ITS RESOURCE CENTER

NJIT
New Jersey Institute
of Technology

Activity 2:
ITS Technology Evaluation and Pilot Deployment

Development of Hardware-in-the-Loop-Simulation (HILS) Environment for Adaptive Traffic Control System

Final Report

Prepared for

State of New Jersey
Department of Transportation

December 2016

ITS Resource Center | NJIT

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STATE OF NEW JERSEY
Department of Transportation

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Executive Summary

This report documents the development of Hardware-in-the-loop simulation (HILS) that has been conducted by New Jersey Institute of Technology (NJIT). Many successful methods to evaluate different signal control procedures exist in the state-of-the-practice. Over the past few decades macroscopic models, microscopic simulation models, or structured observation of field deployment were most frequently used methods. HILS is a type of real-time simulation technique that is used to test how a field component (e.g., a signal controller) responds to realistic or virtual stimuli and whether a physical system model is valid. The simplest signalized intersection HILS framework includes a host computer running the simulation software, controller Interface devices (CID), and a signal controller. The described setup allows an evaluation of a wide variety of scenarios using simulated traffic streams with no exposure of the system to the actual traffic stream.

To properly establish a realistic representation of the road and traffic characteristics, a microscopic traffic simulation package, VISSIM is used. To develop high-fidelity simulation model, extensive calibration efforts have been performed by using field data (e.g., intersection turning movement, travel time) collected from a US-1 segment from Harrison St. to Carnegie Blvd in West Windsor, NJ. A total of four Econolite Cobalt ATC controllers were used in this project with each intersection being controlled by its own controller. Vehicle detection and signal status messages are exchanged between the traffic simulation software and signal controller through an adequate controller interface device (CID). Vehicle actuation signals that are coming from the VISSIM detectors are transferred through CID where they are converted into analog signals readable by the traffic controller.

A side by side comparison of the base-case traffic control observed in the field and Centracs was conducted. The base-case signal operation was simulated using historical signal change data obtained during the data collection process. The signal timing setting for Centracs (e.g. cycle, split, offset, etc.) were assigned according to the parameters used in the field. The Centracs signal control system achieved lower delay and number of stops. The cumulative reduction in delay of up to 400 seconds was observed on the northbound of the US 1 and Harrison Street Intersection. Similar delay reduction was observed for the US1 at Fisher Place intersection. The southbound approach had approximately 150 seconds of the delay reduction, and northbound had up to 100 seconds reduced delay for the whole simulation period. Similar benefits of the Centracs adaptive system were detected for the US 1 and Washington Street, and US1 and Carnegie Boulevard. Detailed simulation results, including mentioned measures of effectiveness such as delay and number of stops are provided in the results section of this report.

Using the HILS environment, it is possible to test the traffic control system with immediate exposure to different traffic conditions that usually occur for only a few hours during the day. Another very useful capability of the HILS is that it allows for repetition of the experiments, which

produces better accuracy and statistical significance of the test. PTV VISSIM microsimulation software offers development of the testbed that has the identical road and infrastructure geometry as the observed location, thus providing opportunity for the system validation and verification without affecting road users and pedestrians. The HILS system described in this project has a capability of incorporating different controllers and different adaptive algorithm types. Combination of Centracs and Cobalt controllers represent just one out of many possibilities that can be used to establish adaptive signal control. NIATT's Controller Interface Device (CID) gives the traffic engineer the opportunity to test any signal-timing plan that can be operated with either a NEMA or 170 traffic controllers, making HILS manufacturer and adaptive software independent.

1. Introduction

1.1. Background

Many successful methods to evaluate different signal control procedures exist in the state-of-the-practice. Over the past few decades macroscopic models, microscopic simulation models, or structured observation of field deployment were most frequently used methods [1]. Macroscopic models such as Transyt and Passer have been frequently used by many practitioners to obtain optimal setup for the fixed-timing system [2]. While similar macroscopic models exist for actuated-coordinated systems, some agencies prefer direct modification of the signal timings in the field to observe the effectiveness of the chosen modification. Although such methods can produce adequate results, especially for parameters such as offset and split [1], certain risks of producing unwanted situations such as significant drop of level of service or grid-lock might occur during the process.

