ADAPTIVE TRAFFIC SIGNAL CONTROL SYSTEM (ACS-LITE) FOR WOLF ROAD, ALBANY, NEW YORK

SPR RESEARCH PROJECT No. C-10-13

Final Report

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ABSTRACT

Adaptive Control Software Lite (ACS-Lite) is a traffic signal timing optimization system that dynamically adjusts traffic signal timings to meet current traffic demands. The purpose of this research project was to deploy and evaluate the ACS-Lite adaptive traffic control system on a congested urban corridor in New York State (NYS). In this case, the Wolf Road Corridor in Albany, New York, was chosen. The primary goal was to document the experiences and key lessons learned from the deployment and evaluation regarding how an adaptive control system can be deployed, the advantages and disadvantages of the system, and whether it is suitable for use in other corridors in NYS. The results of the project showed that for heavily congested corridors adaptive control can improve flow within its own system, but may cause extra delays at the boundaries where there are interactions with other traffic control systems. Therefore, a more comprehensive control/management framework may be needed in some cases. The specific ACS-Lite software also needed to be upgraded and improved in order to work for the selected corridor, which caused delays to this project.

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EXECUTIVE SUMMARY

The purpose of this research project was to deploy and evaluate the ACS-Lite adaptive traffic control system on a congested urban corridor in New York State (NYS). The primary goal of the project was to document the experiences and key lessons learned from the deployment and evaluation regarding how an adaptive control system can be used, whether the system is beneficial, and whether it is suitable for other corridors in the State.

A nine (9) intersection corridor along Wolf Road, Albany, NY, was chosen to be the test site for the installation of the ACS-Lite system in order to demonstrate its benefits and potential problems. An accompanying vehicle detection and arterial travel time (ATT) system was implemented to collect traffic data, such as volume and corridor travel times. The communication system was also upgraded along the corridor to establish communications needed by ACS-Lite and the detection system. To assess the performance of the installed adaptive control system, a "before and after" analysis was conducted to compare the performance of the previous signal control system (called "before" scenarios) with the newly installed ACS-Lite system (called "after" scenarios). The evaluation is based on the measures of effectiveness (MOEs), including corridor travel times, intersection delays, average speeds, queue sizes at major intersections, number of stops, and stop durations, in addition to corridor-wide fuel consumption and carbon footprint. A cost-benefit analysis was then made on the impacts of the installations in a long-term trend.

During the course of the project, the project team was able to successfully deploy (i) the communication devices and systems along the corridor; (ii) the Sensys detection system for traffic volumes and arterial travel times, as well as its data transmission and collection system (i.e., access points, repeaters, among others); (iii) the ACS-Lite signal control system including the field server and control software. Overall, the project team and NYSDOT worked together well to resolve all the issues and the communications between RPI and NYSDOT were always without incident. With the exception of some communication issues at the beginning of the project and hardware (firewall) problems in the middle of the project, the communication systems have worked as expected and the experienced issues were resolved promptly by the project team. The Sensys detection system has also performed as expected, with minor issues

that were resolved quickly. A number of issues were revealed during the course of the project related to ACS-Lite, mainly caused by the incompatibility of the original version of the ACS-Lite software and the controllers on the Wolf Road Corridor. Siemens was able to provide proper support for field investigation and communication with NYSDOT and RPI regarding these issues. However, fixing some of the issues took longer than expected. To a large extent, these ACS-Lite software- related issues are the main reason for the delays experienced in the project.

Major findings and recommendations are summarized as follows:

1. Volume data produced by Sensys detectors matched fairly well with field observations with minor issues when the traffic volume was very low. Similarly, travel times produced by the Sensys travel time system matched fairly well with the Global Position System (GPS) probe data, with minor issues when the traffic was very congested.

2. After deploying ACS-Lite, delays at the Albany Shaker intersection increased dramatically, while delays at the other intersections decreased slightly. In addition, travel times of the corridor only changed slightly with smaller speed variations, indicating the traffic was smoother after the deployment of adaptive control. The fuel consumption was increased slightly, while emissions were decreased slightly. The benefit/cost analysis, without considering the boundary intersections (Albany Shaker Road and Old Wolf Road), showed that in about 15 years, the potential benefits will overcome the total project cost, including both NYSDOT project cost and the cost share of RPI and industry partners. If only the cost to NYSDOT was considered, this would be reduced to about 8 years. One should exercise caution, however, in the interpretation and use of these numbers since the benefits or costs of deploying ACS-Lite are relatively small. Thus, any estimation errors in the analysis could result in different numbers or even opposite conclusions.

3. The research results indicate that for a heavily congested corridor, such as the Wolf Road Corridor, adaptive control can potentially improve traffic flow within its own system. However, this may be achieved by “metering” (i.e., restricting) flow into the system, thereby generating large delays/problems at the boundary intersections, e.g., the Albany Shaker intersection in the Wolf Road Corridor. Obviously, this metering effect would

also depend on the specific adaptive control system as well as the actual traffic conditions of the corridor system.

4. The evaluation results, especially the delay changes at Albany-Shaker Road and the other intersections, seem to suggest that in order to solve the congestion and related issues for Wolf Road, a large network may need to be considered. In such an extended network, the coordination between the freeway and arterials can be investigated in a more holistic manner. Other advanced strategies such as traveler information or route diversion can also be explored. This leads to the integrated corridor management (ICM) approach to better managed congested corridors. The ICM-based approach may be pursued in the future to develop more effective methods to manage congestion and related issues of the Wolf Road Corridor.

5. Overall, this research project was successfully conducted, under the collaboration of NYSDOT, RPI, and the industry partners, although the actual performance of ACS-Lite on the Wolf Road Corridor is mixed. The performance of ACS-Lite in this specific case should not be considered as an indication of its performance on other corridors in general, or taken as a discouragement regarding proactive evaluation/deployment of advanced traffic/transportation control/management technologies, in this case, the adaptive traffic control. As shown in the benefit/cost analysis section of the report, if the boundary intersection issue can be properly handled (e.g., using the ICM-based approach on a larger network), adaptive control does benefit the system as a whole and the cost can be offset by the benefit in a few years (if only DOT cost is considered). Therefore, earlier deployment of certain advanced technologies to NYS corridors will benefit more of the traffic in the state. To do so, research projects, similar to what has been done in this project, are crucial to document experiences and lessons learned, and to further produce specific guidelines on how such technologies can be best deployed and when/where they should be deployed to achieve the utmost benefits. Such research projects are expected to experience more issues, and sometimes delays, due to their unique exploration nature. In fact, the project team is currently working on a research project with NYSDOT and New York State Energy Research and Development Authority (NYSERDA) inquiring whether

and how adaptive control should be deployed in NYS corridors. The findings in this project will provide very useful insight in this regard.

6. NYSDOT has had a well-established and well-conducted procedure to test/evaluate/deploy new control systems/technologies. Before their deployment, Sensys detectors and the ACS-Lite system have been extensively tested in the Traffic Lab. Many issues had been identified and resolved before the field deployment. This project also indicated that real world field testing/deployment of such new systems/technologies may be needed. This is particularly true for certain rare issues that may not be easily reproduced in lab testing, such as the flashing issue at the Albany-Shaker intersection. It is thus recommended that NYSDOT ask technology providers to field demonstrate their product and to resolve problems/issues before the technology can be formally deployed in NYS corridors. In fact, NYSDOT field tested the Sensys detectors in Utica, NY, and resolved a few issues (such as those related to very low temperature in winter times) before the Wolf Road project. This also proves the importance of field testing of new technologies before their formal deployment in NYS.

7. To do the field demonstration, a demo site or corridor may be constructed and maintained. Such a demo site should be well-equipped with detection systems and communication capabilities and be well-maintained and continuously monitored. The site should also be well studied in terms of traffic flow patterns, performances, and potential issues. This demo site will then become a living laboratory for NYSDOT to test and evaluate advanced technologies that may have great potential to solve congestion and related issues of the traffic in NYS. However, one should be cautioned to test certain traffic control technologies or systems since they may interfere with traffic significantly. Testing other technologies and systems, such as those for communications, sensing/detection, and data collection should be easily conducted since they normally do not interfere greatly with traffic flow.

1. INTRODUCTION

1.1 Background

Adaptive Control Software Lite (ACS-Lite) is a signal timing optimization system that dynamically adjusts signal timing to meet current traffic demands. Through a public-private partnership between FHWA, Siemens, The University of Arizona, Purdue University, Siemens/Eagle, Econolite, Quixote/Peek and McCain Traffic, ACS-Lite was developed. Compared with other adaptive signal control systems, ACS-Lite does not require a central control system; it can be controlled remotely through the use of a laptop device. This can dramatically reduce the installation cost (see FHWA, 2006). As stated in the field tests, ACS-Lite has led to estimated annual user cost savings ranging between $88,000 and $757,000. This system, if successfully demonstrated, could be implemented in some of the New York State (NYS) corridors where variability and unpredictability in traffic demand results in excessive delay and stops that cannot be reasonably accommodated by updating coordinated signal timing parameters.

In this project, the research team used a nine (9) intersection corridor along Wolf Road, Albany NY, as a test site to install the ACS-Lite system and demonstrate its benefits (and any potential issues). An accompanying vehicle detection and arterial travel time (ATT) system was implemented to collect traffic data such as volume and corridor travel time. This system aided in the evaluation of the performance of the ACS-Lite system before and after the installation, it also serves as a means to monitor the corridor performance. The Wolf Road Corridor is a major arterial that connects Interstate 87 and several other routes (Route 155 and Route 5). This corridor serves as one of the primary routes for commute purposes from/to central Albany. It also experiences heavy traffic congestion (e.g., long queue and corridor travel time) due to the retail/dining-related trips generated and attracted by the shopping malls and restaurants along the corridor and in the downtown area. Figure 1.1 shows the intersections along the Wolf Road Corridor where ACS-Lite and vehicle detection/ATT systems are deployed.

Figure 1.1: Deployment locations of the ACS-Lite and vehicle detection/ATT systems

To assess the performance of the installed adaptive control system, a "before and after" analysis was conducted to compare the performance of the previous signal control system (called "before" scenario) with the newly installed ACS-Lite system (called "after" scenario). The evaluation is based on the measures of effectiveness (MOEs) suggested by the Federal Highway

Administration (FHWA, 2013), including corridor travel time, intersection delays, average speeds, queue sizes at major intersections, number of stops and stop durations, in addition to corridor-wide fuel consumption and carbon footprint. A cost-benefit analysis was then made to the impacts of the installations in a long-term trend.

The main objectives of this research project were to:

1. Demonstrate and evaluate the Siemens ACS-Lite technology and signal timing optimization system at nine (9) signalized intersections along Wolf Road in Albany, NY.

2. Deploy a Sensys detection and arterial travel time (ATT) system to allow the collection of arterial traffic volume and travel time along this corridor.

3. Conduct a “before and after” traffic study on Wolf Road in Albany, NY, to assess the operation and cost-benefit of the ACS-Lite software and hardware deployments.

4. Document in a final report the results of the study, including findings, conclusions and recommended improvements to future deployments.

1.2 Project Partnership and Scope

UTRC member Rensselaer Polytechnic Institute (RPI) was the lead for this project and non-UTRC members include Siemens ITS, Sensys Networks, Annese and Associates, Inc., and the City College of New York (CCNY). Specifically, Siemens was primarily responsible for the deployment and technical support of the ACS-Lite system; Sensys was primarily responsible for the deployment and technical support of the vehicle detection and ATT system; Annese and Associates established the communications between the field laptops with the remote users; the RPI team led the data collection task for the before and after scenario and provided data analysis and recommendations, with the support of the CCNY. Hereafter, the project team will be referred to as the consultant and the NYSDOT project manager/technical working group will be referred to as NYSDOT.

This project followed a phased approach as shown in Figure 1.2. In Task 1, a detailed field assessment of the Wolf Road corridor was conducted to acquire and validate the information of the existing traffic system (e.g., lane geometry, phase timing, detectors and controllers, etc.), and to investigate the exact placement of the equipment necessary for this project. This task is summarized in Chapter 2. Task 2 was to install and properly tune the ACS-Lite system and the Sensys detection and ATT system along the Wolf Road Corridor. This task is documented in Chapter 3. Task 3 was to provide appropriate training to the staffs from the NYSDOT and other partners (RPI and CCNY) regarding the instruction, installation, and use of the ACS-Lite and Sensys detection and ATT system. This is summarized in Chapter 4. In Task 4, traffic data of the before and after scenarios was collected and analyzed to assess the effectiveness of the installed ACS-Lite system. Details of this task are presented in Chapter 5. This is followed by the concluding remarks in Chapter 6.

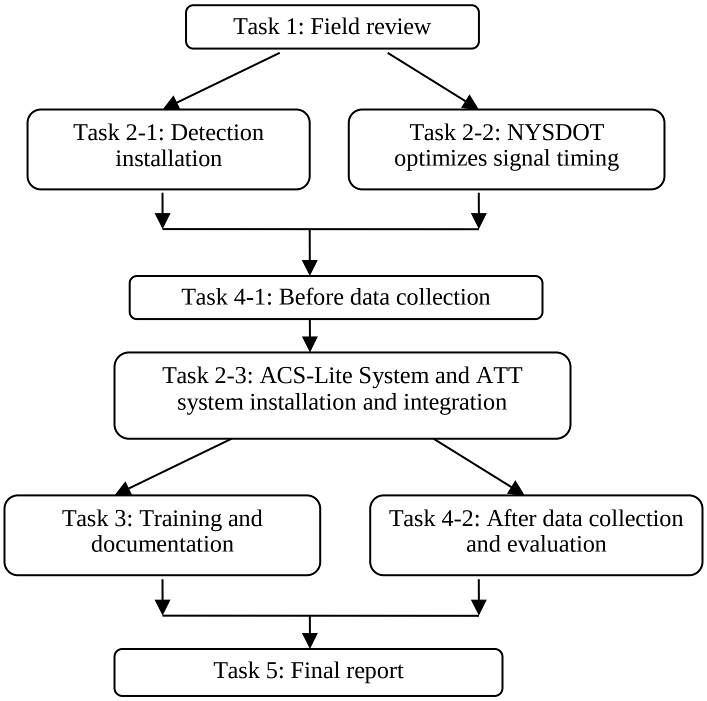


Figure 1.2: Project flow chart

2. FIELD ASSESSMENTS AND PROJECT KICKOFF

In preparation for the ACS-Lite system installation, Siemens and Sensys conducted several field reviews along the Wolf Road Corridor to assess the details and needs of the project. In early August, 2012, the project partners from RPI, Siemens and Sensys met with the officials of NYSDOT and visited the Wolf Road intersections to investigate the exact placement of the equipment necessary for this project. In particular, Siemens conducted the site visit on August 6th, 2012, and Sensys conducted the site visit on August 16, 2012.

Following the site visits, a kick-off meeting was held by the project team on August 23, 2012, at the NYSDOT Main Office at 50 Wolf Road. The purpose of this meeting was to finalize project details prior to deployment. The installation was scheduled to begin the week of September 10th, 2012.

Several independent documents are appended to present the main findings from the field assessments and the kick-off meetings. These documents include the following:

- Appendix 2-A contains the minutes of a pre-kick-off meeting held on April 6th, 2012;
- Appendix 2-B contains the minutes of the kickoff meeting held on August 23rd, 2012;
- Appendix 2-C contains the schematic of each intersection along the Wolf Road Corridor that indicates the preliminary Sensys equipment deployment locations. This includes the travel time sensor arrays, count detectors, advance detectors, routers and access points. Updates during the system deployment were summarized in the subsequent chapters;
- Appendix 2-D contains the field assessment provided by Siemens;
- Appendix 2-E contains the list of equipment needed along the Wolf Road Corridor to support this project.

3. INTERSECTION UPGRADE AND SYSTEM INTEGRATION

This chapter documents the intersection upgrades and system integration that was needed to install the ACS-Lite system along the Wolf Road corridor. This includes system designs and configurations, installation, integration testing and identification of issues. During this phase of the project, Sensys Networks was primarily responsible for setting up and deploying the arterial travel time (ATT) system, Siemens was responsible for setting up and configuring the ACS-Lite system, and Annese and Associates was responsible for setting up the IT connectivity components so that the team could remotely access the field cabinet. In addition, NYSDOT played a critical role to upgrade the existing serial over fiber communication network to IP over fiber communication Network, install Sensys detection systems, install IP-based video PTZ cameras, and test/validate Siemens ACS-Lite software packages. The research group at RPI was responsible for the overall management and coordination during this task.

3.1 Sensys Detection and Arterial Travel Time System

Sensys was primarily responsible for the deployment of the detection and arterial travel time systems along the Wolf Road Corridor. This task was supported by NYSDOT and RPI. Between September 10, 2012, and September 16, 2012, Sensys was on site with NYSDOT kitting the hardware and installing the devices along the Wolf Road corridor. NYSDOT provided two crews with rolling lane closure and pavement drilling equipment. One crew started at the north end of the corridor and the other started at the south end. NYSDOT staff drilled the pavement and members of the Sensys team installed the sensors into the pavement. The side street and driveway detectors were installed by NYSDOT prior to this effort. In addition, NYSDOT also installed the pole mounted equipment, such as the repeaters and access points prior to deploying the sensors along Wolf Road. The installation process of Sensys detectors was smooth and efficient. Overall, the team installed over 200 detectors with corresponding access points and repeaters. This installation process finished ahead of schedule and only a few adjustments were needed from the original drawings. These adjustments are summarized below. For detailed locations of these Sensys equipment, one can refer to Appendix 3-A.

- An extra repeater was added at 50 Wolf Road & Colonie Center North to improve signal strength;

- An existing repeater at Colonie Center South was moved to a different lamp post pole to provide better coverage to sensor;
- Some of the APCCs were adjusted to improve the wireless signal coverage or avoid trees;
- Connection issues at the I-87 southbound ramp due to a bad RJ-45 connector. A new RJ-45 connector was installed and the issue was fixed.

Table 3.1 below summarizes the number of devices that Sensys installed for this project. A description of the installation and configuration procedures is provided below.

- Install sensors in holes w/ 4" diameter, 2¼" depth and fill hole w/ epoxy;
- Install APCC and Isolator in cabinet and mount SPP on pole. Connect them with Cat5 cables;
- Configure APCC properly: assign card ID, wireless frequency, sensor zone, and network properties;
- Configure the SNAPS server properly.

One issue encountered by the Sensys team was related to the network configuration/data delivery. The third party ClientResource tool was timing out and not getting data continuously from the SNAPS server. Any network connection issue would cause a loss in data since the raw event feed RPI received was not buffered or retransmitted. It was found that a large number of event proxy processes were running in the SNAPS server using up all available resource. This would cause the server to lock up. To provide a solution, Sensys setup another SNAPS server to provide load balance (Server 1: http://ny-snaps.sensysnetworks.net, Server 2: http://rpi.sensysnetworks.net). In additional to this, Sensys enforced a delay of a few minutes on data feeds to ensure no loss in data and add a reasonable delay (120 seconds) between retries.

Table 3.1: List of detection equipment installed on the Wolf Road corridor

ITEM #	Description	Quantity
APCC-M-E	APCC with Enhanced Ethernet	8
APCC-SPP	APCC Serial Port Protocol (Digital Radio)	16
APCC-ACC-1	APCC Accessory, Isolator	16
EX240	Extension Card	23
RP240-BH-LL	Repeater, Long Life (1 under contract with RPI)	17
KIT-MTG-EXT	Mounting Kit for Digital Radio & Repeater (1 under RPI contract)	33
VSN240-F	Flush-Mount Wireless Senosrs (30 under RPI contract)	203
VSN240-EPX	Epoxy Tube for Installation of VSN240-F (30 under RPI contract)	203
ATT-HOST	Arterial travel time hosted by Sensys networks for 2 years - 5 stations	1

Following the installation and configuration of the Sensys detectors, a validation test was conducted to compare the detector data (e.g., volume, occupancy, speed and travel time) with manual field observations taken simultaneously, this is presented in Chapter 5.

The Sensys Arterial Travel Time system (Kwong et al., 2009) is designed to match vehicles at different locations along the corridor. Arrays of wireless sensors are installed at intervals along a signalized roadway. When a vehicle passes over the Sensys sensors, a unique, anonymous identifier is assigned to this vehicle. This identifier is then wirelessly transmitted to a nearby Access Point, before backhaul to a central office or Traffic Management Center. By applying algorithms to match the identifiers collected at upstream and downstream locations, the travel time system is able to correctly re-identify up to 70% vehicles. Information of these re-identified vehicles can be used to infer real-times, speeds, occupancies, and individual travel times, which are the keys to corridor traffic management. The algorithm in the Travel Time System uses a statistical maximum likelihood score when comparing vehicles, limits the score to allow for insertion and deletion of vehicles in each sequence, and computes the overall best sequence match using a dynamic programming algorithm. The output of the algorithm is a list of vehicle matches from which travel time and vehicles between the upstream and downstream locations are computed. The Sensys Arterial Travel Time System works best if the vehicle matching algorithm uses the same lane because of vehicle platooning. This may not yield as many pairs of travel time data, but it yields more accurate results, which ultimately is more important. These travel time pairs (called “primary travel time pairs”) along the Wolf Road corridor can be found in Table 3.2.

Table 3.2: Primary travel time pairs along the Wolf Road corridor

From Location	Lane	To Location	Lane	Dir
Colonie Center S.	Left	Colonie Center N.	Left	NB
Colonie Center N.	Left	Sand Creek	Left	NB
Colonie Center N.	Right	Sand Creek	Right	NB
Sand Creek	Left	Computer Dr.	Left	NB
Sand Creek	Left	Metro Park	Left	NB
Sand Creek	Right	Metro Park	Right	NB
Computer Dr.	Left	Metro Park	Left	NB
Metro Park	Left	Albany Shaker	WB Left	NB
Metro Park	Right	Albany Shaker	NB Left	NB
Albany Shaker	Left	Marcus	Left	SB
Marcus	Left	Metro Park	Left	SB
Metro Park	Left	Computer Dr.	Left	SB
Albany Shaker	Left	Computer Dr.	Left	SB
Computer Dr.	Left	Sand Creek	Left	SB
Computer Dr.	Right	Sand Creek	Right	SB
Sand Creek	Left	Colonie Center S.	Left	SB

Although the Sensys Arterial Travel Time System is designed primarily to collect the primary travel time pairs, the team decided to monitor the travel time pairs collected from different lanes at upstream and downstream detector locations (call “secondary” travel time pairs), mainly for research purposes. These secondary travel time pairs are shown in Table 3.3. The configurations of these travel time pairs can be changed remotely if needed.

Table 3.3: Secondary travel time pairs along the Wolf Road corridor

From Location	Lane	To Location	Lane	Dir
Colonie Center N.	Left	Sand Creek	Right	NB
Colonie Center N.	Right	Sand Creek	Left	NB
Sand Creek	Left	Metro Park	Right	NB
Sand Creek	Right	Metro Park	Left	NB
Metro Park	Left	Albany Shaker	NB Left	NB
Metro Park	Right	Albany Shaker	WB Left	NB
Computer Dr.	Left	Sand Creek	Right	SB
Computer Dr.	Right	Sand Creek	Left	SB

3.2 Siemens ACS-Lite System

Siemens was primarily responsible for the deployment of the ACS-List System, with assistance from NYSDOT and RPI. As part of this task, Siemens specified and provided a new field-hardened laptop to host the ACS-Lite software in the field. A description of the installation and configuration procedures is provided below.

- Install the ACS-Lite software;
- Configure communications to all intersections;
- Configure links between intersections;
- Configure detector placements and assigned functionality;
- Configure time-of-day schedule;
- Configure time synchronization options;
- Configure adaptive control options.

