	13.09
Main St at Bridge St & Dana St	Green	Lebanon	Lebanon	TOTAL	50.10	39.01	39.17
Main St at Railroad Ave & Tracy St	Green	Lebanon	Lebanon	NB	15.24	20.25	20.30
Main St at Railroad Ave & Tracy St	Green	Lebanon	Lebanon	SB	19.61	21.78	22.20
Main St at Railroad Ave & Tracy St	Green	Lebanon	Lebanon	EB	19.82	13.35	13.41
Main St at Railroad Ave & Tracy St	Green	Lebanon	Lebanon	WB	31.58	29.04	24.99
Main St at Railroad Ave & Tracy St	Green	Lebanon	Lebanon	TOTAL	86.24	84.41	80.90
Hartford Ave at Maple St (Rte 4 at Rte 5)	Green	Hartford	VTrans	NB	0.18	0.18	0.18
Hartford Ave at Maple St (Rte 4 at Rte 5)	Green	Hartford	VTrans	SB	20.45	21.96	21.52
Hartford Ave at Maple St (Rte 4 at Rte 5)	Green	Hartford	VTrans	EB	0.15	0.20	0.20
Hartford Ave at Maple St (Rte 4 at Rte 5)	Green	Hartford	VTrans	WB	22.40	19.78	19.52
Hartford Ave at Maple St (Rte 4 at Rte 5)	Green	Hartford	VTrans	TOTAL	43.19	42.11	41.42
Maple St at Bridge St & Pine St	Green	Hartford	VTrans	NB	6.17	9.53	9.51
Maple St at Bridge St & Pine St	Green	Hartford	VTrans	SB	11.41	16.71	16.33
Maple St at Bridge St & Pine St	Green	Hartford	VTrans	EB	11.69	12.87	12.75
Maple St at Bridge St & Pine St	Green	Hartford	VTrans	WB	11.06	11.28	11.56
Maple St at Bridge St & Pine St	Green	Hartford	VTrans	TOTAL	40.32	50.39	50.16
Maple St at Prospect St	Green	Hartford	VTrans	NB	20.12	16.84	16.84
Maple St at Prospect St	Green	Hartford	VTrans	SB	20.36	16.73	16.73
Maple St at Prospect St	Green	Hartford	VTrans	EB	5.15	9.46	8.98
Maple St at Prospect St	Green	Hartford	VTrans	WB	4.92	5.68	5.83
Maple St at Prospect St	Green	Hartford	VTrans	TOTAL	50.55	48.72	48.38

* Results given in Seconds of Delay

Aimsun Delay Results

Intersection	Route	Municipality	Jurisdiction	Direction	Existing*	Optimized*	TSP*
Route 10A at River Rd	Green	Norwich	VTrans	SB	15.85	18.60	18.60
Route 10A at River Rd	Green	Norwich	VTrans	EB	28.94	14.86	14.99
Route 10A at River Rd	Green	Norwich	VTrans	WB	19.17	15.79	15.67
Route 10A at River Rd	Green	Norwich	VTrans	TOTAL	63.96	49.25	49.26
Route 10A at I-91 NB	Green	Norwich	VTrans	NB	27.40	28.31	28.65
Route 10A at I-91 NB	Green	Norwich	VTrans	EB	13.22	14.42	13.42
Route 10A at I-91 NB	Green	Norwich	VTrans	WB	20.34	14.05	13.89
Route 10A at I-91 NB	Green	Norwich	VTrans	TOTAL	60.96	56.77	55.96
Route 10A at Route 5 & I-91 SB	Green	Norwich	VTrans	NB	21.94	20.30	19.10
Route 10A at Route 5 & I-91 SB	Green	Norwich	VTrans	SB	25.00	22.37	21.76
Route 10A at Route 5 & I-91 SB	Green	Norwich	VTrans	EB	33.06	30.89	30.97
Route 10A at Route 5 & I-91 SB	Green	Norwich	VTrans	WB	29.13	35.54	34.50
Route 10A at Route 5 & I-91 SB	Green	Norwich	VTrans	TOTAL	109.13	109.10	106.34

* Results given in Seconds of Delay

Travel Time Comparison

Comparison of Blue Bus Travel Time (minutes)				Existing vs Optimized		Existing vs TSP		Optimized vs TSP	
Hanover	Existing	Optimized	TSP	Difference	% Difference	Difference	% Difference	Improvement	% Improvement
Blue Line Loop	14.07	13.42	11.93	0.65	5%	2.14	15%	1.49	11%
Lebanon	Existing	Optimized	TSP	Difference	% Difference	Difference	% Difference	Improvement	% Improvement
Blue I-89 Ramps NB	5.43	5.43	4.87	0.00	0%	0.55	10%	0.55	11%
Blue I-89 Ramps SB	4.78	4.78	4.07	0.00	0%	0.71	15%	0.71	15%
Total I-89	**10.21**	**10.21**	**8.95**	**0.00**	**0.00**	**1.26**	**12%**	**1.26**	**12%**
Total Blue Line	**24.27**	**23.63**	**20.88**	**0.65**	**3%**	**3.40**	**14%**	**2.75**	**12%**

Comparison of Green Bus Travel Time (minutes)				Existing vs Optimized		Existing vs TSP		Optimized vs TSP	
Norwich	Existing	Optimized	TSP	Difference	% Difference	Difference	% Difference	Improvement	% Improvement
to Hanover	8.29	6.24	5.73	2.05	25%	2.56	31%	0.51	8%
Hartford	Existing	Optimized	TSP	Difference	% Difference	Difference	% Difference	Improvement	% Improvement
1. Green Line Loop EB	6.06	5.77	5.40	0.29	5%	0.66	11%	0.37	6%
2. Green Line Loop WB	3.14	2.92	2.83	0.21	7%	0.31	10%	0.10	3%
Total Hartford	**9.20**	**8.70**	**8.23**	**0.50**	**5%**	**0.97**	**11%**	**0.47**	**5%**
Total Green Line	**17.49**	**14.94**	**13.96**	**2.55**	**15%**	**3.53**	**20%**	**0.98**	**7%**
TOTAL SYSTEM	**41.76**	**38.57**	**34.84**	**3.20**	**8%**	**6.93**	**17%**	**3.73**	**10%**

Greenman-Pedersen, Inc.

Engineering and Construction Services