Hardware-in-the-loop simulation (HILS) is a type of real-time simulation technique which is used to test how a field component (e.g., a signal controller) responds to realistic or virtual stimuli and whether a physical system model is valid [*2*] . This technique has been used in various disciplines, such as automotive systems design and testing [3] in automotive engineering, jet engine development [4] in aerospace engineering, power delivery systems [5] in electrical engineering and control systems, [6] in marine engineering. HILS can enhance the testing quality of the simulation by enabling the researcher to expand the testing scope, to the realm where testing could be deemed unsafe, particularly for test operators (e.g. vehicle brake failure, engine failure during a flight test).

HILS has its roots in aviation industry. Beside aeronautical applications it is also used in the development process of medical devices, industrial machines, aerospace systems, automotive devices and many other embedded control systems where the real-world testing is associated with significant costs and safety risks. Putting it in a transportation engineering context, HILS for signalized transportation network is conducted by replacing signal controller emulators in the simulation with corresponding physical hardware (e.g., the actual controller that is ready for deployment in the roadside cabinet). The simplest signalized intersection HILS framework includes a host computer running the simulation software, controller Interface devices (CID), and a signal controller. The described setup allows an evaluation of a wide variety of scenarios using simulated traffic streams with no exposure of the system to the actual traffic stream. Figure 1 describes a concept of HILS for traffic control analysis. Vehicle calls from the simulated traffic are sent through software interface and converted into electrical signal using CID. The electrical signal is recognized as a vehicle call inside of the controller and change in signal status is sent back to simulation software through the same CID device. Since vehicles from the simulated traffic stream respond to signal changes, the whole process is a realistic representation of the real-world traffic control system.