In July 2013, Siemens completed the deployment of SEPAC along the Wolf Road corridor. ACS-Lite was installed and upgraded on the field-hardened laptop. As part of this task, the following tasks were completed:

- Converted all Naztec Apogee intersection timings into SEPAC NTCIP format;
- Created and installed an elaborate I/O Map for all the Wolf Road corridor intersections;
- Installed/upgraded all 1B/1E processor cards for the Wolf Road corridor from SEPAC NTCIP v4.01f to v4.08 in a lab environment (Software upgraded to v4.08 was required because v4.01f software caused all the load switches to go dark upon a flash condition and did not include the 2070 Aux Switch stop time option);
- Tested all converted SEPAC timings against existing Naztec Apogee timings on suitcase testers in a lab environment;
- Installed ACS-Lite v1.5.3 and Tactics View v2.1.0 software on the laptop at the intersection of Wolf Road and Marcus Blvd;
- Upgraded ACS-Lite laptop to ACS-Lite v1.6.0 and Tactics View v2.1.2 (ACS-Lite was upgraded for new features and Tactics was upgraded in order to support new SEPAC v4.08 controller software);
- Installed SEPAC v4.08 controllers on all Wolf Road ACS-Lite Corridor intersections;
- Verified communications from installed ACS-Lite laptop to all Wolf Road SEPAC intersections;

- Programmed all time of day (TOD) schedules, setup all detector information, and created intersection links inside ACS-Lite software;
- Placed ACS-Lite software into “Monitoring Mode” with the “Enable Time Base Selection” turned off once all intersection information was integrated/uploaded into ACS-Lite software;
- Verified ACS-Lite was correctly syncing all the SEPAC controller’s time clocks as programmed;
- Verified successful remote desktop connection and the ability to see ACS-Lite’s hosted website from the NYSDOT network over a secure VPN connection;
- Verified successful remote desktop connection and the ability to see ACS-Lite’s hosted website from a laptop in Houston, Texas over a secure VPN connection.

During the rollout of the ACS-Lite system, several issues were found that inhibited the system from being placed in “Control” mode for adaptive operation, these include:

- The current version of ACS-Lite, v1.6.0 was not designed to run intersections using extended/double clearance overlaps such as at the intersection of Wolf Road, Albany Shaker Road and the I-87 northbound on ramp;
- The version of ACS-Lite was not designed to run intersections using the procedure of advance walk operation such as at the intersection of Wolf Road and Colonie Center North (for the NYSDOT office complex);
- At the request of NYSDOT, all of the intersections along Wolf Road were placed in the “free” operation until the software was modified (ACS-Lite cannot/will not command intersections to run adaptive operation that are programmed to run in “free mode” only).

From November, 2012, until July, 2013, Siemens worked to resolve these aforementioned issues with a new version of the software. In April 2013, the lab testing of SEPAC timings with TACTICS and ACS-Lite was conducted at the NYSDOT traffic lab. Later in April, 2013, the field controllers were installed. The system was not able to go to ‘Control’ mode due to “All Red” after monitor reset or removal of police flash. Also, the system was not able to validate the coordinated plans due to “double clearance” overlap. Between April 26 and July 14, 2013, Siemens continued developing SEPAC and ACS-Lite software to handle “double clearance” overlaps, the “advanced Pedestrian” movements, and the start-up conditions coming out of police flash. Between July 15 and 19, 2013, the ACS-Lite system was upgraded and loaded with new I/O maps at the intersections. This successfully placed ACS-Lite in “Control/Adaptive” mode. On July 22, 2013, the acceptance testing document was considered complete. Appendix 3-B contains some sample screenshots from the ACS-Lite software.

In October, 2013, NYSDOT noticed some issues with respect to the left-turn and side street detection. The Sensys detectors were installed to provide traffic counts for the left turns and side streets where existing presence detection could not provide accurate data. The ACS-Lite system should have been using the existing presence detection in the corridor for phase utilization, not the Sensys detectors. Only the Sensys detectors on the mainline should have been used as system detection, with the exception for the detection at Albany Shaker Road. Siemens, however, configured the system so that all the existing inductive stop bar presence detectors were changed and the system was utilizing Sensys detectors for detection when available. Siemens and NYSDOT worked together to resolve this issue in late October 2013.

3.3 Data Access

A crucial component of this task was to deal with the communications between the field laptop which collected and processed the data coming from the field and to disseminate this information to various users outside the field (Sensys, Siemens, RPI and NYSDOT). Annese and Associates was in the lead for this task. Their primary role was to establish a secure virtual privacy network (VPN) connection to this system for remote users.

Once the router and firewall were chosen, Annese worked closely with NYSDOT and the other partners including Sensys, Siemens, and RPI to ensure it worked properly at each of their locations. A detailed IP mapping scheme can be found in Appendix 3-C. The main tasks that Annese performed are summarized as below:

- Configured the ASA Firewall and Router in lab;
- Mounted and cabled the ASA firewall and Router in traffic cabinet located at Marcus Blvd;

- Assisted NYSDOT in changing IP of the Wolf Road and Marcus camera;
- Assisted NYSDOT in creating admin user account on the ACS-Lite server;
- Assisted NYSDOT in allowing remote desktop access to the ACS-Lite server;
- Verified devices on inside of router could access internet services via Time Warner connection;
- Assisted NYSDOT in installing VPN client and gave overview of how to install and connect to the VPN;
- Tested access to VPN with NYSDOT laptop over Verizon 4G LTE connection;
- Created additional user accounts (16) on ASA firewall for DOT users, RPI, Sensys, and Siemens (remote work following day of install);
- Changed network configuration of ACS-Lite server and configured router respectively after conference call with DOT (remote work following day of install);
- Created access rules for different accounts and verified each account could access correct services across VPN (remote work following day of install).

Setting up the communications was initially more challenging than expected; it was ultimately found that an intersection not within the Wolf Road corridor was creating the problem. The existing fiber optic system used for this project contained the intersection of Route 5 and Wolf Road which is not a part of this study; however the fiber link between involved intersections ran through its controller. The fiber optic modem installed at this intersection to drop and repeat communications was functioning erratically, and this had caused problems for downstream controllers. This was a problem with the fiber optic network and unrelated to the work that Annese preformed.

The following is a summary of the steps to remotely access the server:

1. Open the VPN client (Cisco AnyConnect Secure Mobility Client);
2. Type the IP address (omitted here for security reasons). Click “Connect”;

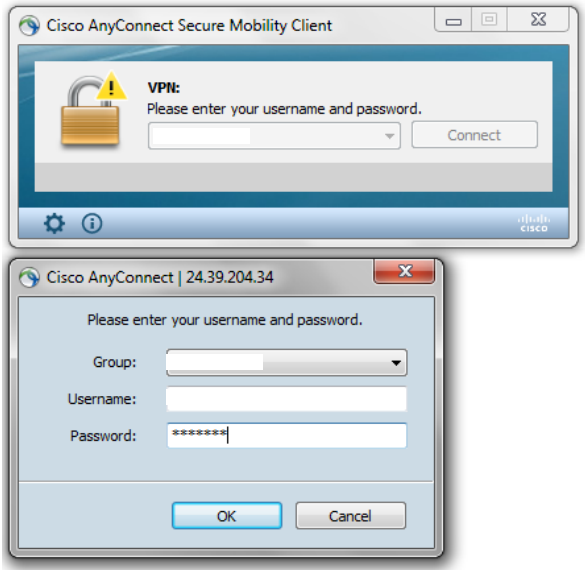
3. Select group (RPI). Enter the username and password (omitted here for security reasons), see Figure 3.1;

4. Open “Remote Desktop Connection” from “Accessories” in the Start Menu;

5. In the Computer box, type the IP address of the server (omitted here for security reasons). Click “Connect”;

6. Type the user name and password (omitted here for security reasons). Click “OK” then go to the remote desktop window, see Figure 3.2;

7. Close the remote desktop window and quit the VPN client when finished. Otherwise, the ACS-Lite system will be rebooted next time another user tries to log into the system remotely, see Figure 3.3.



Cisco AnyConnect Secure Mobility Client

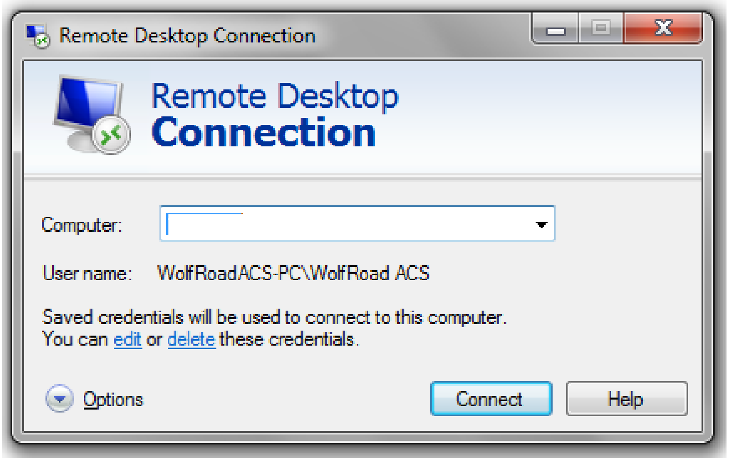
VPN:
Please enter your username and password.

Cisco AnyConnect | 24.39.204.34

Please enter your username and password.

Group:
Username:
Password: *******

Figure 3.1: Remote access to the ACS-Lite server (Step 1-3)



Computer:

User name: WolfRoadACS-PC\WolfRoad ACS

Saved credentials will be used to connect to this computer.
You can edit or delete these credentials.

Figure 3.2: Remote access to the ACS-Lite server (Step 4-6)

2013-10-25 11:07:32
Wolf Rd - Albany, NY

System Manager

Operational Mode
The System Manager (i.e., ACSLITE) is operating in **control** mode, as configured.

● Control
○ Analysis
○ Monitoring
○ Configuration
○ Shutdown

Pattern Selection Mode
☐ Enable Manual Selection Pattern Local Control
☑ Enable Timebase Selection

Figure 3.3: Remote access to the ACS-Lite server (Step 7)

3.4 Communications Upgrades

NYSDOT upgraded the existing serial over fiber optic system to an IP over fiber optic system. This task was completed by first isolating the fiber optic system from its server located at 50 Wolf Road, and then by installing 8 port Ethernet Switches (Garretcom, Inc. Magnum ITS Blades) in each of the 2070 traffic signal controllers. Each switch provides two 100 Mb full duplex fiber optic ports and six RJ-45 auto-negotiating Ethernet ports.

3.5 IP PTZ Cameras

NYSDOT installed four Axis IP based Pan Tilt Zoom (PTZ) cameras to provide remote surveillance of the corridor. Cameras were installed at the intersections of Wolf Road at Colonie Center South, Sand Creek Road, Marcus Road, and I87 SB Ramp/ Route 155. The IP mapping scheme in Appendix 3-C defines the locations of the IP PTZ Cameras.

3.6 Warranties and Maintenance Documentation

Numerous hardware and software components were needed for this project. A summary of the warranties on these various components is provided in Table 3.4. Additional information regarding the warranties and maintenance documentation can be found in Appendix 3-D1 to Appendix 3-D4.

Table 3.4: Hardware and software warranty summary

Supplied by:	Description	Serial Number	Warranty Length	Expiration Date	Cost to Extend Warranty
Sensys	Sensys hardware (detectors, repeaters, access points)	see Appendix A	5 years	7/19/2017	contact Sensys
Siemens	ACS Lite software Warranty	License Key	1 year	7/22/2014	contact Siemens
Siemens	ACS Lite software Maintenance	License Key	1 year	7/22/2014	contact Siemens
Siemens	Dell P21G, field hardened laptop	69PCSS1	2 years	12/27/2015	contact Siemens
Annese	Cisco C881G-V-K9 Router	FTX16388512	1 year	10/31/2013	$129.60

In addition to the warranties, there was ongoing maintenance of the hardware and software. Sensys agreed to monitor and maintain the servers for two years of hosting. In addition, Sensys Networks provided phone support for any other issues that may arise. Siemens had a one year service agreement in place which provided remote support and monitoring of the Wolf Road ACS-Lite system.

3.7 Summary

Throughout the deployment of the ACS-Lite and vehicle detection systems, NYSDOT had been very proactive. This task was slower than anticipated due to the complexity of the deployment. The delays were from several sources including (i) communication issues related to hardware problems at a nearby intersection that is not part of the deployment corridor but that shares some communications with the corridor; (ii) several minor issues with the vehicle detection system; and (iii) controller software (SEPAC) incompatible with the controllers and timing plans at the Wolf Road corridor, as well as I/O mapping issues. The last issue required extensive software development and upgrade, which delayed this task significantly. Although this problem was significant, it was somewhat expected because this was the first time NYSDOT deployed ACS-Lite. ACS-Lite was jointly developed by FHWA and the industry (including Siemens). The original standards, however, did not fit exactly with the traffic signal controller and software standards at NYSDOT (and possibly many other states as well). This resulted in considerable software upgrade and development by some of the industry partners. It is expected that future deployments of ACS-Lite in the State should be much smoother.

Overall, the project team including NYSDOT worked together to resolve all the issues and the communications between the partners and NYSDOT were very smooth. This can be seen by the industry partners' commitments to improve their systems based on NYSDOT forward-thinking in deploying advanced vehicle detection and traffic signal control system, which could potentially mitigate current and future traffic problems along important corridors in NYS.

4. STAFF TRAINING

Sensys and Siemens provided training sessions to staffs from the NYSDOT and other partners (RPI and CCNY) regarding the instruction, installation, and use of their products. The major activities and deliverables of these training sessions are summarized in this Chapter.

4.1 Sensys Training

The Sensys training session covered the Sensys detection and arterial travel time (ATT) systems, as well as their corresponding components. The training session was held at RPI for one and half days on July 24th and 25th, 2013. A list of the attendees is provided in Table 4.1.

Table 4.1: Attendees of the Sensys training session

Name	Agency	Phone	E-Mail
Chris Pagniello (presenter)	TSI	518-406-5116	chris@trafficsystemsinc.com
Paul Mayor	NYSDOT	518-424-3972	paul.mayor@dot.ny.gov
Patricio Vicuna	UTRC-CCNY	345-601-7210	patricio.vicuna@gmail.com
Abdus Salam	NYSDOT	518-783-7746	abdus.b.salam@dot.ny.gov
Ruimin Li	Tsinghua Univ.	617-784-7935	lrmin@tsinghua.edu.cn
Rufus Banks	NYSDOT	518-485-2827	rufus.banks@dot.ny.gov
Jeff Ban	RPI	518-276-8043	banx@rpi.edu
Jeff Wojtowicz	RPI	518-276-2759	wojtoj@rpi.edu
Robert Lang	NYSDOT	518-457-5944	robert.lang@dot.ny.gov
Anil Yazici	UTRC-CCNY	212-650-8071	yazici@utrc2.org
Joe Scanlon	NYSDOT	518-457-4507	jscanlon@dot.ny.gov
John Litteer	NYSDOT	518-391-4611	john.litteer@dot.ny.gov
Peng Hao	RPI	518-364-3671	haop@rpi.edu

The training was done via multi-media presentations. Interactive demonstrations of the systems were provided, followed by in-depth discussions. The major contents covered in the training session are summarized below.

- Introduction to Sensys wireless vehicle detection systems (WVDS)
    - Identify key WVDS components and explain their basic functions;
    - Introduce the Sensys Networks Archive, Proxy, and Statistics (SNAPS) server;
    - Describe a detection zone;
    - Describe the operating distances for sensors, Access Points, and Repeaters.
- Wireless vehicle detection system installation
    - Select the appropriate type(s) and model(s) of sensor for an application;

  - Describe how to properly install magnetometer and MicroRadarTM-sensors;
  - Describe how to properly install an access point;
  - Describe how to properly install a repeater;
  - Describe how to properly install a CC/EX card;
  - Describe how to properly install an APCC card.
- Wireless vehicle detection system Configuration
  - Preconfigure a computer and install TrafficDOT;
  - Determine and configure CC and EX card channels;
  - Make physical connections and launch TrafficDOT;
  - Connect to an access point and turn on Master Mode;
  - Configure a map;
  - Configure an access point, an access point controller card, and a repeater.
- SNAPS server
  - Navigate through the SNAPS user menu, dashboard, and VOS;
  - Describe the steps for Configuring & Administering SNAPS;
  - Describe the types of information that SNAPS reports;
  - Describe the steps for Configuring Travel Time.

The deliverables submitted by Sensys to NYSDOT and RPI at the end of the training session include:

- Training materials and documentations; both hard copies and electrical copies;
- Sensys Wireless Vehicle Detection System: Reference Guide (P/N 152-240-001-001, Rev D, July 2010); hard copies;
- Sensys VDS240 Wireless Vehicle Detection System: TrafficDOT v2.6 Set Up and Operating Guide (P/N 152-240-001-052, Rev A, November 2012); hard copies;
- Sensys VDS240 Wireless Vehicle Detection System: SNAPS Professional v2.8 Set Up and Operating Guide (P/N 152-240-001-050, Rev B, October 2012); hard copies.

4.2 Siemens Training

The Siemens training sessions covered the ACS-Lite system configuration and operation, and SEPAC firmware. Upon NYSDOT's request, multiple Siemens training sessions were conducted during the course of the project: two were conducted at the NYSDOT's traffic lab, for one and half days in total; one was conducted at the NYSDOT headquarter on September 25th and 26th 2013 for one and half days. The attendees of the training sessions at NYSDOT traffic lab were mainly DOT traffic engineers and managers, as well as RPI researchers. Table 4.2 below lists the attendees of the main Siemens training session in September, 2013.

Table 4.2: Attendees of the Siemens training session

Name	Agency	Phone	E-Mail
Nicholas Bushek (presenter)	Siemens	877-420-2070	nicholas.bushek@siemens.com
Paul Mayor	NYSDOT	518-424-3972	paul.mayor@dot.ny.gov
Abdus Salam	NYSDOT	518-783-7746	abdus.b.salam@dot.ny.gov
Rufus Banks	NYSDOT	518-485-2827	rufus.banks@dot.ny.gov
Guillermo Ramos	NYSDOT	518-457-1273	Guillermo.Ramos@dot.ny.gov
John Litteer	NYSDOT	518-391-4611	john.litteer@dot.ny.gov
Jeff Ban	RPI	518-276-8043	banx@rpi.edu
Jeff Wojtowicz	RPI	518-276-2759	wojtoj@rpi.edu
Peng Hao	RPI	518-364-3671	haop@rpi.edu

The training sessions were done via multi-media presentations, demonstrations, and interactions with the live systems, followed by in-depth discussions. Below is a summary of the major items covered by the Siemens training sessions.

- Traffic Controller Active Status Screens;
- Instructed and explained what each status screen looks like, the values contained within each screen and what the values in each represented;
- Manual Entry of Basic Controller Values;
- Instructed and displayed where basic controller timing values (min green, yellow, pedestrian internals, etc.) are inputted via the controller's front panel;
- Manual Entry of Advanced Controller Values;
- Instructed and displayed where advanced controller values (alternate sequencing, start-up options, etc.) are inputted via the controller's front panel;

- Vehicle and Pedestrian detection setup and programming;
- Instructed and displayed where vehicle and pedestrian call phases are inputted via the controller's front panel;
- Vehicle and Pedestrian Recall Values;
- Instructed and displayed where vehicle and pedestrian recalls are inputted via the controller's front panel;
- Ring Structure rules changes for ACS-Lite validation/operation;
- Instructed attendees on the requirement when phases are unused or disabled, that they MUST be removed from the default 8 phase ring structure for ACS-Lite to validate correctly and allow for operation;
- Coordination setup;
- Explained the different coordinated modes of SePAC offers and displayed where to input them via the controller's front panel;
- Time Base Coordination Configuration/Programming;
- Instructed attendees on the correct setup of coordinated patterns and explained the action to pattern relationship used within SePAC NTCIP software. Instructed and displayed where these values are inputted via the controller's front panel;
- Back and Restore from Datakey Procedure;
- Explained and demonstrated the procedures on how to correctly initiate a backup of the controller's values to a removable datakey, check/verify the backup date, and to correctly erase the datakey. Explained and demonstrated the steps required to restore a controller's values from the datakey;
- System Data-Alarm Logs;
- Instructed and explained where the controller system alarms logs are located and what the most common alarms are defined as. Also pointed out where in the software manual an explanation/definition can be found for any/all alarms;

- Interactive SePAC software controller programming;
- Practice and controller programming on mock intersection.

The deliverables submitted by Siemens to NYSDOT and RPI at the end of the training sessions include:

- ACS-Lite Adaptive Control Software Lite User Manual (version 1.5.3);
- SePac NTCIP controller software.

5. BEFORE AND AFTER DATA COLLECTION AND ANALYSIS

This chapter presents the before and after evaluation of the ACS-Lite adaptive signal control system that was deployed along the Wolf Road Corridor in Albany, New York. The findings of the evaluation will help the New York State Department of Transportation (NYSDOT) make more informed decisions regarding whether adaptive control deployment is beneficial. The results of this evaluation will also be important to NYSDOT when assessing other corridors in NYS that might benefit from the installation of an adaptive signal system. This task was led by RPI with support from industry partners (Siemens and Sensys Networks) and support from CCNY.

This Chapter is divided into seven subchapters. Chapter 5.2 describes the overall data collection plan, including the major measures of effectiveness (MOEs) that were used for before and after comparisons, as well as the data items that were collected to calculate/estimate the MOEs. Chapter 5.3 and Chapter 5.4 provide details of the data collected for the before and after periods respectively, as well as some analysis results including observations and trends, among others. Chapter 5.5 presents the comparison results and discussions of before and after MOEs. The benefit-cost analysis is presented in Chapter 5.6. Summaries of key observations and findings, lessons learned, major recommendations, and concluding remarks are given in Chapter 5.7.

5.1 Data Collection Plan

In general, data collection for before and after evaluations needs to be conducted in a systematic fashion so the results from both the before and after time periods are directly comparable. These studies should normally take place under favorable weather conditions during the midweek (on typical Tuesdays, Wednesdays, and Thursdays). If there are any periods of inclement weather or other atypical traffic observances, the data should be flagged accordingly. It is also important to be consistent with other events, for example, the data collection for both periods should be done when the local schools are in session; this will minimize the differences in travel patterns.

In this project, the above general guidelines were followed. The main data collection took place during the AM peak, mid-day, and PM peak (7:00-9:00 am, 11:00 am-1:00 pm, and 3:30-

5:30 pm respectively). Due to battery issues in the video cameras used in the data collection, the queue data were only collected for approximately 1-1.5 hours (or even shorter in certain cases) during each of the above three specified time slots. Also the after data collection started half an hour later for each data collection period in order to coordinate with the queue data collection. Data was also collected on Saturday afternoon from 2 pm to 3 pm. The after data collection was completed about a month after the ACS-Lite system was deployed, therefore the consultant does not expect major changes with respect to other traffic variables, besides the signal control strategy. The actual data collection dates for before and after scenarios are summarized as follows:

- Before Data Collection
  - Weekdays: April 10th and April 11th, 2013;
  - Weekends (Saturdays): March 30th and April 13th, 2013.
- After Data Collection:
  - Weekdays: October 16th, October 17th and November 6th, 2013;
  - Weekends (Saturdays): September 21st and September 28th, 2013.

The main data sources for the evaluation came from the following:

- Data from traffic controllers (2070 controllers running Apogee or SEPAC software), including cycle-by-cycle signal timing information such as cycle length, green splits (or effective red and green times) (from Siemens or NYSDOT)
- Data from the installed adaptive traffic sensors, including:
  - Individual vehicle travel times (from Sensys);
  - Detector data (from Sensys), such as raw event data (vehicle actuation) and aggregated volume, occupancy, and speeds (30 seconds and 5 minutes).
- Manual counts (using laptop programs) and queue lengths at selected intersections (using video cameras)
- GPS floating car data collected by the RPI and the CCNY team

The detector, travel time, and signal timing data from Sensys servers were partially archived before the “before” data was collected. These archived data helped the research team develop models and algorithms to calculate side street delays and other corridor and intersection-based traffic performance measures.

Prior to collecting any data for the evaluation, the research team collected sample data at each intersection to validate the Sensys detectors. On an intersection-by-intersection basis, data was collected simultaneously for selected movements. The data was collected for approximately one half hour for each intersection and was compared to the data collected by the detectors. Some major discrepancies were noted, which later proved to be related to detector malfunctioning. After the malfunctioned detectors were replaced, it was found that the Sensys detector data match fairly well with field observations. Details can be seen in Appendix 5-B of this report. The team also conducted similar test drives through the corridor with GPS devices to validate the data provided from the travel time arrays, which show consistent results between floating car travel times and those from primary travel time arrays (i.e., the upstream and downstream arrays were on the same lane). Details are summarized in Appendix 5-C.

The main evaluation criteria for the before and after study were the corridor system delay and the side street delay. Other measures of effectiveness (MOEs) included corridor travel times and delays, average speeds, queue length, duration of stops, number of stops, point X to point Y travel times, emissions, and fuel consumption. Data that can be used to calculate/estimate the above MOEs were collected for both the periods before and after the ACS-Lite system was deployed. Further details regarding the MOEs and the related data collected during the before and after periods are provided in the following subsections.

5.1.1 Travel time and delay

The time to traverse two points was measured using the Sensys arterial travel time (ATT) system, and validated using GPS floating car data. The travel time information (recorded in seconds) was collected in both directions for vehicles that traversed the entire corridor. The following driving scheme was proposed to the drivers of the GPS floating cars. Due to various reasons (communication and coordination problems, schedule change, etc.), these suggestions were not strictly followed during the data collection process:

- One vehicle in each direction should start at the beginning of the data collection time period;

- The subsequent vehicles should depart with 3-5 minute headways, make designated turnabout and repetitively travel in both directions until the end of the data collection period. If multiple vehicles find themselves bunched together during the study period, one or more of them should stop for several minutes so they can be separated. In the actual data collection, this was not exactly followed due to the actual driving conditions;
- There are two through lanes on Wolf Road. Several vehicles should travel in a particular lane and minimize lane-changing behavior. At least one driver should drive normally and perform rational lane-changing.

The team had 6 (six) vehicles with GPS logging devices traveling the Wolf Road corridor during the before data collection periods to collect travel times. For the after data collection, only 3 (three) vehicles were available. After travel times were collected, corridor average speeds, number of stops, and stopped times were calculated accordingly.

The driving route and designated turnabout for GPS floating cars are illustrated in Figure 5.1. This route covers 8 (eight) signalized intersections along the Wolf Road corridor. Turnabouts were made at the north end and south end of the study area. In particular, for drivers approaching the north end in the left lane, they were asked to make a left-turn onto Albany Shaker Road, and then make a turnabout when possible; for drivers approaching the north end in the right lane, they were asked to make a right-turn onto Albany Shaker Road, and then go through the roundabout at Albany Shaker Road and Maxwell Road; for drivers approaching the south end, they were asked to make a turn outside of the Wolf Road corridor and then enter again.

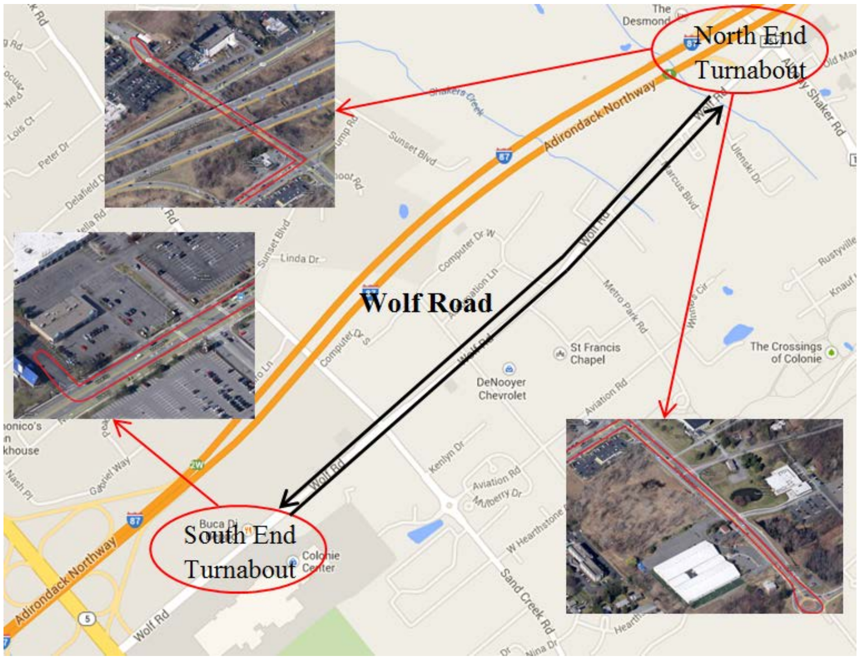


Figure 5.1: Driving route and designated turnabout for GPS floating cars

5.1.2 Queue length

Queue length data was collected at selected locations of the corridor, mainly at minor road segments such as Sand Creek Road, Albany Shaker Road, and Old Wolf Road. Data was also collected at Wolf Road (to the Albany Shaker Road direction) due to the limited queue storage space at this location. During the weekends (Saturdays from 2:00 to 3:00 pm), queue length data was collected at Colonie Center North to capture the large weekend traffic volume at this location.

5.1.3 Average speed

The average speeds through the corridor were computed using the GPS floating car data. This included the average speed through the entire corridor as well as between various segments of the corridor (as defined by the locations of the Sensys travel time arrays). The average speeds are presented in miles per hour (MPH).

5.1.4 Average number of stops

The average number of stops through the corridor was calculated based on the GPS floating car data. In specific, if the speed of a vehicle drops below 5 MPH, this is considered a vehicle stop. After a stop, vehicle speeds up to 8 MPH are not considered vehicle stop. The number of vehicle stops along the corridor was averaged over all the runs of all the floating cars in each direction of travel during each time period.

5.1.5 Duration of stop

Similar to the number of stops data, the duration of each vehicle stop (speed lower than 5 MPH) was documented from the GPS floating car data. This data was averaged over all the runs for all the floating cars in each direction of travel during each time period.

5.1.6 Fuel consumption and emissions

The improvements in traffic progression and corridor travel time can lead to decreased fuel consumption and emissions. The team estimated the fuel consumption and emissions for vehicles traveling the entire corridor before and after the deployment of ACS-Lite. The vehicle classification data was collected in October, 2012. Since the traffic mixture through the corridor is not expected to change due to the presence of the ACS-Lite system, the collected vehicle classification data was used for both the before and after scenarios of the evaluation study.

Using the second-by-second GPS floating car data and the vehicle class information, the fuel consumption and emissions were estimated using CMEM (Comprehensive Modal Emission Model) developed by the University of California, Riverside (http://www.cert.ucr.edu/cmem/). CMEM is a micro-level emission model that can estimate vehicular fuel consumption and emissions for each individual vehicle using GPS (i.e., time-speed) data. The vehicle categorization defined in CMEM cover a wide spectrum of vehicle classes, ranging from small passenger cars to 18 wheelers. The model can also capture other internal and external factors that can impact the fuel consumption and emissions, e.g., vehicle soak time, catalyst, road grade, coefficient of friction, etc. After the estimation for single vehicle is done, the results can be interpolated based on the total corridor volume and traffic mix to obtain the total fuel consumption and tailpipe emissions (carbon dioxide, carbon monoxide, hydrocarbons and oxide of nitrogen) for the entire corridor.

5.1.7 Traffic volume count

Traffic volumes were collected for each approach using the Sensys count detectors placed near the stop bars of each lane. As aforementioned, prior to the evaluation study, the team collected traffic count data at each intersection to validate the sensor counts collected using the Sensys count detectors.

5.1.8 Minor street delay

Given the collected traffic volumes on several cross streets, the average delays on minor streets were estimated using the HCM delay estimation procedure (Roess et al., 2010).

5.1.9 Simulation model

City College of New York (CCNY) voluntarily developed a VISSIM model for the Wolf Road Corridor, which was calibrated using real data obtained from field detectors and GPS data collection. A summary of the model development and findings is attached in Appendix 5-A of this final report.

5.1.10 Summary of data items

Table 5.1 provides a summary of the data items that were collected at specific time periods of a day. The collected data items were split into the “before” dataset and the “after” dataset. In the following sections, detailed descriptions and analyses of these data elements are provided.

Table 5.1: Collected data items

Time Period	Corridor Travel Time		Manual Data Collection		Queue Length			
	# vehicles	# time periods	Vehicle Class	Detector Verification	Old Wolf	Albany Shaker	Sand Creek	Colonie Center N.
AM	6	2	x	2 people per intersection for approx. 30 min each	x	x	x	-
	6	2						
midday	6	2	-		-	x	x	-
PM	3	2	x		x	x	x	-
	3	2						
Sat. PM	3	2	-		-	x	x	x

Based on the evaluation results, the team also conducted a benefit-cost analysis. The benefit was estimated using delay reductions, as well as fuel consumption and emission savings. The cost included the funding provided by NYSDOT and the cost share from RPI and the industry partners.

5.2 Before Data Collection and Analysis

This section summarizes the MOEs and other data elements collected for the weekday and weekend periods before the deployment of the ACS-Lite system. The typical peak-hour volumes of the intersections along the Wolf Road corridor are summarized in Table 5.2. The intersection volume here is defined as the summation of the volumes from all approaches of an intersection.

Table 5.2: Intersection peak-hour volumes – before periods

Intersection	AM	MID	PM	SAT
Albany Shaker	2942	2950	3946	2519
I-87 Off Ramp	1180	904	1028	951
Marcus Blvd.	2232	2504	3130	2435
Metro Park Road	1892	2608	2917	2684
Computer Drive	2188	3792	3682	2673
Sand Creek Road	2284	3508	3762	3448
Colonie Center North	1968	3762	3856	2799
Colonie Center South	2336	4102	4454	3215

5.2.1 Intersection delay

Table 5.3 shows the average intersection delay and LOS for the three weekday peak periods (i.e., “AM”, “MID” and “PM”) and the weekend peak (indicated by the “SAT” column). Similar MOEs are provided in Table 5.4, but only for the minor streets at each intersection.

Table 5.3: Average intersection delay (seconds) and level of service – before periods

Intersection	Peak Period							
	AM	LOS	MID	LOS	PM	LOS	SAT	LOS
Albany Shaker	50.6	D	35.7	D	57.2	E	32.3	C
I-87 Off Ramp	40.0	D	27.3	C	38.1	D	26.7	C
Marcus Blvd.	3.1	A	3.4	A	5.2	A	3.4	A
Metro Park Road	10.8	B	7.8	A	10.5	B	8.4	A
Computer Drive	7.4	A	10.5	B	15.6	B	6.5	A
Sand Creek Road	22.7	C	36.7	D	44.6	D	38.7	D
Colonie Center North	50.6	D	35.7	D	57.2	E	14.4	B
Colonie Center South	1.5	A	13.3	B	19.3	B	30.8	C

Table 5.4: Average minor streets (east/west) delay and level of service – before periods

Intersection	Peak Period							
	AM	LOS	MID	LOS	PM	LOS	SAT	LOS
Albany Shaker	60.8	E	43.3	D	72.1	E	34.3	C
I-87 Off Ramp	40.0	D	27.3	C	38.1	D	26.7	C
Marcus Blvd.	29.4	C	29.3	C	34.1	C	33.1	C
Metro Park Road	15.8	B	15.4	B	15.5	B	15.0	B
Computer Drive	15.2	B	15.4	B	18.6	B	21.0	C
Sand Creek Road	22.4	C	43.5	D	49.0	D	49.3	D
Colonie Center North	14.0	B	21.3	C	37.9	D	39.9	D
Colonie Center South	19.2	B	29.3	C	40.4	D	43.8	D

To further illustrate the delays of the corridor, Table 5.5 – Table 5.8 depict the delay for each movement of every intersection for the weekday AM peak, midday, PM peak, and the Weekend peak (Saturday 2:00-3:00 pm), respectively. Notice here that north/south approaches of an intersection indicate the major street, i.e., Wolf Road, while the east/west approaches represent minor streets.

Table 5.5: Average movement delays for weekday AM peak – before periods

Intersection	Movement (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	22.4	21.8	64.7	37.9	N/A	N/A	39.3	87.5
I-87 Off Ramp	40.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	0.4	N/A	28.7	N/A	0.9	34.9	30.0	N/A
Metro Park Road	2.3	N/A	21.3	N/A	0.5	55.3	22.1	N/A
Computer Drive	2.2	21.5	15.5	N/A	3.6	20.3	14.7	N/A
Sand Creek Road	18.5	32.1	19.9	27.8	22.7	35.4	19.4	31.4
Colonie Center North	4.0	12.6	14.1	N/A	3.1	21.3	13.9	N/A
Colonie Center South	0.3	28.9	22.9	N/A	0.1	26.2	16.9	16.8

* N/A indicates no such movement exists

Table 5.6: Average approach delays for weekday midday peak – before periods

Intersection	Approach (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	23.1	20.4	39.8	41.1	N/A	N/A	38.0	58.5
I-87 Off Ramp	27.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	1.0	N/A	27.6	N/A	0.8	34.4	29.7	N/A
Metro Park Road	7.7	N/A	15.3	N/A	3.1	23.8	16.8	N/A
Computer Drive	6.8	24.3	6.8	N/A	8.6	24.6	15.0	N/A
Sand Creek Road	28.7	49.3	43.2	57.4	30.8	49.3	36.6	43.9
Colonie Center North	12.6	16.4	12.6	N/A	8.8	28.5	21.8	N/A
Colonie Center South	10.4	36.9	10.4	N/A	8.9	35.9	28.0	26.6

* N/A indicates no such movement exists

Table 5.7: Average approach delays for weekday PM peak – before periods

Intersection	Approach (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	36.3	27.9	88.2	54.0	N/A	N/A	57.4	68.0
I-87 Off Ramp	38.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	3.3	N/A	30.5	N/A	1.6	40.5	35.0	N/A
Metro Park Road	9.9	N/A	13.5	N/A	3.3	21.5	15.0	N/A
Computer Drive	16.6	30.5	16.6	N/A	8.9	31.0	18.0	N/A
Sand Creek Road	33.6	55.0	47.6	67.7	42.3	56.8	44.5	48.3
Colonie Center North	6.3	12.4	6.3	N/A	5.2	22.8	18.4	N/A
Colonie Center South	12.8	45.2	12.8	N/A	16.9	44.7	40.1	37.3

* N/A indicates no such movement exists

Table 5.8: Average approach delays for weekend peak period – before periods

Intersection	Approach (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	29.5	26.2	21.4	35.0	N/A	N/A	14.9	29.0
I-87 Off Ramp	26.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	1.9	N/A	34.8	N/A	1.3	39.3	31.5	N/A
Metro Park Road	8.9	N/A	13.9	N/A	3.9	20.4	15.2	N/A
Computer Drive	2.4	33.4	21.1	N/A	3.5	31.2	20.8	N/A
Sand Creek Road	29.5	62.8	48.3	68.8	31.7	53.5	43.4	50.1
Colonie Center North	14.4	29.8	18.9	N/A	2.3	29.3	40.4	N/A
Colonie Center South	23.7	59.4	50.8	N/A	24.2	57.0	40.5	38.5

* N/A indicates no such movement exists

The calculated delay and LOS measures in Table 5.2 – Table 5.8 confirm that the Albany-Shaker intersection is the most congested one in the entire corridor. This is due to its large volumes (especially during the AM and PM peak periods) and limited storage capacity, which result in long delays and queue spillbacks in several directions. The second most congested intersection is at Sand Creek Road; large delays are observed during the midday and PM peak periods. Figure 5.2 and Figure 5.3 illustrate the average intersection delay and the average minor street delay for each intersection of the corridor during each time period. The intersections are ordered from north to south along the corridor, starting from Albany Shaker, and ending with Sand Creek and Colonie Center. Several congestion patterns can be discovered from these figures. It is very clear that the intersection delays follow a U-shaped trend in Figure 5.2. The values are quite large at the Albany Shaker intersection during most time periods, and drop significantly At the Marcus Blvd. intersection, then remain at similar levels at Metro Park and Computer Drive. The intersection delays start to increase again at Sand Creek and continue up to the intersections around the Colonie Center Mall. The first three peak periods illustrate the impacts caused by commuting trips on the corridor. The AM and PM peaks consistently have the most significant delays; the PM delays are the highest except the I-87 off ramp. The average delays for the weekend peak period are generally similar to the weekday midday peak period, except the intersection at Colonie Center South which is most likely attributed to the increased shopping trips during weekends.

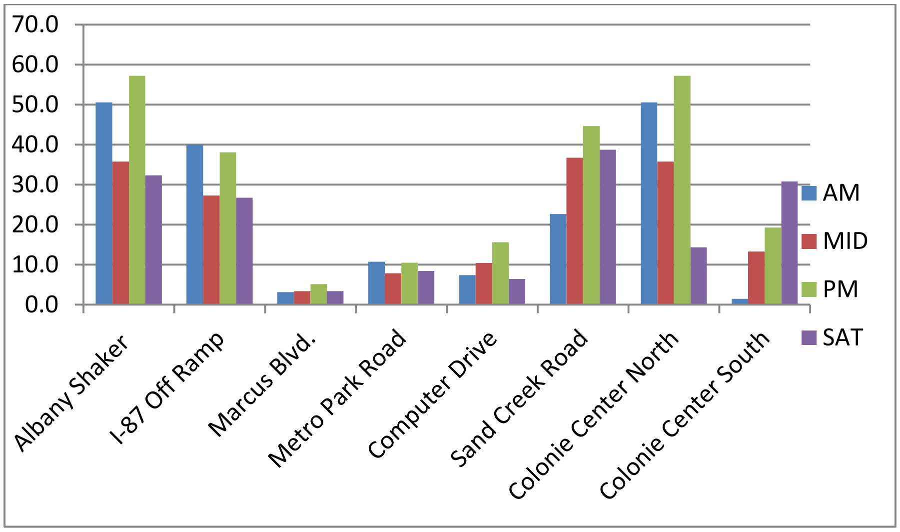


Figure 5.2: Average delay by intersection – before periods

Figure 5.3 shows the minor street delays (east/west approaches) along the corridor. The U-shaped trend still exists, but is less apparent than that for the total intersection delays. Only the Albany Shaker intersection and the I-87 off ramp seem to be largely affected by commuting trips. For the other intersections, there is a steady increase in delay as the day progresses. The two Colonie Center intersections have similar patterns: their highest delays occur during the PM period and the weekend due to the increase in shopping trips. The minor intersections (Metro Park, and Computer) remain almost unchanged throughout the peak periods.

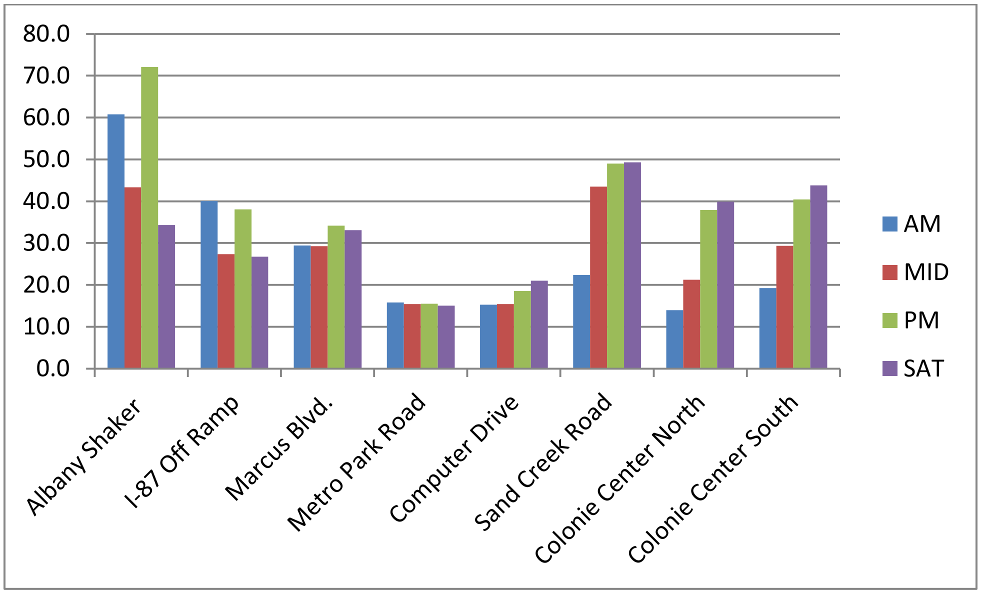


Figure 5.3: Average minor street delays by intersection – before periods

5.2.2 Queue length

The lane-by-lane queue length information for specific approaches and intersections are shown in Table 5.9 – Table 5.12 during the weekday and weekend peak periods. As mentioned in Chapter 5.2.2, the queue length data were mainly collected at the minor streets around the Albany Shaker and the Sand Creek intersection.

Table 5.9: Queue lengths during weekday AM peak – before periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	7.0	6.4	2.1
Albany Shaker WB Bridge	10.2	10.0	4.8
Albany Shaker WB	5.9	4.7	12.1
Albany Shaker NB	9.6	4.6	10.6
Old Wolf Road	22.58	N/A	4.83
Sand Creek EB	4.4	N/A	3.3
Sand Creek WB	3.1	N/A	1.9

* N/A indicates no such movement exists

Table 5.10: Queue lengths during weekday midday peak – before periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	4.4	3.7	3.7
Albany Shaker WB Bridge	5.6	6.0	3.9
Albany Shaker WB	4.1	3.1	11.5
Albany Shaker NB	9.7	6.2	8.4
Sand Creek EB	6.7	N/A	7.1
Sand Creek WB	5.6	N/A	3.0

* N/A indicates no such movement exists

Table 5.11: Queue lengths during weekday PM peak – before periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	6.3	6.9	9.9
Albany Shaker WB Bridge	8.1	10.6	11.4
Albany Shaker WB	8.7	7.9	12.7
Albany Shaker NB	14.5	15.3	13.7
Old Wolf Road	17.85	N/A	4.28
Sand Creek EB	11.3	N/A	6.9
Sand Creek WB	13.5	N/A	3.3

* N/A indicates no such movement exists

Table 5.12: Queue lengths during weekend peak – before periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	4.9	4.1	4.4
Albany Shaker WB Bridge	3.7	3.9	7.5
Albany Shaker WB	7.6	4.9	9.5
Albany Shaker NB	10.9	7.0	8.1
Sand Creek EB	8.5	N/A	5.3
Sand Creek WB	6.1	N/A	2.9
Colonie Center WB	3.2	N/A	4.9

* N/A indicates no such movement exists

Figure 5.4 – Figure 5.7 provide graphical representation of the queue length information at each approach. In Figure 5.4, the queue lengths during the AM peak indicate that the Albany Shaker intersection received the largest traffic demand. This is most likely caused by drivers' travel westbound through the intersection to turn left onto I-87 and drivers' commute to work from I-87. The figure shows that the queue length for the shared left turn/through lane (indicated as "Thru 1" in the figure), on the Old Wolf Road approach, was about three times larger than that for the left turn lane. This is a direct result of most commuters exiting I-87 towards the Wolf Road corridor. They preferred to take the shared lane to ensure that they could easily make the right turn at the Albany Shaker intersection, towards Wolf Road. Compared with the AM and Midday peak periods, queue lengths during the PM peak period (see Figure 5.6) were considerably larger. In particular, the queue lengths for the left turn at the Albany Shaker intersection and the through lanes on the northbound approach increased significantly during the PM peak. This is most likely due to the large demand of commute traffic that aimed to merge onto I-87. In Figure 5.5 and Figure 5.7, the queue lengths during the midday and weekend peak periods tend to be less than the other two periods due to the relative small commute traffic volume. The observations here are consistent with the delay pattern illustrated in Figure 5.3.