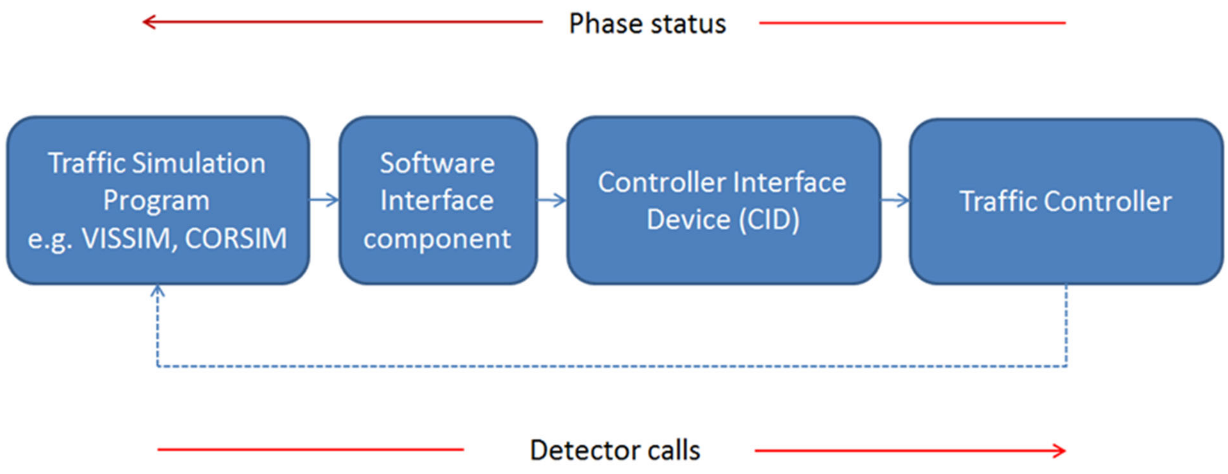


Figure 1. Conceptual HILS Framework

1.2. HILS Applications in Transportation

According to Stevanovic et al. [6], there are three ways to conduct advanced controller operation analysis: emulator-in-the-loop simulation (EILS), software-in-the-loop simulation (SILS), and hardware-in-the-loop simulation (HILS). EILS is based on an internal module of a typical simulation program. For instance, VISSIM [7], a microscopic simulation software developed by PTV, has its internal emulator for signal operations during the simulation. The emulator is based on NEMA standards. During each simulation second, the status of the detectors and the signal head is passed to the emulator, which then returns the signal head status for the next simulation second. Since the emulator is part of the overall simulation package, its speed is quick and the setup is easy, not to mention the seamless coordination it has with the traffic simulation model. Despite the fact that microscopic simulation has evolved over the past decades, it remains inadequate to deliver the level of sophistication and verity of control operation as an actual controller.

Differing from EILS, SILS uses a standalone virtual controller that is external to the simulation software to conduct the simulation. A virtual controller interface is typically developed to display the information (e.g., signal head phase, remaining green time) which is being exchanged. In the MOST Project [8], PTV America, in partnership with Econolite Control Product and the University of Idaho, have developed a ASC/3 controller software for SILS [9]. The controller software runs nearly identical to that of its ASC/3 hardware counterpart. The controller software can run signal timing either faster or slower than real time. Nonetheless, the ASC/3 software still lacks some features of a physical controller (e.g. communication capability within a field cabinet or within a centralized traffic signal system) [10].

HILS is a real-time system where the traffic simulation software sends detector information to a physical controller and executes a retrieve phase during each simulation second [11] through CID. The CID assumes the role of interfacing between the hardware controller and the simulation software via electrical signals. Both SILS and HILS can be considered as real-time systems which are classified based on failure tolerance (i.e. failure to meet the deadline). The timing constraints of a real-time system can be divided into hard temporal constraints and soft temporal constraints. HILS is considered as a soft temporal constrained real-time system, because an occasional missed deadline should not cause the simulation to fail completely. It may, however, affect some measure of effectiveness (MOE). Bullock et al. [12] proposed a HILS framework which was comprised of a CID, a microscopic simulation engine (i.e. CORSIM), and a software interface module providing the linkage between the CID and the microscopic simulation software. Technical issues pertaining to HILS were discussed, including task scheduling, assessment of real-time simulation error, and result comparisons between CORSIM emulator and HILS.

1.3. Project Goals and Objectives

The primary purpose of this research is to develop a HILS system that allows real-time assessment of complex traffic control systems using high-end signal controllers and traffic management tools. Capabilities of the developed system will enable the investigation of actuated-coordinated, traffic-responsive, and adaptive signal controls without exposure of the system to the real traffic, which eliminates disruption of the traffic streams and costs associated with such procedure. The following goals and objectives are established to conduct this research:

Goals:

- Evaluate the effectiveness of different signalization setups using microsimulation to replace the real-world traffic conditions.
- Obtain high-fidelity field data, such as traffic volumes and speeds for the selected location and time of the day, to successfully replicate traffic stream conditions for the simulated environment.

Objectives:

- Select a signalized arterial in New Jersey as a test-bed for the Hardware-in-the-Loop Simulation
- Develop a microsimulation platform for a selected test-bed using PTV VISSIM while incorporating the existing network geometry and signalization setup.
- Collect relevant volume, speed, and signalization data to accurately replicate real-world conditions under the HILS environment.

- Conduct model calibration using traffic speed data obtained from probe-vehicles and Bluetooth sensors deployed in the field.
- Configure hardware components and evaluate performance measures for different evaluation scenarios.