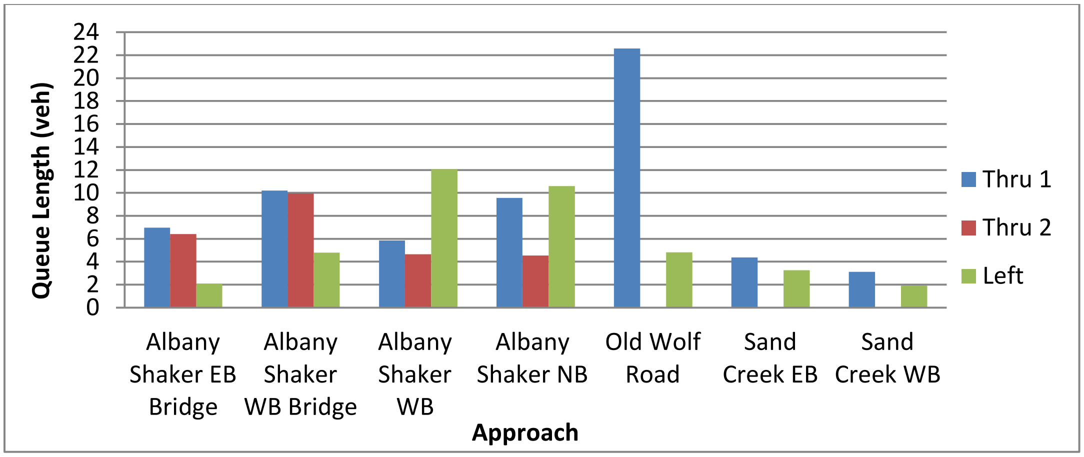


Figure 5.4: Queue lengths during weekday AM peak – before periods

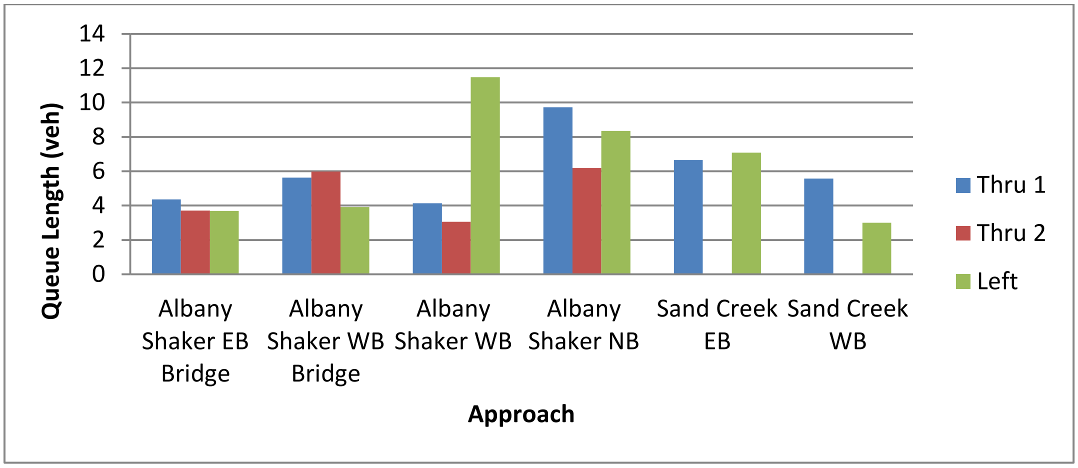


Figure 5.5: Queue lengths during weekday midday peak – before periods

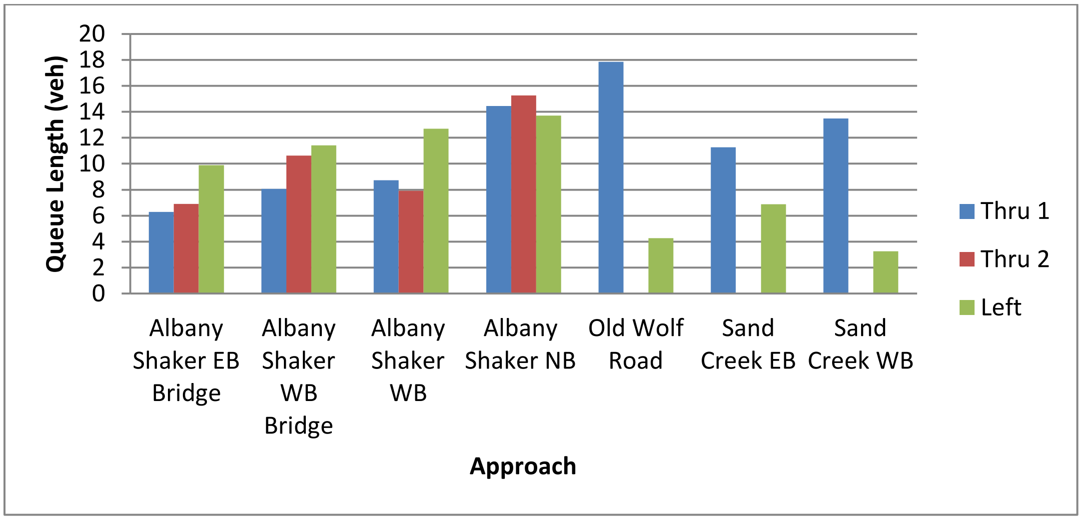


Figure 5.6: Queue lengths during weekday PM peak – before periods

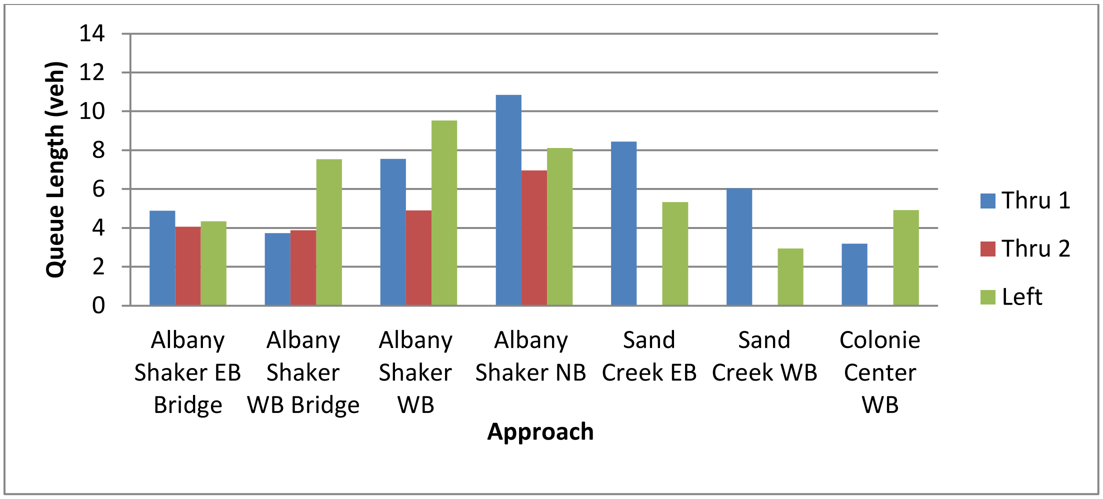


Figure 5.7: Queue lengths during weekend peak – before periods

5.2.3 Travel time, average speed and number of stops

The GPS floating car data was processed to determine the average speed, travel time, number of stops and stop duration for each probe vehicle used in this study. These MOEs were organized by the direction of travel and also by the turning movement at the north end of the route (left turn or right turn). One can refer to Figure 5.1 for the driving routes and designated turnabouts. Table 5.13 – Table 5.16 summarize the results for the weekday and weekend peak periods. Visualized representations of these MOEs can be found in Figure 5.8 – Figure 5.11.

Table 5.13: Travel data during weekday AM peak – before periods

Direction of Travel	Left Turn at North End			
	Speed (mph)	Travel Time (sec)	Number of Stops	Stop Time (sec)
Northbound	23.2	285.2	2.8	72.3
Southbound	24.5	263.6	2.2	48.9
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	26.4	244.7	1.8	31.5
Southbound	22.1	257.8	2.0	55.2

Table 5.14: Travel data during weekday midday peak – before periods

Direction of Travel	**Left Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	19.7	327.3	3.2	87.3
Southbound	20.8	312.3	3.0	67.4
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	20.9	312.1	2.9	63.4
Southbound	21.9	290.0	2.6	62.1

Table 5.15: Travel data during weekday PM peak – before periods

Direction of Travel	**Left Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	18.4	351.6	3.6	97.1
Southbound	18.8	342.3	3.4	93.2
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	19.1	335.8	3.1	78.9
Southbound	21.5	298.6	2.7	65.5

Table 5.16: Travel data during weekend peak – before periods

Direction of Travel	**Left Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	17.8	398.8	3.8	160.0
Southbound	19.2	314.8	2.5	84.8
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	19.3	317.8	4.3	93.3
Southbound	20.0	302.8	2.8	83.5

The results for the average travel speeds throughout the corridor shows a decreasing trend from the AM peak to the weekend peak period consistently across all directions of travel and turning movements. The figures show that the travel speeds are inversely proportional to the travel times, stop durations, and number of stops. The latter three MOEs are also directly proportional to each other since one would expect that making more stops and longer stops would result in longer travel times. These observations justified the congestion patterns discovered in Chapter 5.2.1 and Section 5.2.2.

For the weekend peak period, the calculated MOEs vary across different measurements and do not have a consistent trend like the weekday data. In particular, Figure 5.8 to Figure 5.11 show that the weekend values can be either higher or lower than the PM peak period, even for the same direction and turning movement.

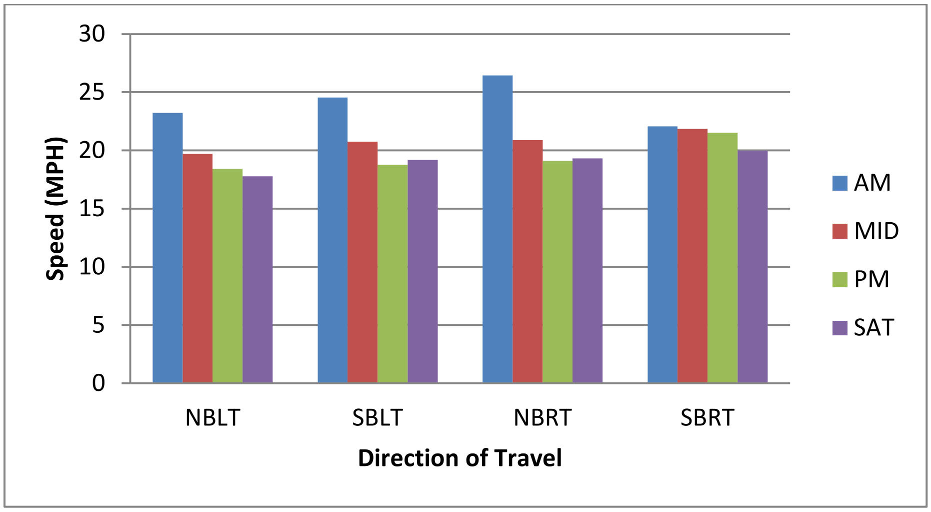


Figure 5.8: Average travel speeds – before periods

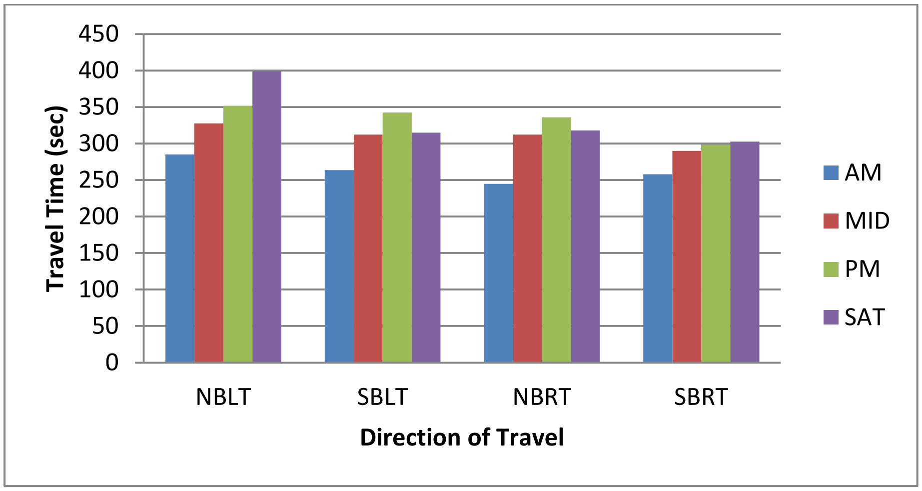


Figure 5.9: Average travel times – before periods

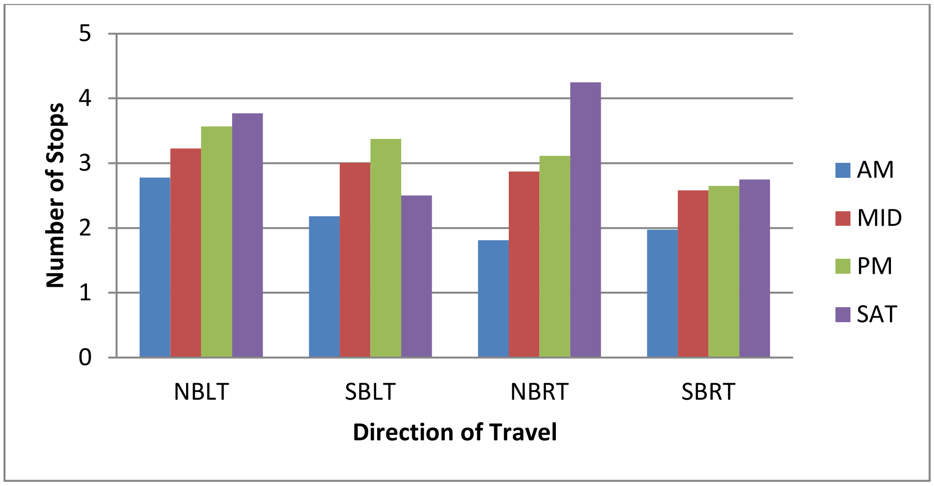


Figure 5.10: Average number of stops – before periods

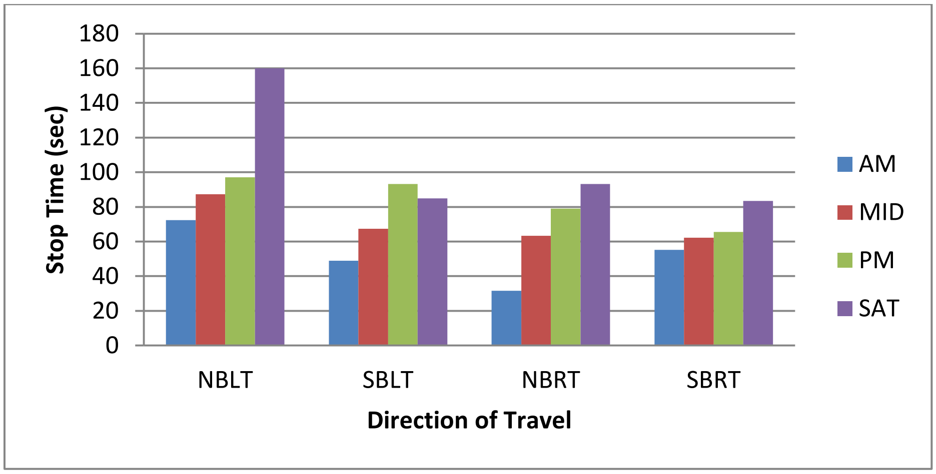


Figure 5.11: Average stop duration – before periods

5.2.4 Emissions and fuel consumption

In order to estimate fuel consumption and emissions for individual vehicles, the GPS floating car data were used as the input to the CMEM emission model. The output results include the overall fuel consumption, carbon dioxide, and nitrogen oxide, in addition to other tailpipe emissions. Since carbon dioxide and nitrogen oxide are the only pollutants considered in the benefit/cost analysis section, other emissions are not shown here. The average fuel consumption and emissions were calculated for two types of vehicles, i.e., passenger cars and pick-up trucks. The results are summarized in Table 5.17 and Table 5.18. Due to schedule issues, no pick-up truck participated in the weekend data collection for the before scenario. Therefore "SAT" data are not presented in Table 5.18. The estimated fuel consumption and emissions in each table are grouped by the travel directions along the corridor (northbound and southbound).

Table 5.17: Emissions and fuel consumption data for passenger car – before periods

Peak Period	Direction of Travel	Distance Traveled (miles)	Fuel Used (g)	CO_2 (g)	NO_X (g)
AM	Northbound	1.8	243.00	686.84	2.85
	Southbound	1.6	200.96	566.39	2.43
MID	Northbound	1.8	263.81	752.69	2.93
	Southbound	1.6	218.01	618.23	2.52
PM	Northbound	1.8	278.15	792.17	2.91
	Southbound	1.6	218.86	623.01	2.40
SAT	Northbound	1.8	261.66	774.27	1.81
	Southbound	1.6	233.29	858.38	1.69

Table 5.18: Emissions and fuel consumption data for pickup truck – before periods

Peak Period	Direction of Travel	Distance Traveled (miles)	Fuel Used (g)	CO_2 (g)	NO_X (g)
AM	Northbound	1.8	314.2	952.7	3.4
	Southbound	1.6	287.8	872.5	2.9
MID	Northbound	1.8	342.7	1036.6	3.4
	Southbound	1.6	285.9	871.6	2.9
PM	Northbound	1.8	366.8	1116.1	3.3
	Southbound	1.6	289.0	871.5	2.8

The estimated fuel consumption and CO_2 emissions during different peak periods are plotted in Figure 5.12 and Figure 5.13. The results clearly indicate that fuel consumptions and emissions increased gradually through different periods during the weekday. The weekend results are in general close to the results of weekday PM peak period.

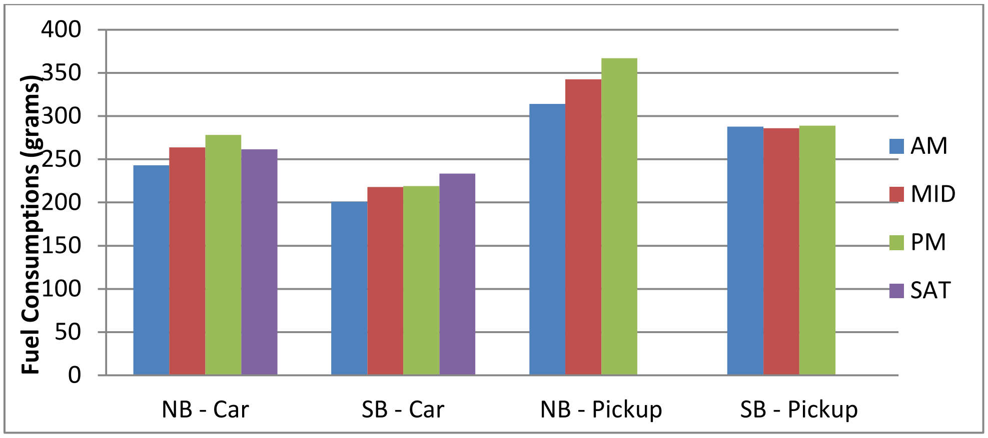


Figure 5.12: Average fuel consumption – before periods

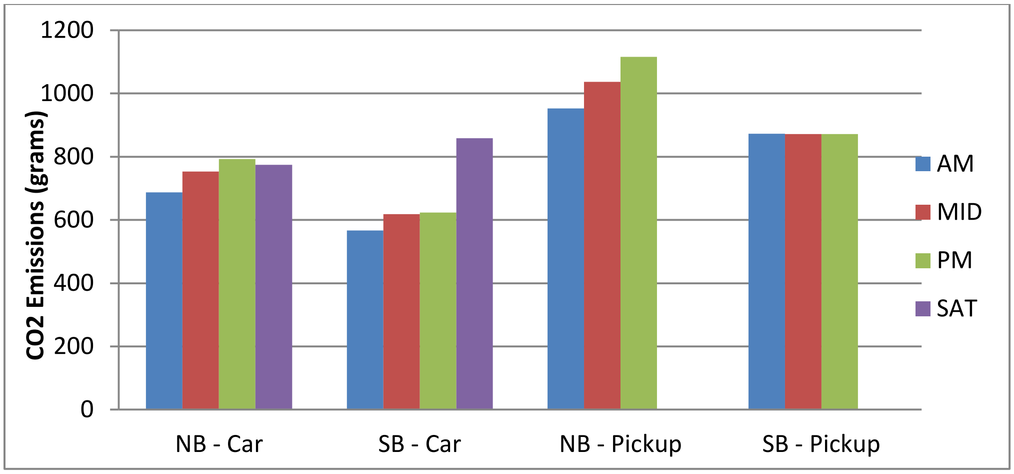


Figure 5.13: Average CO_2 emission – before periods

5.2.5 Observations and discussion

The key observations based on the data collected during the "before" period are summarized in this section. Brief discussions are also provided.

Delay patterns and queue length information are commonly used to assess the performance of signalized intersections and arterial corridors. It is found that these two measures have strong correlations with each other. In Figure 5.14 and Figure 5.15, the average movement delay and queue length at Albany Shaker and Sand Creek are compared side-by-side. These two intersections are the most congested along the corridor. The revealed patterns in these two figures are highly consistent with each other. Both figures show that the largest queue length and delay occur during the AM and PM peaks, especially during the PM peak. This was mainly caused by the large demand of commute traffic during the AM and PM peak periods. These figures clearly indicate that longer queue lengths directly correlate to longer delays because vehicles will have to spend more time waiting in the queue. Longer delays will in turn cause longer queues to build up.

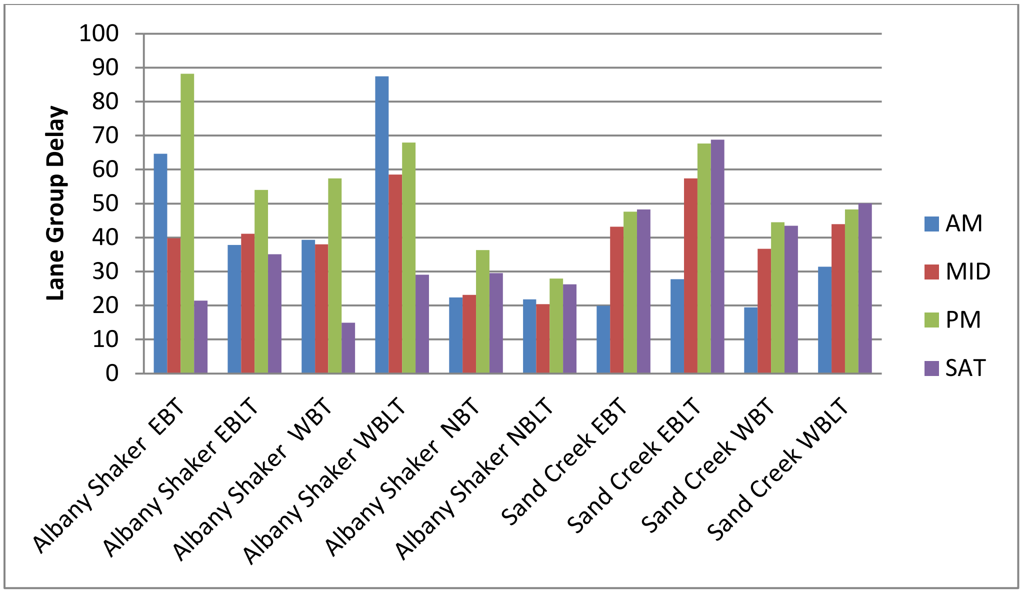


Figure 5.14: Average delay by lane group – before periods

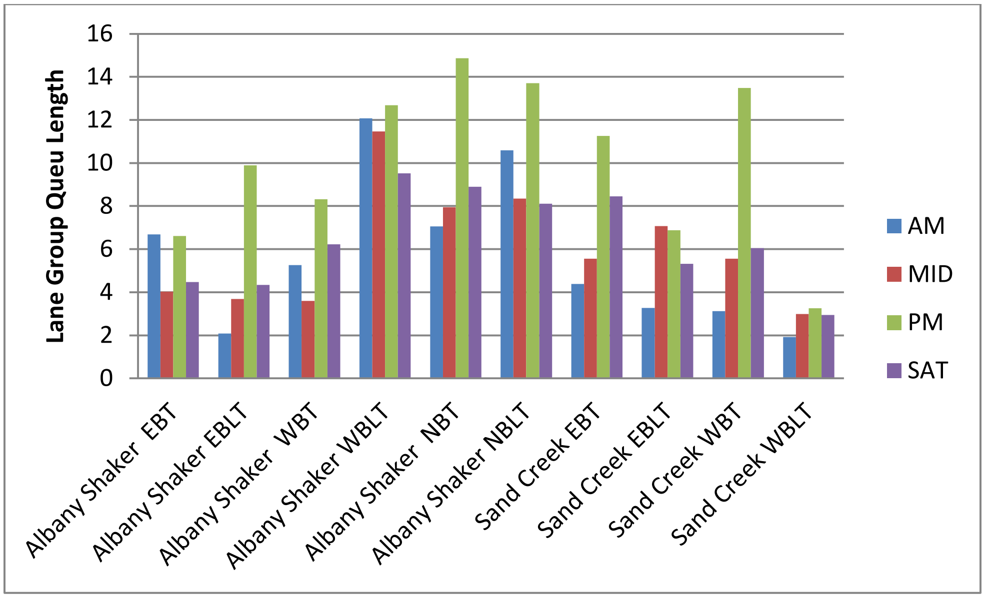


Figure 5.15: Average queue lengths by lane group – before periods

Delays and queues also directly affect vehicle progression along the corridor that was captured by the GPS floating car data. By scrutinizing other MOEs such as average travel time, number of stops and stop duration, it was found that these MOEs were also consistent with the delay and queuing patterns. Similar trends are also reflected by the fuel consumption and emissions results. As the day progressed, there was a steady increase in the fuel consumption and emission values. The weekend peak period data was slightly different and did not follow a consistent trend.