2. Methodology

Task 1 addresses simulation model development. To properly establish a realistic representation of the road and traffic characteristics, high-end simulation software such as PTV VISSIM is used. Data collection is necessary for the accurate system evaluation and will be described in the next section of this report. Calibration was also conducted in order to fine tune the model using high-fidelity data sources collected from the project location. Development of the HILS system includes controller configuration where all necessary controller parameters were adjusted corresponding to those observed deployed in the field. Integration of the model was performed on a Windows platform, where the software serves as a bridge between the microsimulation model and external hardware devices. Communication equipment utilized TCP/IP communication protocol, and a static IP address was assigned to each controller, making it permanently accessible during the simulation. ATCS software can be added as a separate component, and can utilize the same TCP/IP protocol to establish connection with controllers. The ATCS algorithm has the highest priority in the system, and has the ability to readjust controller settings to achieve greater system efficiency. The overall methodology framework is illustrated in Figure 2 below.

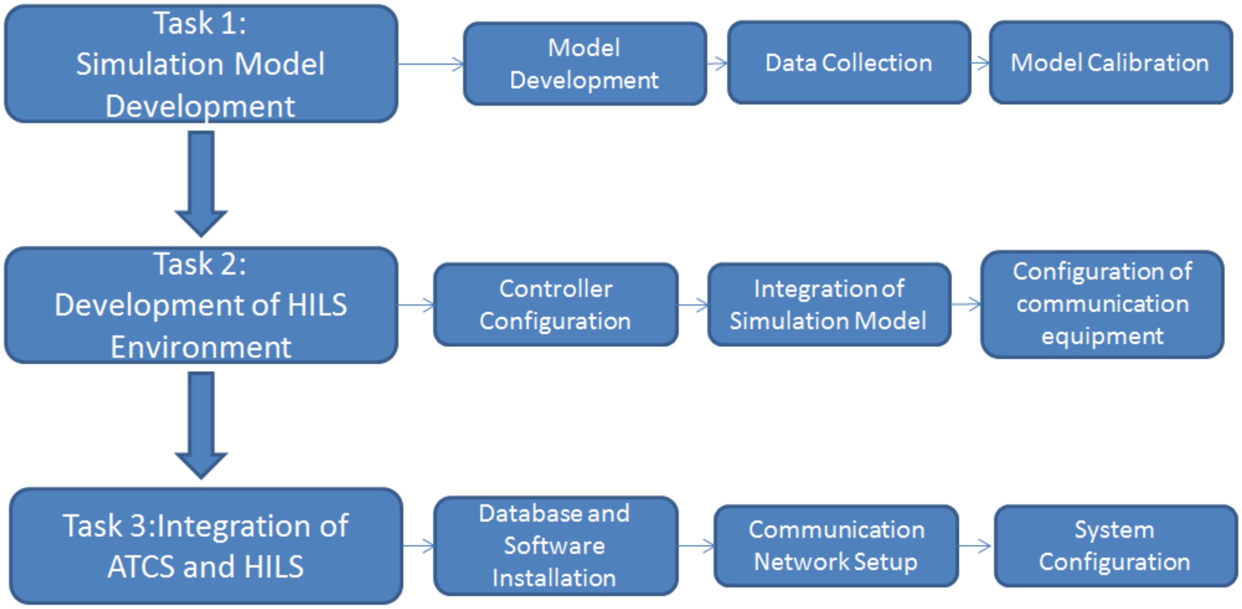


Figure 2. Overall Methodology Framework

2.1. Task 1: Simulation Model Development and Calibration

2.1.1. Spatial and Temporal Scope for Simulation Model

The simulation model replicates a typical mid-day and PM-peak period traffic situation. The VISSIM simulation model was developed for a section of US 1 in New Jersey initially selected for the analysis. This section includes the following signalized intersections: US 1 @ Carnegie Center Boulevard (MP 10.0), US 1 @ Washington Road (MP 11.27), US 1 at Fisher Place (MP 11.38), and US 1 @ Harrison Street (MP 11.83). The microsimulation model for this section of US 1 was developed for both off-peak and PM peak periods. The PM peak model includes a three-hour period from 4:00 PM to 7:00 PM and the off-peak period covers another three hours from 1:00 PM to 4:00 PM. The data collection location is presented in Figure 1 below.

2.1.2. Data Collection

Data collection was conducted considering three particular goals:

- To obtain volume data for the microsimulation model using video records from the traffic signal image detector for capturing turning movement counts.
- Obtain mid-block traffic volumes using Wavetronix radar detectors provided by NJDOT
- Obtain prevailing travel time data using a combination of floating car methods using GPS loggers, Bluetooth and WiFi detectors installed along the corridor.

Turning movement data was determined by conducting manual counts of the traffic flow as recorded from the traffic signal image detectors. The video records covered all four approaches (i.e. NB, SB, WB, and EB) for all four intersections described above. Traffic counting was conducted in 5-minute intervals to ensure appropriate input for the VISSIM microsimulation model. The floating car assessment was conducted using 5 vehicles equipped with GPS loggers that were dispatched from the staging area in the near proximity of the project location. The data collection headway was maintained throughout the whole data collection period with the help of a dispatcher located at the staging area who was equipped with a stopwatch. All headway irregularities detected by the dispatcher were mitigated by stopping vehicles that were running faster than the predetermined headway of 2 minutes, and returning them back to the road after the correct headway was established again. This provided a high-density speed data for the observed period with an adequately balanced headway. Bluetooth and WiFi sensors were deployed as illustrated in Figure 4 below. All device pairs ensured detection of vehicles at the beginning and the end-point of each mid-block section of the corridor, thus providing an entering and exiting timestamp for each covered section of the road.

2.1.3. Model Calibration

The VISSIM simulation model was developed and calibrated using multiple traffic counts and travel time data sources described in the previous section. The developed simulation model was calibrated and fine-tuned to represent the actual field conditions. In this project, travel time was selected as an index of comparison. The field travel time data obtained from GPS equipped probe vehicles was used as ground truth travel time. VISSIM provides a possibility of using 25 different variables for the purpose of calibration; however, the number of combinations for the 25 parameters is enormous. Therefore, the research team applied the Quasi Monte Carlo (QMC) algorithm to reduce the number of combinations down to a reasonable level. After multiple simulation runs were conducted using QMC based parameter sets, the parameter values were calibrated and selected as illustrated in Table 1 below.

Table 1. Calibrated Parameter Values

Variable Name	Value
Accepted deceleration (own)	-0.58
Accepted deceleration (trailing vehicle)	-7.48
Amber behavior alpha	1.51
Amber behavior beta 1	-0.26
Amber behavior beta 2	0.68
Maximum cooperative deceleration	-11.37
Deceleration reduction distance (own)	171.47
Deceleration reduction distance (trailing vehicle)	329.16
Look ahead distance (maximum)	268.65
Look ahead distance (minimum)	251.69
Look back distance (maximum)	405.13
Look back distance (minimum)	89.17
Maximum deceleration (own)	-3.97
Maximum deceleration (trailing vehicle)	-8.54
Minimum headway	2.00
Safety distance reduction factor (lane change)	0.48
Safety distance reduction factor (signals)	0.32
Safety distance reduction factor end (signals)	194.46
Safety distance reduction factor start (signals)	215.53
Temporary lack of attention - sleep duration	1.37
Temporary lack of attention - sleep probability	0.13
W74ax: Average standstill distance (Wiedemann 74)	3.61
W74bxAdd: Additive factor for security distance	4.09
W74bxMult: Multiplicative factor for security distance	2.34
Desired Speed Distribution Number	2.10

The travel time results obtained from the calibrated VISSIM model were compared again to the ground truth travel times. In Figure 3, the mean travel time of VISSIM and ground truth was 315.1 sec and 275.51 sec, respectively, for the entire Northbound segments, while the mean travel time of VISSIM and ground truth was 300.2 sec and 317.5 sec, respectively, for the entire Southbound segments.