5.3 After Data Collection and Analysis

This section summarizes the MOEs and other data elements collected for the weekday and weekend periods after the deployment of the ACS-Lite system. For comparison purpose, the collected data and analyses are presented in a format similar to the “before” scenario. Table 19 below shows the intersection volumes. Compared with Table 5.2 for the “before volumes”, there was no major change in terms of the corridor volumes.

Table 5.19: Intersection peak hour volumes – after periods

Intersection	AM	MID	PM	SAT
Albany Shaker	3354	3116	3499	2505
I-87 Off Ramp	885	846	826	729
Marcus Blvd.	1798	2373	2517	2435
Metro Park Road	1728	2685	2991	2334
Computer Drive	1914	3468	3549	2420
Sand Creek Road	2098	3503	3614	3432
Colonie Center North	1822	4286	3791	2744
Colonie Center South	1845	4229	4438	3242

5.3.1 Intersection delay

The average total intersection delay and level of service are summarized in Table 5.20. Similar MOEs are provided in Table 5.21, but only for the minor streets at each intersection.

Table 5.20: Average intersection delay (sec) and level of service – after periods

Intersection	Peak Period							
	AM	LOS	MID	LOS	PM	LOS	SAT	LOS
Albany Shaker	86.4	F	72.4	E	105.8	F	31.2	C
I-87 Off Ramp	20.3	B	16.0	B	9.1	A	13.8	B
Marcus Blvd.	15.0	B	6.1	A	5.1	A	9.3	A
Metro Park Road	10.9	B	9.2	A	9.2	A	10.2	B
Computer Drive	6.7	A	8.1	A	11.2	B	10.5	B
Sand Creek Road	15.0	B	42.4	D	40.2	D	37.8	D
Colonie Center North	6.0	A	12.1	B	9.2	A	11.6	B
Colonie Center South	4.0	A	9.3	A	15.3	B	17.5	B

Table 5.21: Average minor streets (east/west) delay – after periods

Intersection	Peak Period							
	AM	LOS	MID	LOS	PM	LOS	SAT	LOS
Albany Shaker	106.7	F	92.3	F	156.6	F	32.8	C
I-87 Off Ramp	20.3	C	16.0	B	9.1	A	13.8	B
Marcus Blvd.	29.9	C	27.2	C	28.3	C	15.9	B
Metro Park Road	20.5	C	17.3	B	15.9	B	20.5	C
Computer Drive	15.8	B	16.3	B	25.9	C	10.6	B
Sand Creek Road	14.2	B	48.0	D	44.3	D	46.5	D
Colonie Center North	18.5	B	26.3	C	23.6	C	19.3	B
Colonie Center South	24.9	C	26.2	C	35.6	D	26.3	C

To further illustrate the delays of the corridor, Table 5.22 – Table 5.25 depict the delay for each movement of every intersection for the weekday AM peak, midday, PM peak, and the Weekend peak (Saturday 2-3 pm), respectively. Similar to the “before” scenario, the north/south approaches of an intersection indicate the major street, i.e., Wolf Road, while the east/west approaches represent minor streets.

Table 5.22: Average movement delays during weekday AM peak – after periods

Intersection	Movement (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	34.0	34.7	95.4	191.6	N/A	N/A	33.3	210.0
I-87 Off Ramp	20.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	8.3	N/A	27.9	N/A	17.3	26.4	30.5	N/A
Metro Park Road	1.7	N/A	19.8	N/A	0.4	48.6	20.6	N/A
Computer Drive	1.3	21.2	15.6	N/A	1.5	20.4	16.1	N/A
Sand Creek Road	14.2	21.3	14.0	16.3	13.0	24.6	10.7	21.7
Colonie Center North	3.7	26.3	18.0	N/A	3.3	22.3	19.0	N/A
Colonie Center South	2.6	33.4	27.6	N/A	1.8	30.2	23.3	23.2

* N/A indicates no such movement exists

Table 5.23: Average approach delays during weekday midday peak – after periods

Intersection	Approach (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	33.2	31.9	53.1	264.0	N/A	N/A	30.7	152.7
I-87 Off Ramp	16.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	1.1	N/A	20.1	N/A	7.5	17.1	28.8	N/A
Metro Park Road	8.2	N/A	16.1	N/A	3.3	26.6	17.6	N/A
Computer Drive	3.2	24.4	3.2	N/A	5.2	24.2	15.8	N/A
Sand Creek Road	37.8	53.9	49.0	61.4	34.2	54.3	40.0	49.7
Colonie Center North	10.6	27.2	10.6	N/A	6.2	27.2	26.8	N/A
Colonie Center South	6.7	33.5	6.7	N/A	5.3	33.0	24.3	23.2

* N/A indicates no such movement exists

Table 5.24: Average approach delays during weekday PM peak – after periods

Intersection	Approach (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	39.6	34.3	47.1	532.9	N/A	N/A	32.6	138.8
I-87 Off Ramp	9.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	0.9	N/A	20.5	N/A	7.9	17.9	30.4	N/A
Metro Park Road	9.3	N/A	14.1	N/A	2.9	25.0	16.2	N/A
Computer Drive	4.2	29.3	4.2	N/A	4.7	28.6	19.7	N/A
Sand Creek Road	35.7	49.8	40.4	56.9	34.1	52.4	42.7	46.0
Colonie Center North	6.9	25.0	6.9	N/A	3.4	24.2	22.9	N/A
Colonie Center South	11.6	41.5	11.6	N/A	12.3	40.8	34.9	32.6

* N/A indicates no such movement exists

Table 5.25: Average approach delays during weekend peak – after periods

Intersection	Approach (Thru or Left)							
	NBT	NBLT	EBT	EBLT	SBT	SBLT	WBT	WBLT
Albany Shaker	33.2	13.2	26.6	26.8	N/A	N/A	25.9	17.6
I-87 Off Ramp	13.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Marcus Blvd.	11.1	N/A	11.3	N/A	6.5	11.7	16.9	N/A
Metro Park Road	10.7	N/A	11.6	N/A	6.5	12.4	22.0	N/A
Computer Drive	11.1	8.8	10.7	N/A	9.2	10.2	10.4	N/A
Sand Creek Road	28.9	43.7	49.5	57.6	30.1	48.8	37.2	52.9
Colonie Center North	13.1	14.0	13.8	N/A	6.0	17.4	19.4	N/A
Colonie Center South	18.7	31.4	37.5	N/A	9.7	30.9	23.6	22.0

* N/A indicates no such movement exists

The above results confirm that the intersections of Albany-Shaker Road and Sand Creek Road continued to be the two most congested intersections of the corridor after the ACS-Lite system was deployed. In particular, the average approach delays of Albany-Shaker Road increased significantly after the ACS-Lite system was deployed, especially at the minor streets (i.e., the Albany-Shaker Road). By scrutinizing the actual green times before and after the deployment of the ACS-Lite system, it was found that in the "after" scenario, the green times for the left turns of westbound and southbound were significantly smaller than those in the before scenario (reduced from about 40 seconds to less than 20 second in the PM peak period). This explains the dramatic increment of approach delays in the after scenario for the westbound and eastbound left turn traffic.

Figure 5.16 and Figure 5.17 indicate the average total intersection delay and the average minor street delay for each intersection. Unlike the U-shape trend in the "before" scenario, the average intersection delays in the "after" scenario follow a flat trend across the intersections except at the Albany Shaker and the Sand Creek intersections. The delays at the Albany Shaker now pose a serious problem to the Wolf Road corridor as the delays are now within the 80 second to 100 second range or higher for most of the peak periods. By comparing the intersection delays with the side street delays, it was found that the patterns in these two figures are highly consistent. This seems to suggest that the side street delays are the primary determinants of the overall intersection delays (at least for the Albany Shaker intersection). With respect to the other intersections (other than the Albany Shaker intersection), it was found the intersection delays and side-street delays got reduced in the "after" scenario. This implies that traffic was running more smoothly at the other intersections (i.e., within the ACS-Lite system since the Albany-Shaker intersection is the boundary intersection at the north end of the corridor) in the "after" scenario. Reduced intersection delays and side street delays were observed during all the peak periods of the "after" scenario, except at the Albany Shaker intersection.

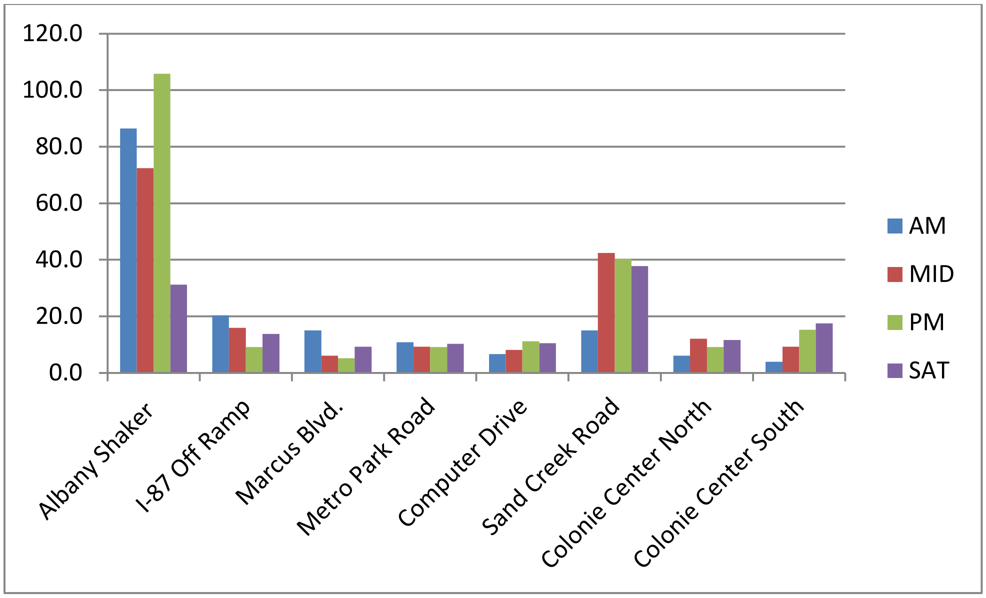


Figure 5.16: Average delay by intersection – after periods

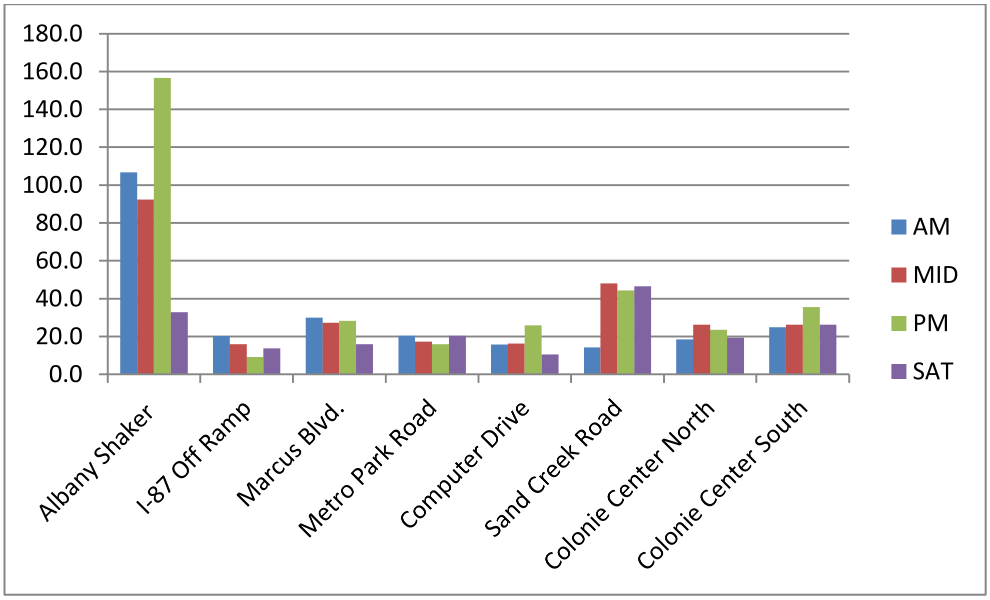


Figure 5.17: Average side street delays by intersection – after periods

5.3.2 Queue length

The lane-by-lane queue length information for specific approaches and intersections are shown in Table 5.26 – Table 5.29 during the weekday and weekend peak periods.

Table 5.26: Queue lengths during weekday AM peak – after periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	7.88	9.98	6.13
Albany Shaker WB Bridge	8.38	8.47	5.55
Albany Shaker WB	5.14	4.26	10.67
Albany Shaker NB	13.21	6.76	13.39
Old Wolf Road	10.41	N/A	21.33
Sand Creek EB	4.23	N/A	3.07
Sand Creek WB	3.66	N/A	1.87

* N/A indicates no such movement exists

Table 5.27: Queue lengths during weekday midday peak – after periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	7.53	7.63	4.50
Albany Shaker WB Bridge	7.22	7.16	4.42
Albany Shaker WB	2.66	2.11	7.54
Albany Shaker NB	11.06	9.52	17.20
Sand Creek EB	4.48	N/A	3.47
Sand Creek WB	4.59	N/A	2.01

* N/A indicates no such movement exists

Table 5.28: Queue lengths during weekday PM peak – after periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	12.11	13.18	8.95
Albany Shaker WB Bridge	7.93	12.99	9.63
Albany Shaker WB	10.14	8.69	13.01
Albany Shaker NB	14.23	15.25	19.67
Old Wolf Road	19.72	N/A	15.67
Sand Creek EB	11.33	N/A	6.66
Sand Creek WB	14.18	N/A	3.36

* N/A indicates no such movement exists

Table 5.29: Queue lengths during weekend peak – after periods

Approach	Lane		
	Thru 1	Thru 2	Left
Albany Shaker EB Bridge	3.88	3.21	3.50
Albany Shaker WB Bridge	1.99	2.19	2.51
Albany Shaker WB	3.22	4.29	5.45
Albany Shaker NB	7.65	6.97	7.60
Sand Creek EB	6.34	N/A	4.03
Sand Creek WB	7.19	N/A	3.17
Colonie Center WB	2.47	N/A	3.70

* N/A indicates no such lane exists

Figure 5.18 – Figure 5.21 provide graphical representation of the queue length information at each approach. Similar to the before data, the queue lengths for the Albany-Shaker Road and the Old Wolf Road are the largest. Noteworthy there is very limited queue storage space for eastbound left turn at Albany-Shaker Road (under the I-87 bridge). This explains why the PM peak delay of eastbound left turn is extremely high but the queue length is only about 10 vehicles - roughly the maximum queue storage space at this location. Due to this reason, queue length is not considered as the main MOE here for the before and after comparison.

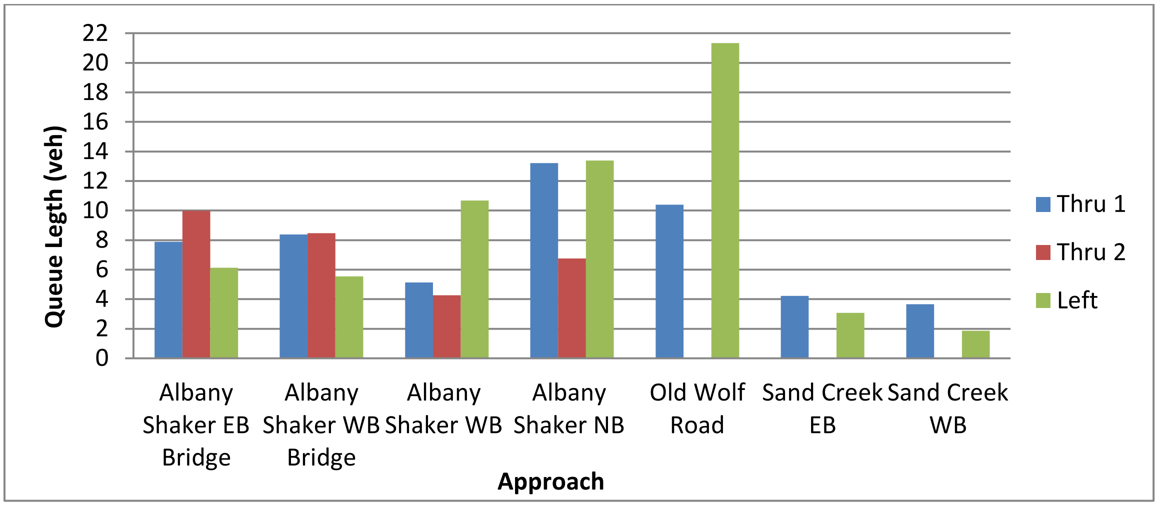


Figure 5.18: Queue lengths for weekday AM peak – after periods

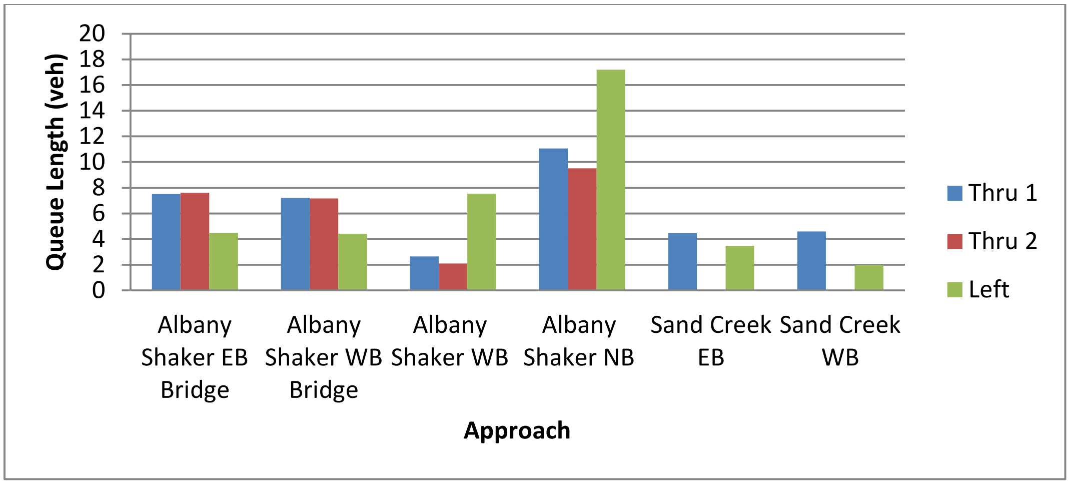


Figure 5.19: Queue lengths for weekday midday peak – after periods

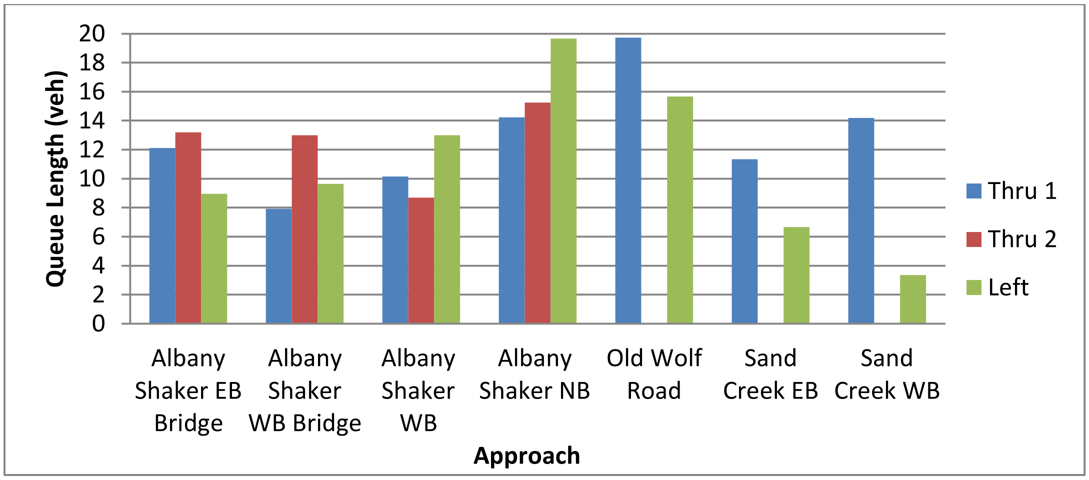


Figure 5.20: Queue lengths for weekday PM peak – after periods

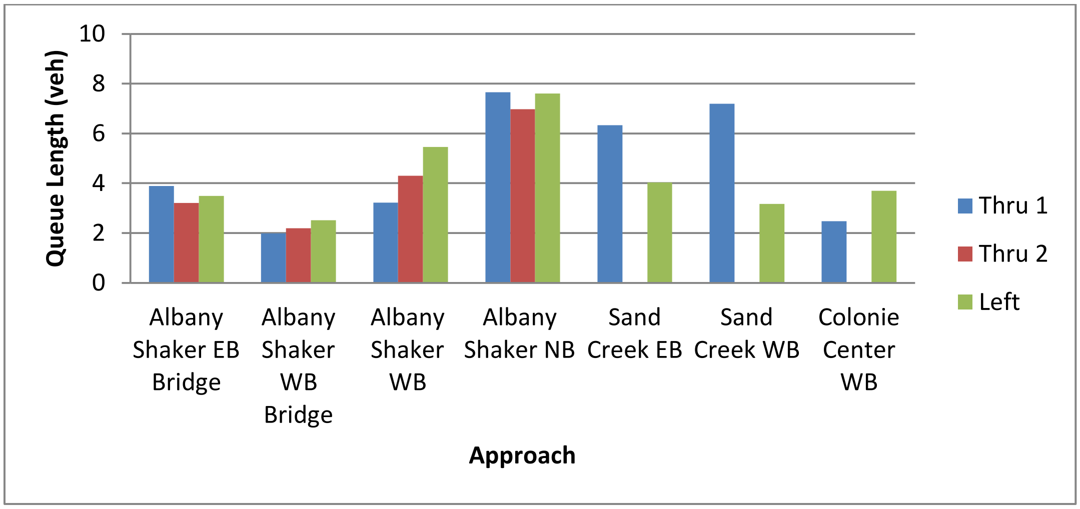


Figure 5.21: Queue lengths for weekend peak – after periods

5.3.3 Travel time, average speed, and number of stops

Table 5.30 – Table 5.33 summarize the average speed, travel time, number of stops, and stop duration for the weekday and weekend peak periods.