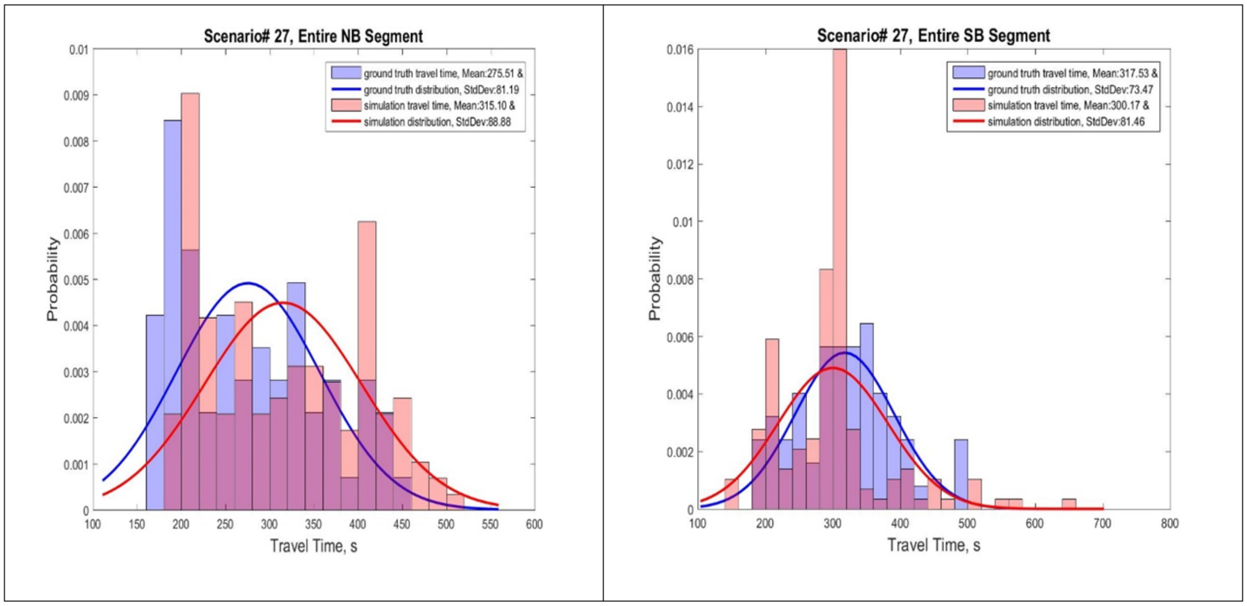


Figure 3. Travel Time Distribution comparison between VISSIM and Ground Truth Data