Table 5.30: Travel data for weekday AM peak – after periods

Direction of Travel	Left Turn at North End			
	Speed (mph)	Travel Time (sec)	Number of Stops	Stop Time (sec)
Northbound	24.6	262.8	1.9	61.5
Southbound	26.1	238.9	2.0	59.1
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	27.5	230.4	2.1	35.2
Southbound	25.4	237.2	2.1	43.1

Table 5.31: Travel data for weekday midday peak – after periods

Direction of Travel	Left Turn at North End			
	Speed (mph)	Travel Time (sec)	Number of Stops	Stop Time (sec)
Northbound	19.3	325.8	3.1	92.2
Southbound	20.2	307.1	3.2	73.8
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	18.4	344.4	3.6	100.5
Southbound	22.1	282.0	2.7	62.8

Table 5.32: Travel data for weekday PM peak – after periods

Direction of Travel	Left Turn at North End			
	Speed (mph)	Travel Time (sec)	Number of Stops	Stop Time (sec)
Northbound	17.7	364.0	3.6	124.9
Southbound	19.5	315.2	2.8	90.6
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	18.3	335.4	3.6	102.4
Southbound	19.3	336.4	3.3	101.0

Table 5.33: Travel data for weekend peak – after periods

Direction of Travel	Left Turn at North End			
	Speed (mph)	Travel Time (sec)	Number of Stops	Stop Time (sec)
Northbound	20.8	298.4	2.7	77.7
Southbound	20.1	309.8	2.7	85.5
Direction of Travel	**Right Turn at North End**			
	Speed (mph)	**Travel Time (sec)**	**Number of Stops**	**Stop Time (sec)**
Northbound	21.5	288.9	2.7	64.1
Southbound	22.4	280.5	2.4	73.5

Figure 5.22 – Figure 5.25 indicate the average travel speeds, travel times, numbers of stops, and stopped times, respectively. The figures show that the MOEs calculated using the GPS probe data are correlated with each other. In particular, the travel speeds are inversely proportional to other MOEs; Travel time, stop duration, and number of stops are directly proportional to one another. These observations are consistent with the congestion patterns discovered in Chapter 5.3.1 and Chapter 5.3.2.

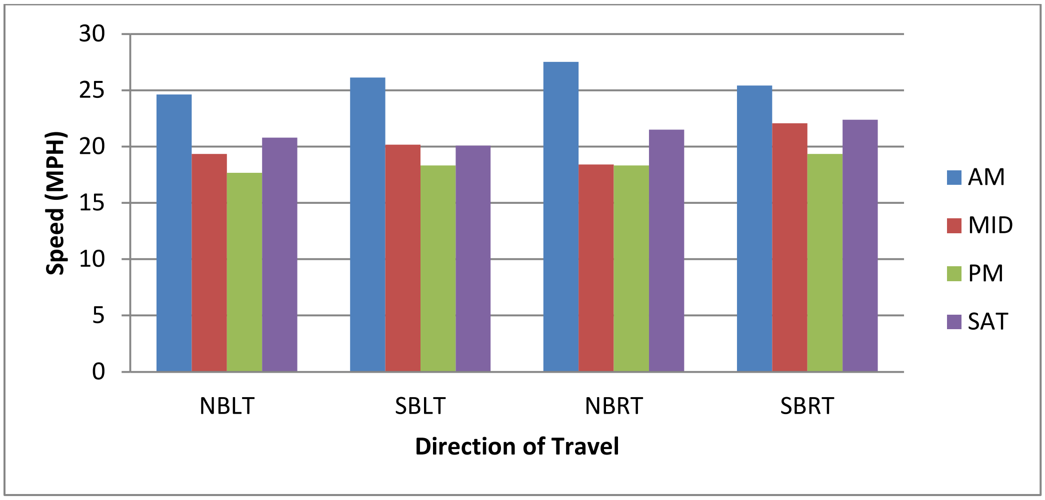


Figure 5.22: Average travel speeds – After periods

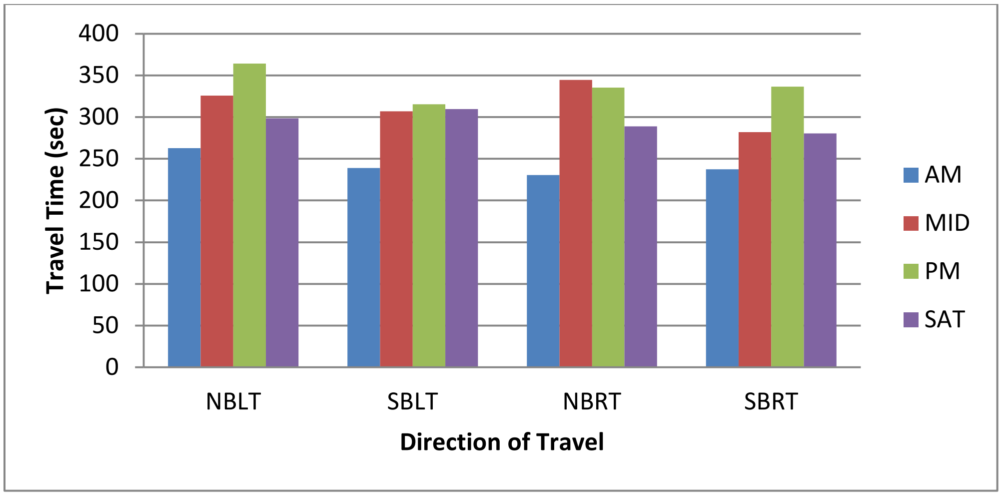


Figure 5.23: Average travel times – after periods

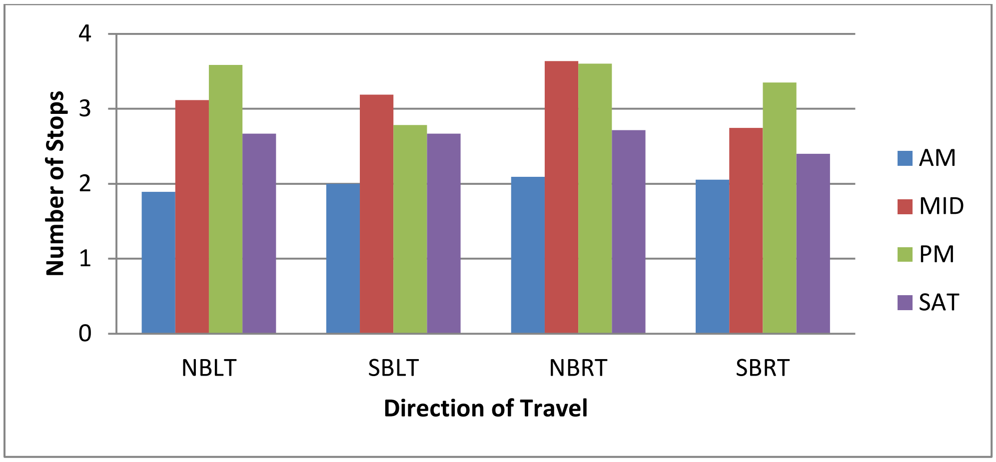


Figure 5.24: Average number of stops – after periods

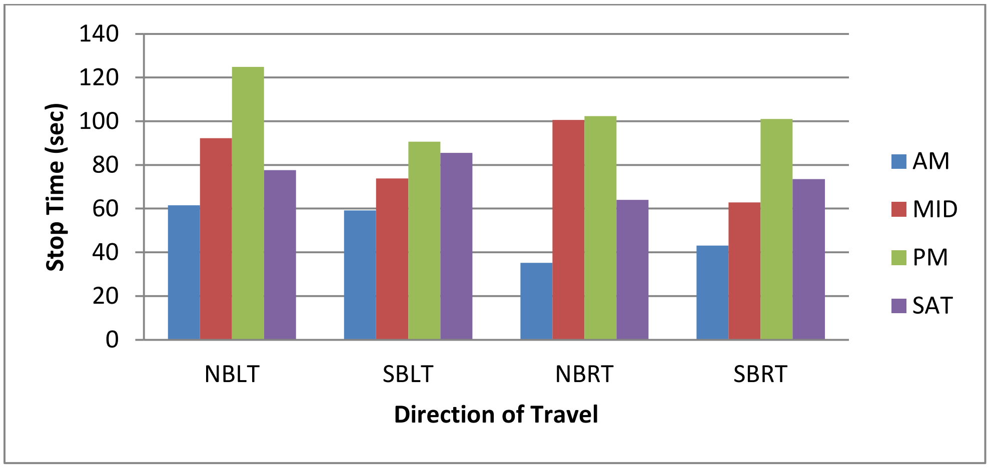


Figure 5.25: Average stop duration – after periods

Compared with the "before" scenario, the congestion patterns conveyed by the "after" GPS floating car data are quite similar with some differences for the weekend patterns. First, similar to the before scenario, there was a steady increase in travel time (decrease in average speed), number of stops, and stop duration throughout the weekday periods (AM peak, mid-day, PM-peak). Different from the before scenario, the weekend travel time, number of stops, and stop duration were less than those for the PM-peak period during weekdays.

5.3.4 Emissions and fuel consumption

The estimated average fuel consumption and emissions results are summarized in Table 5.34 and Table 5.35, for passenger cars and pickup trucks respectively. The results in each table are categorized into the two travel directions along the corridor (northbound and southbound).

Table 5.34: Emissions and fuel consumption data for passenger car – after periods

Peak Period	Direction of Travel	Distance Traveled (miles)	Fuel Used (g)	CO_2 (g)	NO_X (g)
AM	Northbound	1.8	222.0	580.0	72.1
	Southbound	1.8	224.1	606.2	71.4
MID	Northbound	1.8	271.6	725.5	65.2
	Southbound	1.8	236.9	668.5	58.7
PM	Northbound	1.8	293.8	760.3	84.3
	Southbound	1.8	247.4	678.6	75.4
SAT	Northbound	1.8	243.1	575.2	279.4
	Southbound	1.8	238.4	563.6	323.1

Table 5.35: Emissions and fuel consumption data for pickup truck – after periods

Peak Period	Direction of Travel	Distance Traveled (miles)	Fuel Used (g)	CO_2 (g)	NO_X (g)
AM	Northbound	1.8	302.9	916.2	3.3
	Southbound	1.8	302.6	914.4	3.3
MID	Northbound	1.8	344.0	1045.7	3.1
	Southbound	1.8	333.0	1008.3	3.2
PM	Northbound	1.8	389.6	1193.1	3.0
	Southbound	1.8	329.1	1006.8	3.0
SAT	Northbound	1.8	298.1	901.7	3.4
	Southbound	1.8	282.8	853.4	3.3

The estimated fuel consumption and CO_2 emission during different peak periods are further illustrated in Figure 5.26 and Figure 5.27. The results show a mild increase in fuel consumption and CO_2 emission across different periods of the weekday, while the weekend fuel consumption and emissions are significantly smaller than those for weekday PM-peak periods. The patterns are consistent with the MOEs calculated using the GPS floating car data.

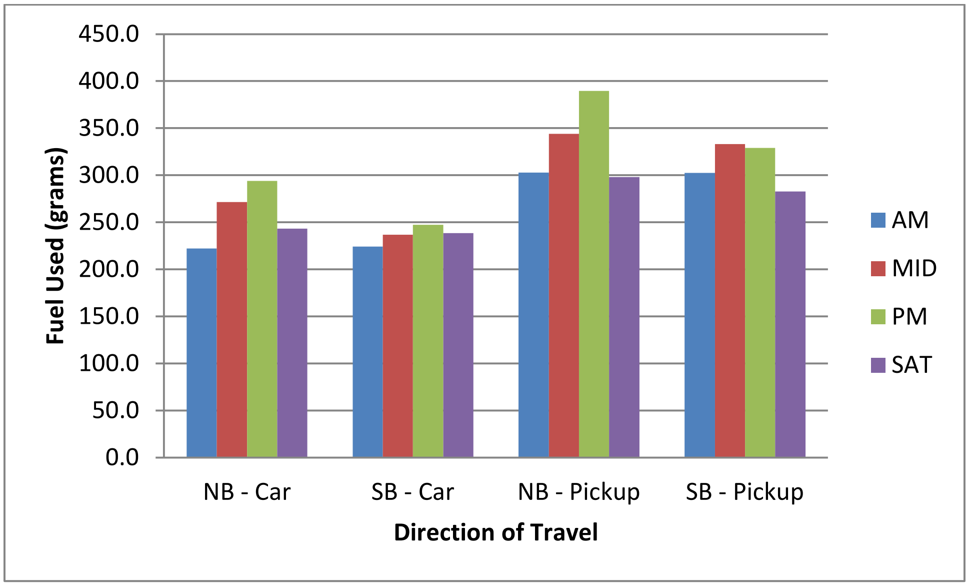


Figure 5.26: Average fuel consumption for each vehicle class – after periods

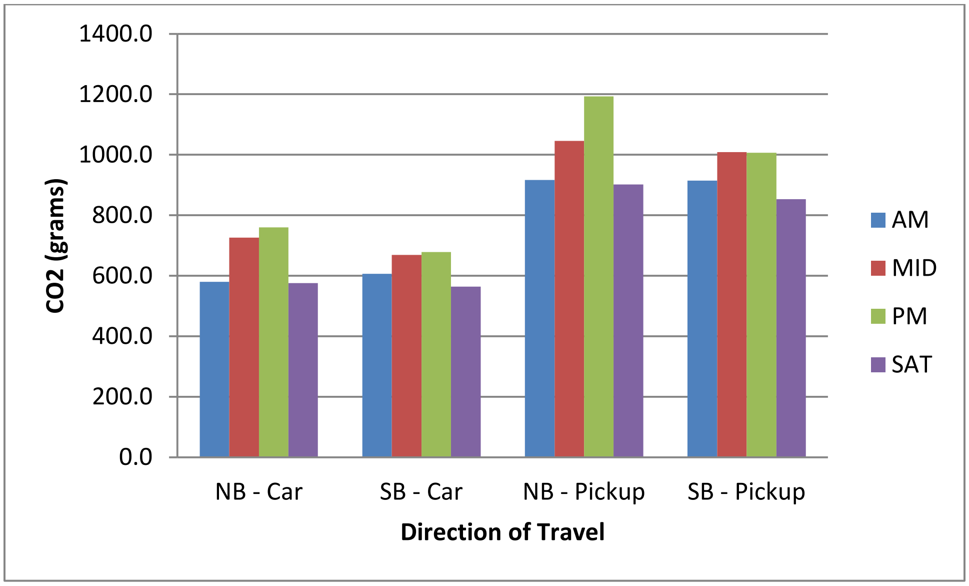


Figure 5.27: Average CO_2 emission for each vehicle class – after period

5.3.5 Discussion

Many of the trends exhibited by the MOEs for the before scenario are also present in the MOEs for the after scenario. The GPS data and emissions data have an increasing trend from the AM peak to the PM peak and the queue length data generally follow the same trend as the before period queue length data. The most important difference can be seen in the delay pattern for the after scenario.

The delays for the Albany Shaker intersection are significantly higher than all the other intersections, specifically at the eastbound and westbound approaches as shown in Figure 5.28. As mentioned previously, the U-shaped trend that was apparent in the before period delays has now become a flatter trend, with most of the delays shifted towards the Albany Shaker end of the corridor. It is possible that the reduced delays along most of the corridor will allow for a smoother flow, which could reduce emissions. The cost/benefit analysis will reveal if this is true.

The figures below have been organized by lane groups to allow for a comparison between the delays and queue lengths with those reported in Chapter 5.5.3. Note that the scale in Figure 5.28 has been adjusted to better represent the lane group delays; the delay for the PM period of the Albany Shaker EBLT lane group overshadows the other lane groups with a delay beyond 500 seconds. There are no obvious correlations between the data in the figures which is most likely due to the different capacities and green times at each approach. For example, the Albany Shaker NB approach has very large queue lengths but very low delay; this is because the capacity can accommodate the queue lengths appropriately and the allocated green time can properly service the vehicles in the queue.

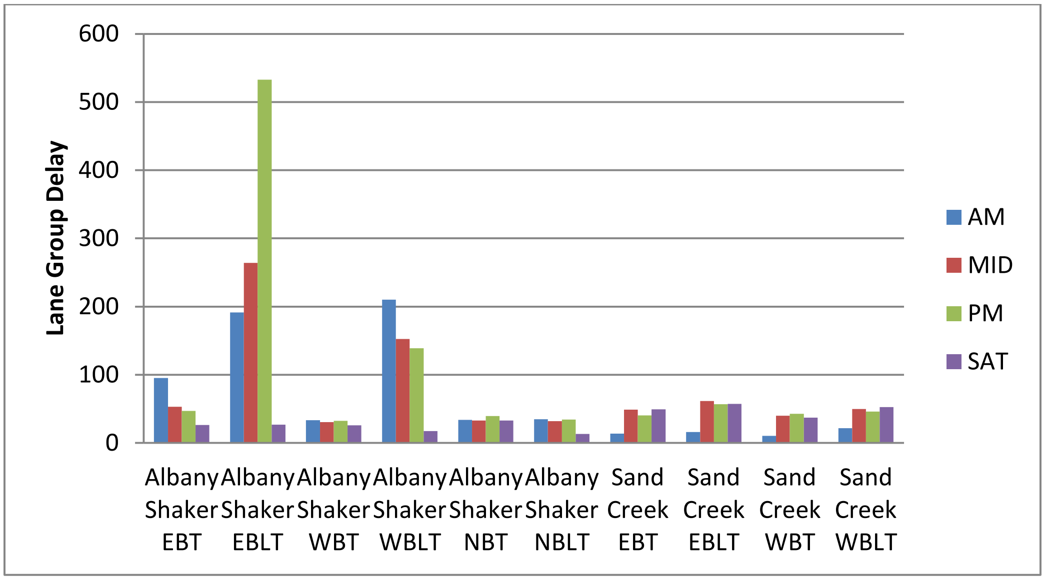


Figure 5.28: Average delay by lane group – after periods

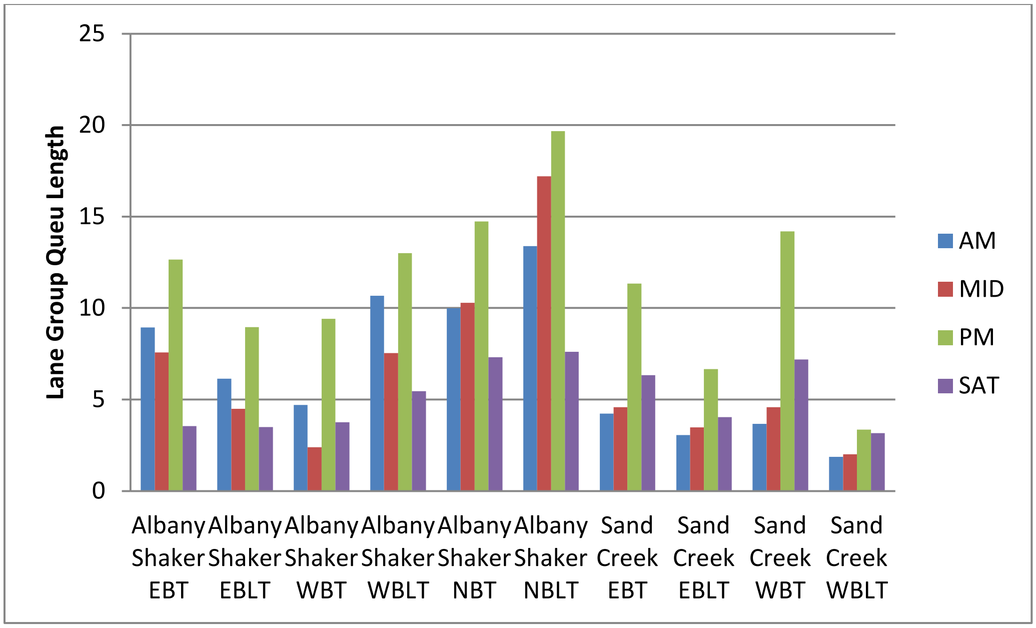


Figure 5.29: Average queue lengths by lane group – after periods

5.4 Before-After Comparison and Analysis

The comparison for the delay data shows some notable changes in the performance of the corridor after the deployment of the ACS-Lite system; see Figure 5.30 and Figure 5.31. Delays significantly increased at the Albany Shaker intersection with the majority of the increase on the minor streets. There were minor reductions in delay on the other intersections, especially at the Colonie Center North intersection. Due to the fact that the ACS-Lite system was not active during the weekends, there were no significant changes in delays during the weekends. This is particularly the case at the Albany Shaker intersection where the largest changes occurred in the after period collection during weekdays.

The delay results seem to indicate that adaptive control can potentially improve the flow within its own system. However, this may be achieved by “metering” (i.e., restricting) flow into the system, thereby generating large delays/problems at the boundary intersections, e.g., the Albany Shaker intersection at the Wolf Road corridor. Notice that the southbound boundary intersection is Colonie Center South, which is a minor intersection, and delay did not change much. The next intersection of Colonie Center South, Central Ave, is the major intersection which, however, is not included in the adaptive control system. In this sense, a larger area/network may need to be considered to provide a more systematic view and management of the traffic system. In the Wolf Road case, the nearby freeway I-87 may need to be considered so that both the freeway and arterials can be coordinated and managed simultaneously. This leads to the need for integrated corridor management (ICM) to be pursued in the future to provide a more holistic solution to the congestion issues on Wolf Road corridor, as well as its nearby freeways and arterials.

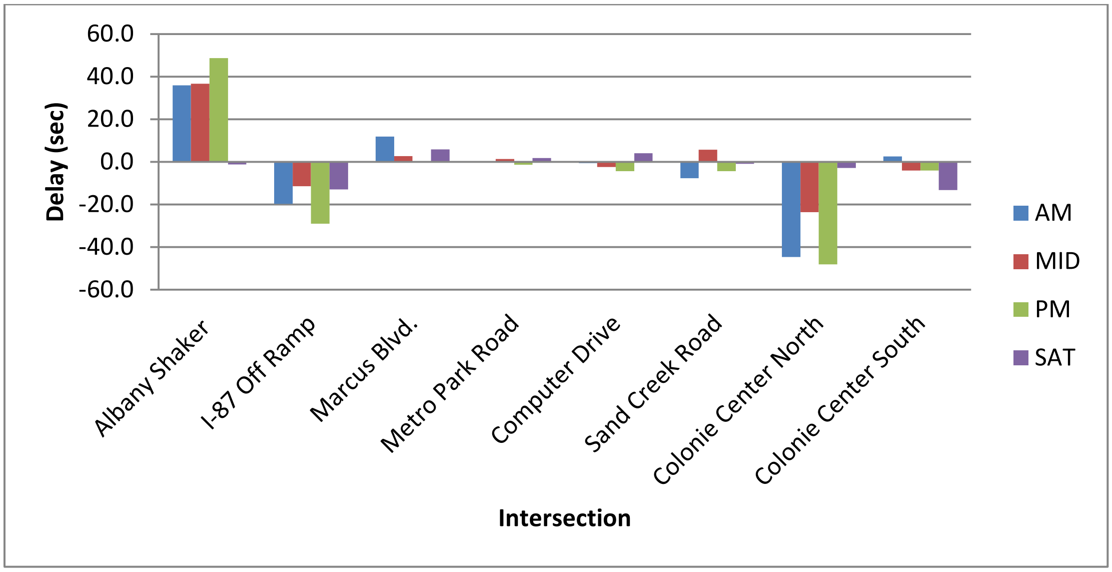


Figure 5.30: Change in intersection delays

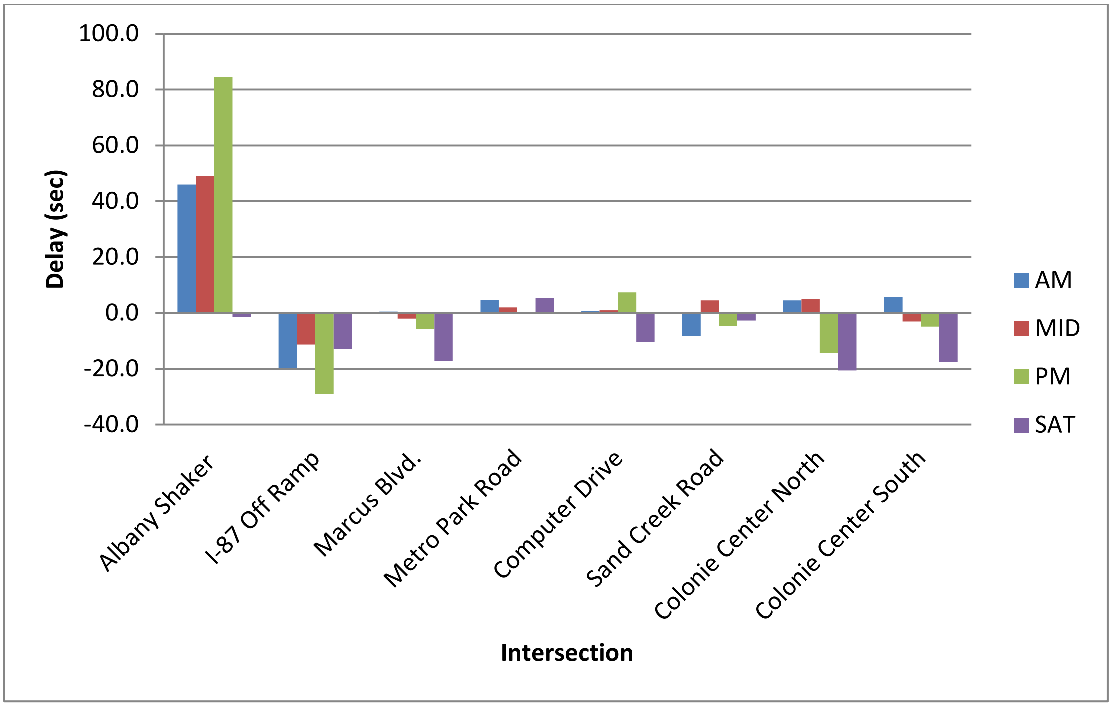


Figure 5.31: Change in side street delays

The queue length comparison graphs for the weekday collection periods do not show many significant changes between the before and after collection periods; see Figure 5.32 to Figure 5.35. There was a small to moderate increase in queue lengths at the Albany Shaker intersection which is consistent with the changes in the delay comparison graphs. A significant increase in queue lengths was found at the Old Wolf Road approach. Note that in the AM peak period, the queue length for the shared through/left lane decreased, but the queue length for the left turn only lane increased more dramatically. This seems to indicate that due to more severe congestion at Old Wolf Road during the "after" AM period, drivers tried to use the left turn lane more often compared with the "before" AM period. This can also be seen by comparing Figure 5.4 and Figure 5.18. The comparison graph for the Saturday peak period shows a small to moderate decrease in queue lengths for almost all of the approaches; this is also consistent with the delay comparison graphs.

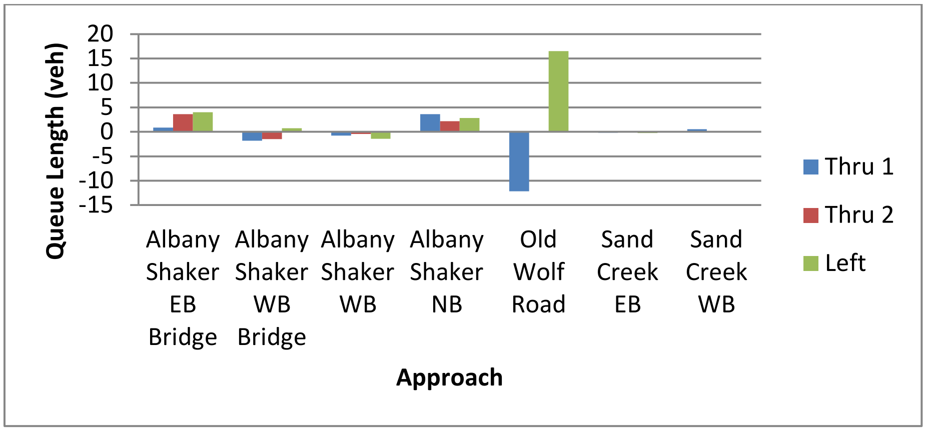


Figure 5.32: Change in queue length for AM peak

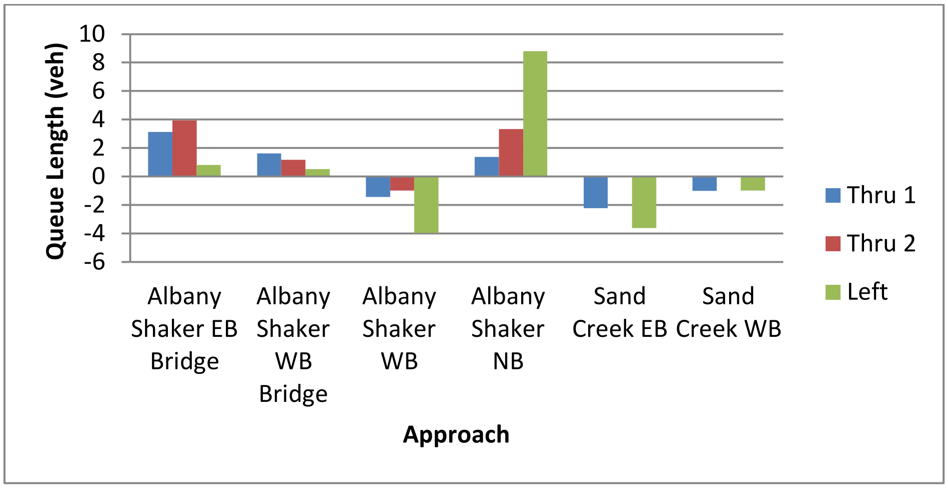


Figure 5.33: Change in queue length for midday peak

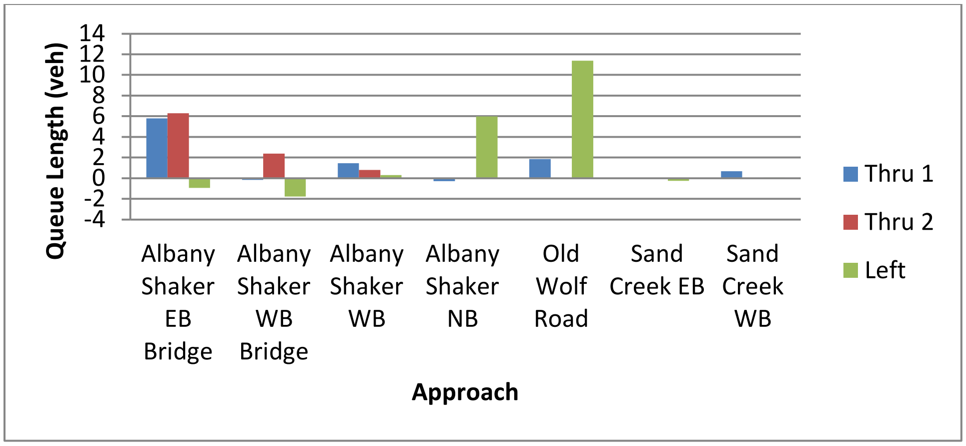


Figure 5.34: Change in queue length for PM peak

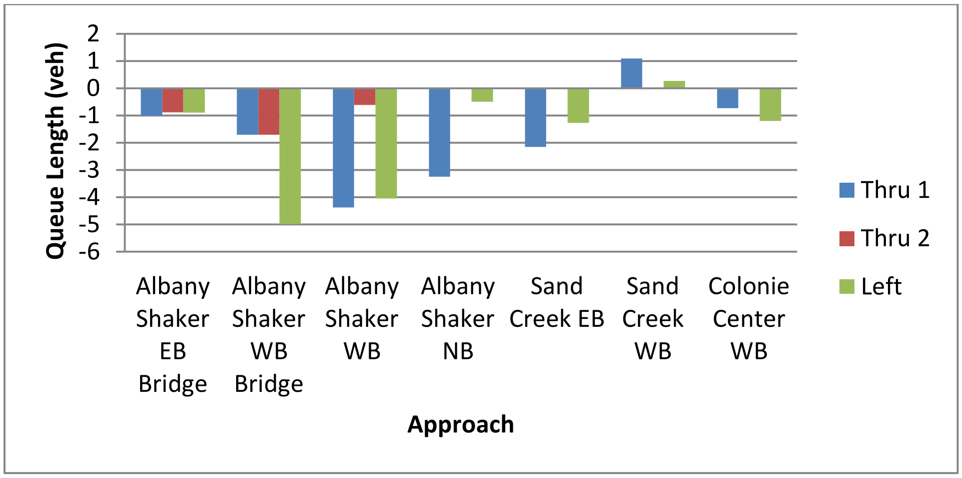


Figure 5.35: Change in queue length for weekend peak

The comparison graphs for the GPS data exhibit mixed results in terms of travel times, number of stops, and stop durations, as shown in Figure 5.36 to Figure 5.39. The data for the northbound right (NBRT) is significantly different than the data for the rest of the movements, especially for the midday peak period. After further investigation, these differences were attributed to the small sample size of the data collected for the after period. The sample size for the northbound right and the southbound left movements (complementary movements for a driver constrained to the right lane) are significantly smaller than the other two movements for the after period collection. Table 5.36 shows the number of samples for each driving direction of each data collection period for both the before and after scenarios. As indicated by the italic numbers, the northbound right turn and southbound left turn for the after periods suffered because of a relatively small number of samples. As a result, GPS travel times were not used directly in the delay analysis.

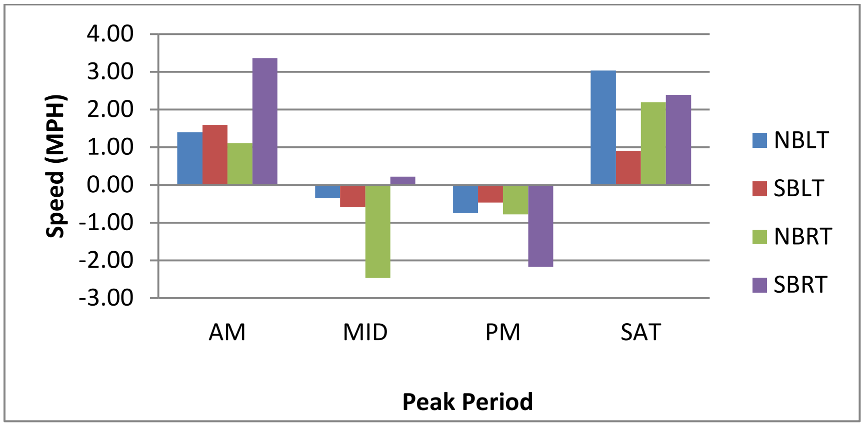


Figure 5.36: Change in travel speed

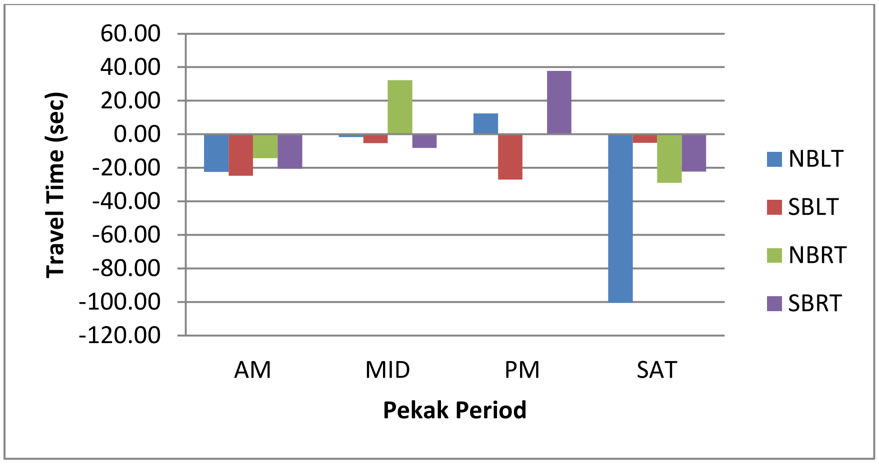


Figure 5.37: Change in travel time

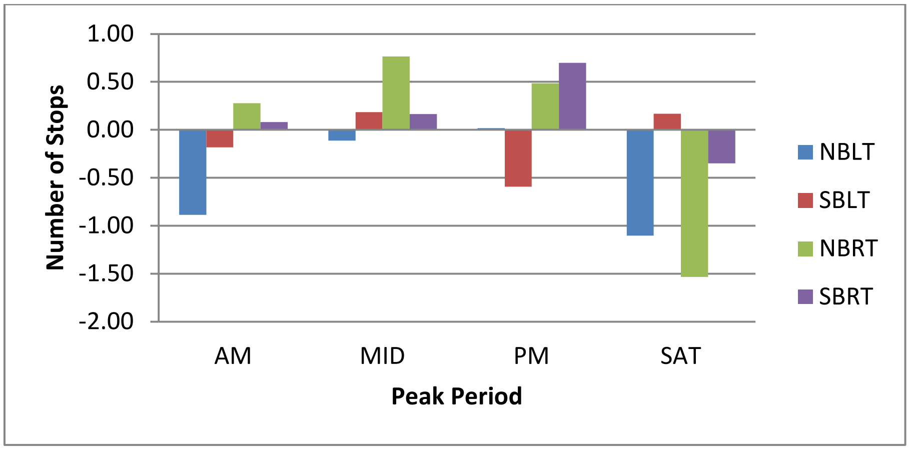


Figure 5.38: Change in number of stops

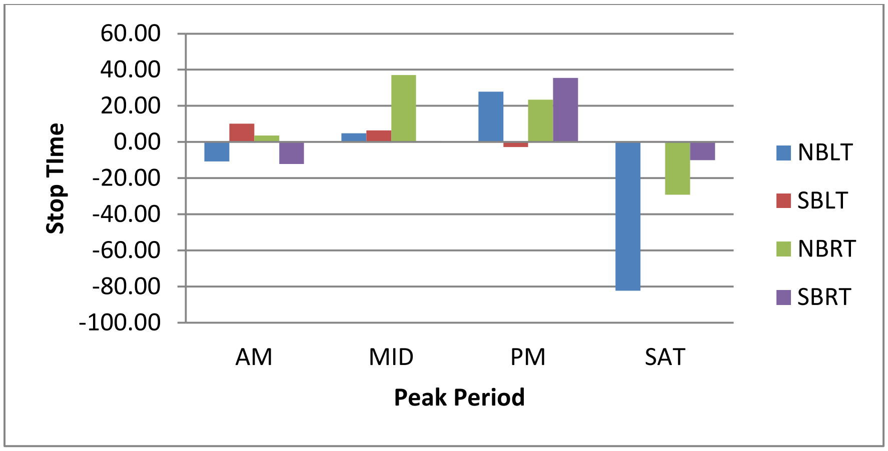


Figure 5.39: Change in stop duration

Table 5.36: Sample size of GPS travel times

Scenario	**Peak Period**	**Movement**			
		NBLT	**NBRT**	**SBLT**	**SBRT**
Before	**AM**	24	47	47	25
	MIDDAY	28	37	38	28
	PM	30	24	23	29
After	**AM**	37	***11***	***9***	38
	MIDDAY	35	12	16	35
	PM	24	21	23	23

Figure 5.40 and Figure 5.41 show that there were only small changes for fuel consumption and emissions between the before and after weekday peaks. For passenger cars, fuel consumption decreased for the northbound traffic for the AM-peak period, but increased slightly for the other periods. The CO_2 emission of the northbound traffic decreased while emission increased for the southbound traffic. Also, there was a significant decrease in fuel consumption and CO_2 emission for the weekend peak period. This is consistent with the patterns in delays and GPS probe data.

It is important to note that conclusions should not be made for the pickup truck emissions data due to the lack of data. There was no pickup truck data for the Saturday peak period in the after scenario and only one pickup truck was used in the data collection. Due to these problems and the fact that trucks only constituted a small portion of the total traffic volume on the corridor, only passenger vehicles will be considered in the benefit/cost analysis.

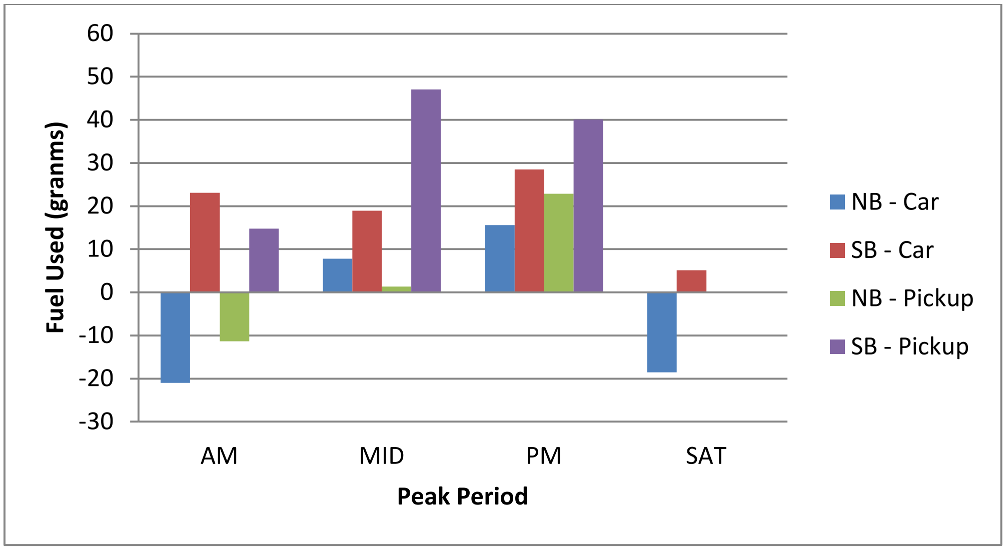


Figure 5.40: Change in fuel consumption

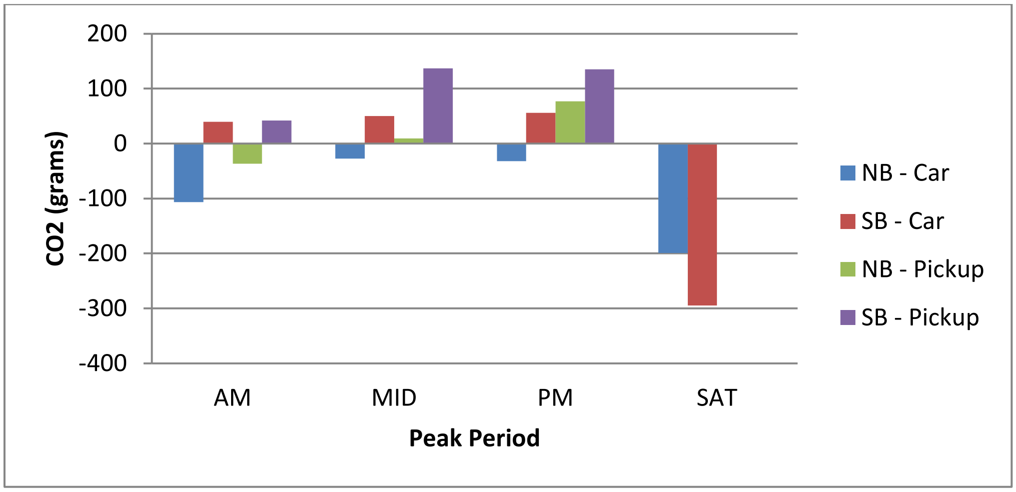


Figure 5.41: Change in CO_2 emission

5.5 Benefit /Cost Analysis

The benefit/cost analysis was based on traffic volumes, delay, and fuel consumption/emissions data from the weekday peak periods. With respect to the delay analysis, the product of the delays for the major movements and minor movements at each intersection and their respective volumes were summed to obtain an estimation of the total delay for the major and minor approaches. This is shown in Table 5.37 and Table 5.38 respectively. Table 5.39 displays the total or combined delay for each intersection of the entire corridor; this was used in the cost/benefit analysis. The volumes for each movement were averaged over the before and after collection periods for consistency.

Table 5.37: Total delays for major movements - NB and SB approaches

Intersection	Before delay (seconds)			After delay (seconds)		
	AM	MID	PM	AM	MID	PM
Albany Shaker	19044	23503	51703	29407	34592	58005
Marcus Blvd.	3607	3778	8683	28481	10604	10229
Metro Park Road	16198	15623	20239	14040	16885	19813
Computer Drive	9350	20755	31227	7304	13376	13528
Sand Creek Road	28588	73629	89936	19375	87204	82153
Colonie Center North	9874	32794	17060	11799	27850	16150
Colonie Center South	1895	29057	47476	6302	19580	38445
Total	88556	199139	266325	116708	210091	238324

Table 5.38: Total delays for minor movements – EB and WB approaches

Intersection	Before delay (seconds)			After delay (seconds)		
	AM	MID	PM	AM	MID	PM
Albany Shaker	136822	85420	156771	241789	183737	319008
Marcus Blvd.	2027	4498	5378	2026	4169	4481
Metro Park Road	5008	7186	7265	4666	7533	7810
Computer Drive	5903	11372	24315	6167	7758	11408
Sand Creek Road	21097	55239	73746	13425	61243	66246
Colonie Center North	778	19484	10538	1022	17800	12071
Colonie Center South	1444	21108	28922	1879	15398	25745
Total	173079	204307	306934	270974	297636	446768

Table 5.39: Total delays – combined movements

Intersection	Before delay (seconds)			After delay (seconds)		
	AM	MID	PM	AM	MID	PM
Albany Shaker	155866	108923	208474	271196	218328	377013
Marcus Blvd.	5634	8276	14061	30507	14773	14710
Metro Park Road	21206	22809	27504	18706	24418	27623
Computer Drive	15253	32127	55542	13470	21134	24935
Sand Creek Road	49685	128868	163683	32800	148447	148399
Colonie Center North	10652	52278	27598	12821	45650	28221
Colonie Center South	3339	50165	76398	8181	34978	64190
Total	261635	403445	573260	387682	507728	685092

Next, the corridor-wide emission and fuel consumption were evaluated. Similar to the delay analysis, the volumes were multiplied by the fuel consumption/emissions to obtain the total fuel consumption/emissions of the corridor traffic. Since the data was broken into segments with intersections as the endpoints, the volumes of the intersections at the endpoints were averaged to estimate the number of vehicles on the segment. Table 5.40 displays the intersections that correspond to each segment. Table 5.41 – Table 5.43 show the results of the analysis and the totals for each direction.

Table 5.40: Emissions segment information

Segment	Segment Start	Segment End	Direction
1	Colonie Center South	Colonie Center North	NB
2	Colonie Center North	Sand Creek Road	NB
3	Sand Creek Road	Computer Drive	NB
4	Computer Drive	Metro Park Road	NB
5	Metro Park Road	Marcus Blvd.	NB
6	Marcus Blvd.	Albany Shaker Road	NB
7	Albany Shaker Road	I-87 SB Ramp	NB
8	I-87 SB Ramp	Albany Shaker Road	SB
9	Albany Shaker Road	Marcus Blvd.	SB
10	Marcus Blvd.	Metro Park Road	SB
11	Metro Park Road	Computer Dive	SB
12	Computer Drive	Sand Creek Road	SB
13	Sand Creek Road	Colonie Center North	SB
14	Colonie Center North	Colonie Center South	SB

Table 5.41: AM peak period fuel consumption/emissions analysis results

Segment	Before (grams)			After (grams)		
	Fuel Used	CO_2	NOx	Fuel Used	CO_2	NOx
1	28601	78844	436	34709	79732	411
2	30860	87145	354	31654	79712	380
3	24115	67553	285	21567	53648	288
4	24524	69477	314	22714	57071	310
5	19089	53082	262	17811	44710	234
6	26317	76226	269	24007	62130	219
7	19437	55390	157	11014	42951	161
NB Total	172944	487718	2079	163477	419953	2002
9	10340	28472	129	4002	33229	269
10	44326	127222	502	53728	140823	661
11	19148	52557	266	19019	46848	257
12	18274	51176	230	18792	47195	244
13	15054	42338	165	13575	33332	151
14	22978	65663	277	23250	60151	289
SB Total	119779	338955	1441	128363	328349	1602

Table 5.42: Midday peak period fuel consumption/emissions analysis results

Segment	Before (grams)			After (grams)		
	Fuel Used	CO_2	NOx	Fuel Used	CO_2	NOx
1	43653	123830	512	40691	107713	453
2	50310	144935	512	49639	135436	418
3	35227	99908	375	34430	88760	334
4	42778	122162	493	40910	109916	414
5	36906	103878	478	32919	86406	366
6	44901	131220	465	49629	136198	365
7	22111	61016	238	33055	86761	263
NB Total	275887	786948	3073	281273	751190	2613
9	17540	47470	268	10061	58974	194
10	52014	150200	589	49736	134590	510
11	29801	82784	398	31076	81870	324
12	38694	109509	441	37059	98805	383
13	38226	109100	375	40614	109631	325
14	46992	134561	506	44066	117952	457
SB Total	205727	586155	2309	202552	542848	1999

Table 5.43: PM peak period fuel consumption/emissions analysis results

Segment	**Before (grams)**			**After (grams)**		
	Fuel Used	**CO_2**	**NOx**	**Fuel Used**	**CO_2**	**NOx**
1	35452	99038	437	41359	106452	440
2	46179	133327	482	46320	121498	450
3	36712	103787	361	38592	99739	346
4	54985	158363	544	49901	129039	595
5	52949	149632	666	49667	123523	643
6	69581	199206	642	78382	208807	674
7	38469	108404	372	50223	127362	367
NB Total	334328	951758	3505	354443	916419	3514
9	31887	59997	224	10222	83956	290
10	45608	131911	519	48534	126661	632
11	28639	79779	376	29251	72109	382
12	36788	104296	409	34419	86694	418
13	46129	132632	426	50952	132351	404
14	53570	153213	593	56664	147491	616
SB Total	210735	601831	2322	219820	565307	2451

Using the totals from the combined total delays and total emissions/fuel consumption of each peak period, a benefit/cost analysis was performed. The amount of time from the total delays, fuel consumption, and emissions were all converted to monetary values to assess the costs. These unit conversions are indicated in Table 5.44. For the assessment of costs due to delays, personal vehicle occupancy was assumed to be one person per vehicle (which is conservative) and only the value of time for all purposes was used. For the assessment of fuel consumption costs, the density of gasoline was assumed to be 750 grams per liter and the fuel price is the average of the two shown in Table 5.44 ($3.63 per gallon).

Table 5.44: Monetary values for cost/benefit analysis

Cost/benefit category	Value of travel time (per person per hour)			Value of fuel (regular gas price per gallon)	Value of tailpipe emissions (per metric ton)	
	Personal	Business	All Purposes		CO_2	NO_X
Monetary value (USD)	$12.00	$22.90	$12.50	$3.44~$3.82	$22.80	$5217.00
Sources	USDOT, TIGER Benefit/Cost Analysis Resource Guide			AlbanyGasPrices.com	USDOT, TIGER Benefit/Cost Analysis Resource Guide	

Table 5.45 below displays the total costs in monetary values as well as the cost differences (i.e., benefits) between the before and after scenarios. The benefits were calculated by subtracting costs of the after collection period from the before collection period; negative values represent money lost due to the implementation of the ACS-Lite system and positive values represent money saved. The table shows that overall the adaptive system led to worse system performance. Notice that such a conclusion here is made with the understanding that when the after data was collected, the adaptive system experienced two issues: the half-cycle for left turn at Sand Creek and the algorithm problem at Albany Shaker. Therefore the conclusion here may become less critical or reversed if such issues can be corrected.

Since the delays for the Albany Shaker intersection were exceptionally high for the after collection period relative to the before collection period, it may be of interest to assess the costs with the exclusion of the intersection. Table 5.46 shows the costs and cost differences with the Albany Shaker intersection excluded from the calculation and comparison. The table reveals that excluding the Albany Shaker intersection from the cost analysis will result in savings. The results show that for the corridor itself, adaptive control does bring some improvements, roughly \$145 per day (only AM, PM, and midday periods are considered). Considering 260 work days per year, this is approximately \$37,700 saving per year. On the other hand, the total project cost is: \$569,823, including \$300,354 from NYSDOT, and \$269,469 cost shared by RPI and the industry partners (Siemens and Sensys). Operational and maintenance costs are not considered here since those costs for adaptive control are expected to be lower compared with fixed-time or actuated signal control especially when the re-timing of signals is considered. Figure 5.42 shows that the b/c ratio of the project over 20 year period, assuming the total project cost. It clearly shows that in order for the system to be beneficial, if only the traffic within the system is concerned, about 15 years are needed to break even with the total project cost. Figure 5.43 shows the same results, but using only the NYSDOT cost. It indicates that if only the NYSDOT cost is concerned, about 8.0 years are needed to break even with the cost.

Table 5.45: Total costs and cost differences for the Wolf Road corridor

Cost Type	Before			After			Cost Difference
	AM	MID	PM	AM	MID	PM	
Total Delay Costs	$908	$1,401	$1,990	$1,346	$1,763	$2,379	**-$1,188**
Fuel Costs	$374	$616	$697	$373	$618	$734	**-$38**
CO2 Emissions Costs	$19	$31	$35	$17	$30	$34	**$4**
NOx Emissions Costs	$18	$28	$30	$19	$24	$31	**$2**
Total Cost	$1,320	$2,076	$2,753	$1,743	$2,408	$3,173	**-$1,220**

Table 5.46: Total costs and cost differences for the Wolf Road corridor (excluding Albany Shaker intersection)

Cost Type	Before			After			Cost Difference
	AM	MID	PM	AM	MID	PM	
Total Delay Costs	$367	$1,023	$1,267	$404	$1,005	$1,070	**$177**
Fuel Costs	$374	$616	$697	$373	$618	$734	**-$38**
CO2 Emissions Costs	$19	$31	$35	$17	$30	$34	**$4**
NOx Emissions Costs	$18	$28	$30	$19	$24	$31	**$2**
Total Cost	$779	$1,698	$2,029	$801	$1,650	$1,864	**$145**

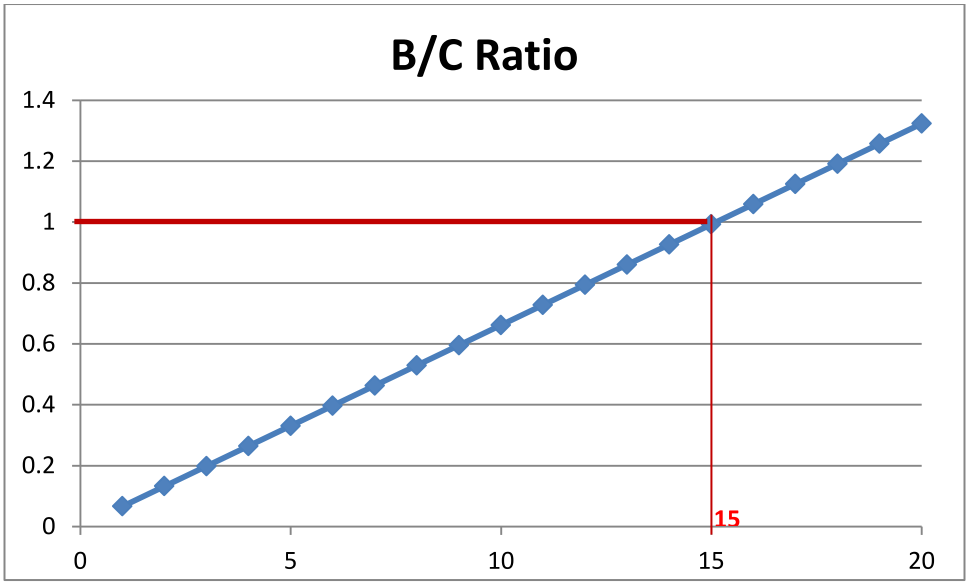


Figure 5.42: Benefit/cost ratio – total project cost

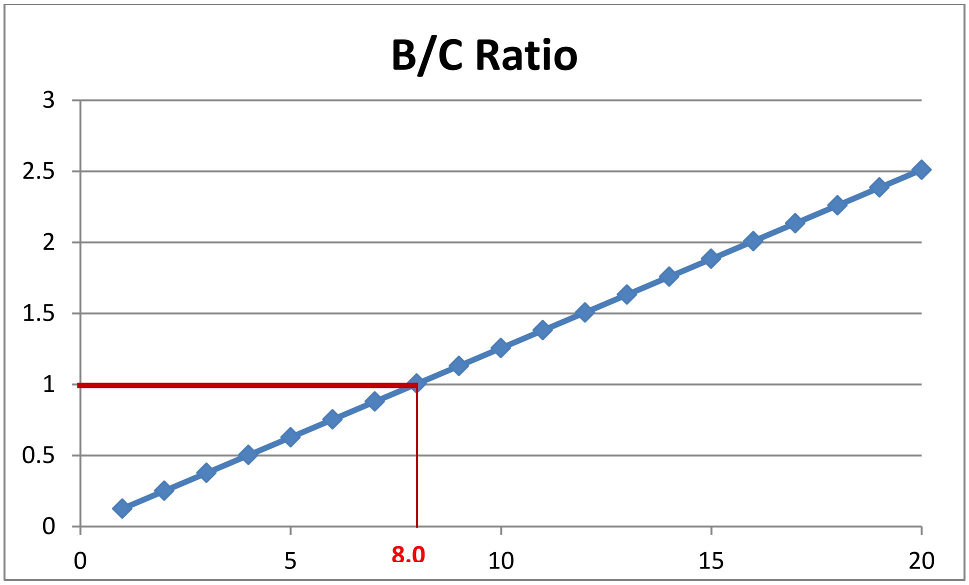


Figure 5.43: Benefit/cost ratio – NYSDOT cost

One should be cautious to interpret and use the exact numbers in the above benefit/cost analysis. As can be seen from Table 5.45 and Table 5.46, the benefits or costs of deploying ACS-Lite are relatively small in this case. Thus, any estimation errors in the analysis could result in different numbers or even opposite conclusions. However, the analysis does show that the main benefit of adaptive control (like ACS-Lite in this study) is to improve traffic flow within the system, which can subsequently result in fewer fuel consumption and/or emissions. The main issue, however, seems to be the possibly increased congestion at the boundary intersections (the Albany-Shaker intersection in the Wolf Road case).

5.6 Major Findings

This section summarizes the major findings from the before and after evaluation.

1. Several issues were found regarding ACS-Lite. First, because the current Siemens version of ACS-Lite cannot modify the cycle time to meet traffic demands, initially the Sand Creek intersection was configured to run a fixed half-cycle. This caused complaints from the public for excessively long delays especially for left turn lanes. Second, there was a software problem which caused the signal at the Albany Shaker intersection to go into flashing mode when transitioning to ACS-Lite. The flashing problem did not happen during the after data collection (in mid-October, 2013). Siemens has been working on fixing the problem since Nov., 2013. By the time this report was submitted (June, 2014),

Siemens had updated the ACS-Lite control software, which are currently under testing/validation.

2. After deploying ACS-Lite, delays at Albany Shaker intersection increased dramatically, while delays at the other intersections decreased slightly. In addition, travel times of the corridor only changed slightly with smaller speed variations, indicating the traffic was slower but smoother after the deployment of adaptive control. The fuel consumption increased slightly, while emissions were decreased slightly.

3. The benefit/cost analysis, without considering the boundary intersections (Albany Shaker Road and Old Wolf Road), showed that in about 15 years, the potential benefits will overcome the total project cost, including both NYSDOT project cost and the cost share of RPI and industry partners. If only NYSDOT cost is concerned, this would be reduced to about 8 years.

4. For a heavily congested corridor (such as the Wolf Road corridor), adaptive control can potentially improve traffic flow within its own system. However, this may be achieved by "metering" (i.e., restricting) flow into the system, thereby generating large delays/problems at the boundary intersections, e.g., the Albany Shaker intersection in the Wolf Road corridor. This side-effect would depend on the specific adaptive control system as well as the actual traffic conditions of the corridor system.

5. The evaluation results, especially the delay changes at Albany-Shaker Road and the other intersections, seem to suggest that in order to solve the congestion and related issues for Wolf Road, a large network may need to be considered. For instance, the nearby freeways (I-87) and arterials (such as Route 5 (Central Ave), Route 151 (Albany-Shaker Road), Route 155, in addition to Sand Creek Road) may also need to be considered; see Figure 5.44 below for an illustration of such a larger network. In this figure, the blue lines indicate the scope of the current Wolf Road project, while the dashed red line outlines the expanded, larger network. In such an extended network, the coordination between the freeway and arterials can be investigated in a more holistic manner. Other advanced strategies such as traveler information or route diversion can also be explored. This leads to the integrated corridor management (ICM) approach to better manage congested

corridors. This ICM-based approach may be pursued in the future to develop more effective methods to manage congestion and related issues of the Wolf Road corridor.

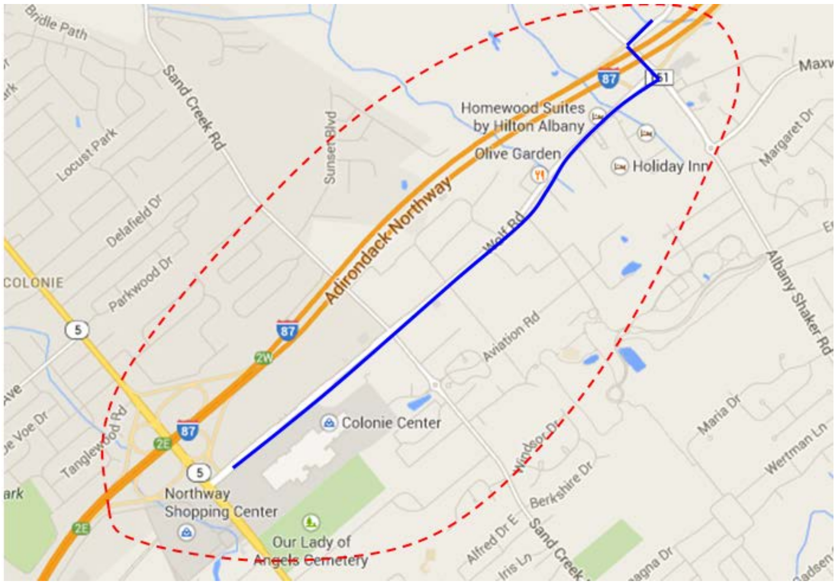


Figure 5.44: An ICM approach for Wolf Road corridor

6. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research project was to deploy and evaluate the ACS-Lite adaptive traffic control system on a congested urban corridor in New York State (NYS). In this case the Wolf Road Corridor in the Albany, NY, area was chosen. The main goal of the project was to document the experiences and key lessons learned from the deployment and evaluation regarding how an adaptive control system can be deployed, whether the system is beneficial, and whether it is suitable for other corridors in the State. Since this was the first deployment of an ACS-Lite system in NYS, it was expected that the deployment may experience more issues and/or delays than installing control systems that have already been widely used in the State.

6.1 Overall Assessment of the Project and Summary of Issues

This NYSDOT-funded project was a collaboration between RPI and industry partners including Siemens, Sensys Networks, and Annese & Associates. CCNY also provided in-kind support to the project. The project started in April, 2012, and was completed by September, 2014. The total project cost was $569,823, including $300,354 from NYSDOT, and $269,469 cost match from RPI and the industry partners. The project team was able to successfully deploy (i) the communication devices and systems along the corridor; (ii) the Sensys detection system for traffic volumes and arterial travel times, as well as its data transmission and collection system (i.e., access points, repeaters, among others); (iii) the ACS-Lite signal control system including the field server and control software. Throughout the deployment of ACS-Lite and vehicle detection systems, NYSDOT was very proactive. Overall, the project team and NYSDOT worked together well to resolve all the concerns, and the communications between RPI and NYSDOT have been very smooth. This can be seen by the industry partners' commitments to improve their systems based on NYSDOT's forward thinking in deploying advanced vehicle detection and traffic signal control systems.

With the exception of some communication issues at the beginning of the project and hardware (firewall) problems in the middle of the project, the communication systems have worked as expected and the experienced issues were resolved promptly by the project team. The Sensys detection system also performed as expected, with minor issues that were resolved quickly by Sensys. These issues included detector malfunctioning, discrepancies of Sensys detector volume with manual counts when traffic volumes were very low, and differences between the Sensys travel times and GPS probe travel times when traffic was congested. Sensys was also able to inform the project team in advance that such discrepancies may exist due to the way data was collected or how the algorithm worked. At the beginning of the project, Siemens promised to provide the ACS-Lite control software that would work for the Wolf Road Corridor. However, as the project proceeded, a number of issues were revealed, mainly caused by the incompatibility of the original version of the ACS-Lite software and the controllers on the Wolf Road Corridor (see more details later in this section). Siemens was able to provide proper support for field investigation and communication with NYSDOT and RPI regarding these issues, however, resolving them took longer than expected. Because of these and other related concerns, ACS-Lite was turned off in mid-December, 2013. On March 26, 2014, the ACS-Lite system was turned on again on the Wolf Road Corridor, except for the Albany-Shaker and Old Wolf Road intersections due to the flashing problem at the Albany-Shaker intersection. To a large extent, these ACS-Lite software-related issues are the main reason for the delay experienced in the project. The specific ACS-Lite related issues are summarized as follows:

1. Controller software (SEPAC) was incompatible with the controllers and timing plans on the Wolf Road corridor;

2. There were I/O mapping issues that required extensive software development and upgrade, which delayed the project significantly;

3. The original version of ACS-Lite could not accommodate advanced pedestrian options, which are required by the Albany-Shaker intersection;

4. Because the current Siemens version of ACS-Lite can’t modify the cycle time to meet traffic demands, initially the Sand Creek intersection was configured to run a fixed half-cycle. This caused complaints from the public for excessively long delays especially for left turn lanes; and

5. There was a software problem which caused the signal at the Albany Shaker intersection to go into flashing mode when transitioning to ACS-Lite.

Siemens conducted extensive software development and upgrade, and was able to fix most of the above issues, except the last one. This flashing problem did not happen during the after data collection (in mid-October 2013). The problem was noted in November 2013, after which, Siemens worked on fixing it. Siemens updated the ACS-Lite control software, which are currently under testing and validation.

6.2 Major Findings

1. Volume data produced by Sensys detectors matched fairly well with field observations with minor issues when the traffic volume was very low. Similarly, travel times produced by the Sensys travel time system matched fairly well with the GPS probe data, with minor issues when the traffic was very congested.

2. After deploying ACS-Lite, delays at the Albany Shaker intersection increased dramatically, while delays at the other intersections decreased slightly. In addition, travel times of the corridor only changed slightly with smaller speed variations, indicating the traffic was smoother after the deployment of adaptive control. The fuel consumption was increased slightly, while emissions were decreased slightly. The benefit/cost analysis, without considering the boundary intersections (Albany Shaker Road and Old Wolf Road), showed that in about 15 years, the potential benefits will overcome the total project cost, including both NYSDOT project cost and the cost share of RPI and industry partners. If only NYSDOT cost is concerned, this would be reduced to about 8 years. One should be cautioned, however, to interpret and use these numbers since the benefits or costs of deploying ACS-Lite are relatively small. Thus, any estimation errors in the analysis could result in different numbers or even opposite conclusions.

3. The research results indicate that for a heavily congested corridor (such as the Wolf Road Corridor), adaptive control can potentially improve traffic flow within its own system. However, this may be achieved by “metering” (i.e., restricting) flow into the system, thereby generating large delays/problems at the boundary intersections, e.g., the Albany Shaker intersection in the Wolf Road corridor. Obviously, this metering effect would also depend on the specific adaptive control system as well as the actual traffic conditions of the corridor system.

4. Overall, this research project was successfully conducted, under the collaboration of NYSDOT, RPI, and the industry partners, although the actual performance of ACS-Lite

on the Wolf Road Corridor is mixed, as summarized above. The performance of ACS-Lite in this specific case should not be considered as an indication of its performance on other corridors in general, or taken as a discouragement regarding proactive evaluation/ deployment of advanced traffic/transportation control/management technologies, in this case, the adaptive traffic control. As shown in the benefit/cost analysis section of this report, if the boundary intersection issue can be properly handled (e.g., using the ICM-based approach on a larger network), adaptive control does benefit the system as a whole and the cost can be offset by the benefit in a few years (if only NYSDOT cost is considered). Therefore, earlier deployment of certain advanced technologies to NYS corridors will benefit more of the traffic in the State. To do so, research projects, similar to what has been done in this project, are crucial to document experiences and lessons learned, and further to produce specific guidelines on how such technologies can be best deployed and when/where they should be deployed to achieve the most benefits. Such research projects are expected to experience more issues, and sometimes delays, due to their unique exploration nature. In fact, the project team is currently working on a research project with NYSDOT and NYSERDA on whether and how adaptive control should be deployed in NYS corridors. The findings in that project will provide very useful insight in this regard.

7. STATEMENT ON IMPLEMENTATION

The research methods, results, and findings of this project can be communicated with managers and engineers at transportation agencies in NYS as well as other states in the United States to provide insight about adaptive traffic signal control. These findings can be used to help decision makers when implementing adaptive control related projects in NYS. The project team may also summarize main research methods and results of the project and present and/or publish them in professional conferences and as journals articles. To resolve the remaining issues of the Wolf Road Corridor, certain implementation steps, based on the findings of this project, can be summarized as follows:

1. The evaluation results, especially the delay changes at Albany-Shaker Road and the other intersections, seem to suggest that in order to solve the congestion and related issues for Wolf Road, a large network may need to be considered. For instance, the nearby freeways (I-87) and arterials (such as Route 5 (Central Ave), Route 151 (Albany-Shaker Road), Route 155, in addition to Sand Creek Road) may also need to be considered; see an example of the extended network in Figure 5.44. In such an extended network, the coordination between the freeway and arterials can be investigated in a more holistic manner. Other advanced strategies, such as traveler information or route diversion, can also be explored. This leads to the integrated corridor management (ICM) approach to better manage congested corridors. The ICM-based approach may be pursued in the future to develop more effective methods to manage congestion and related issues of the Wolf Road Corridor.

2. NYSDOT has had a well-established and well-conducted procedure to test/evaluate /deploy new control systems/technologies. Before their deployment, Sensys detectors and ACS-Lite system have been extensively tested in the Traffic Lab. Many issues had been identified and resolved before the field deployment. However, this project indicated that real world field testing/deployment of such new systems/technologies may also be needed. This is particularly true for certain rare issues that may not be easily reproduced in lab testing, such as the flashing issue at the Albany-Shaker intersection. It is thus recommended that NYSDOT ask technology providers to field demonstrate their product and to resolve problems/issues before the technology can be formally deployed in NYS

corridors. In fact, NYSDOT field-tested the Sensys detectors in Utica, NY, and resolved a few issues (such as those related to very low temperature in winter time) before the Wolf Road project. This also proves the importance of field testing of new technologies before their formal deployment in NYS.

3. To do the field demonstration, a demo site or corridor may be constructed and maintained. Such a demo site should be well-equipped with detection systems and communication capabilities, and be well-maintained and continuously monitored. The site should also be well studied in terms of traffic flow patterns, performances, and potential issues. This demo site will then become a living laboratory for NYSDOT to test and evaluate advanced technologies that may have great potential to solve congestion and related issues of the traffic in NYS. However, one should be cautioned to test certain traffic control technologies or systems since they may interfere with traffic significantly. Testing other technologies and systems, such as those for communications, sensing/detection, and data collection should be easily conducted since they normally do not interfere much with traffic flow.

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