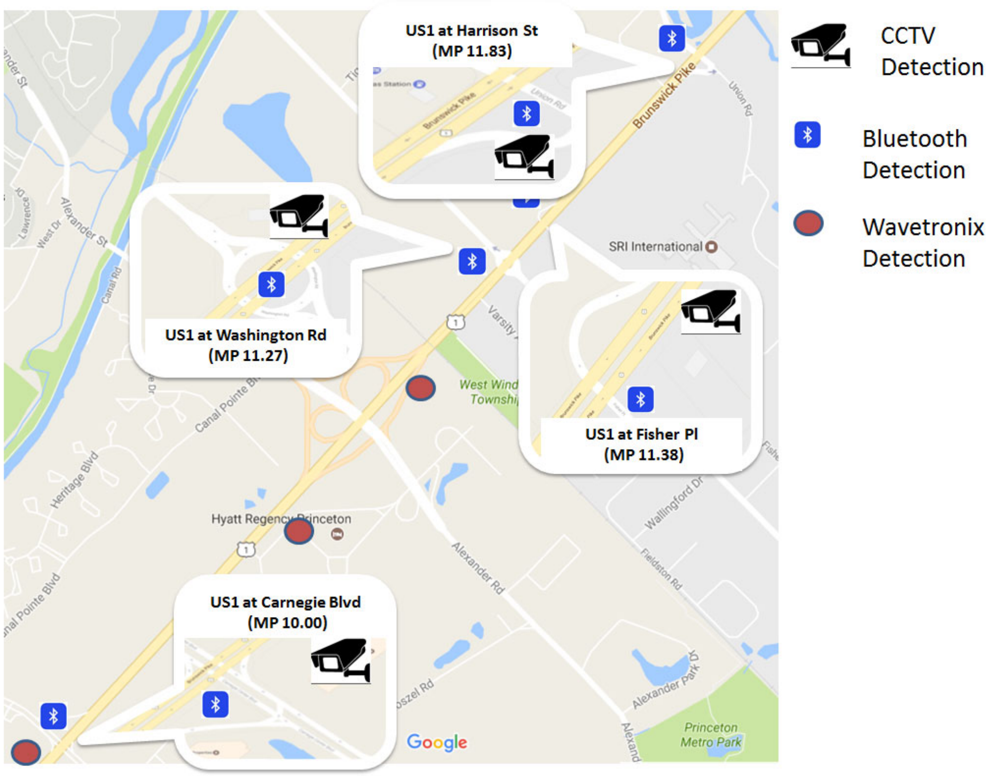


Figure 4. Data Collection Area on US 1 (From Harrison St to Carnegie Blvd)

2.1.4. Network Coding

A network coding task was performed using PTV VISSIM 8.00 and the following features were added to replicate the real world conditions:

Table 2. Network Coding Procedure in PTV VISSIM

VISSIM Function	Network coding task
Signal Control	VAP based signal control Lane based detectors
Speed limit	Desired speed areas Assign priority rules
Network adjustment	Link-link connectivity Adding shape points to better match background
Data input	5 minute volume rates Turning movement assignment Vehicle composition (% HV, passenger cars, buses)

The high fidelity volume inputs obtained during the data collection effort were entered into VISSIM microsimulation models with 5-minute intervals. To adequately incorporate turning movements, the VISSIM static routing decision feature was utilized with the same 5-minute update interval. All the intersection movements were considered in the same fashion as it was observed in the field since intersection movements in VISSIM consider vehicle route decisions for every possible movement of the intersection. Video files collected in field allowed the vehicle route probabilities to be determined precisely and with respect to that, the simulation updated vehicle routing probabilities with corresponding volume rates using five-minute intervals. Lane based detectors were added in the exact manner they are installed at the project location and an adequate detector-to-controller assignment was maintained in the model. This is extremely important as detector to controller assignment is one of the key features for the adaptive system setup which will be described in greater detail later in this report. Priority rules were added at sections of the network where stop or yield signs were present, and signal head distribution matches the real world conditions. This feature ensures that the simulation-based traffic flows correspond to realistic traffic flows in the field. To exchange signal control messages with HILS devices the VISSIM Vehicle Actuated Programming (VAP) was utilized. This whole information exchange process will be described in more detail in the next section of this report.

2.2. Task 2: Development of the HILS Environment

Hardware in the loop simulation (HILS) very reliably mimics the operations of the controllers installed in the field. Propagation and data transmission delays are negligible for this system which allows real time simulation and adequate synchronization. A real time interface between PTV VISSIM traffic simulation and NEMA TS2 traffic controller results in more realistic simulations compared to the generic model embedded in the simulation program. A common feature of HILS systems is that they are developed to optimize certain system measures of effectiveness (MOE) without affecting traffic streams on roadways. Vehicle detection and signal status messages are exchanged between the traffic simulation software and signal controller through an adequate controller interface device. Figure 5 shows an information exchange between a microsimulation computer and intersection control devices. Vehicle actuation signals that are coming from the VISSIM detectors are transferred through CID where they are converted into analog signals readable by the traffic controller. In the same fashion, signal status signals are transferred from the controller and processed by CID to be recognized by the VAP module and reflected in VISSIM. CID devices communicate with controllers through serial connection, and CID devices use USB interface to establish connection with the simulation computer.

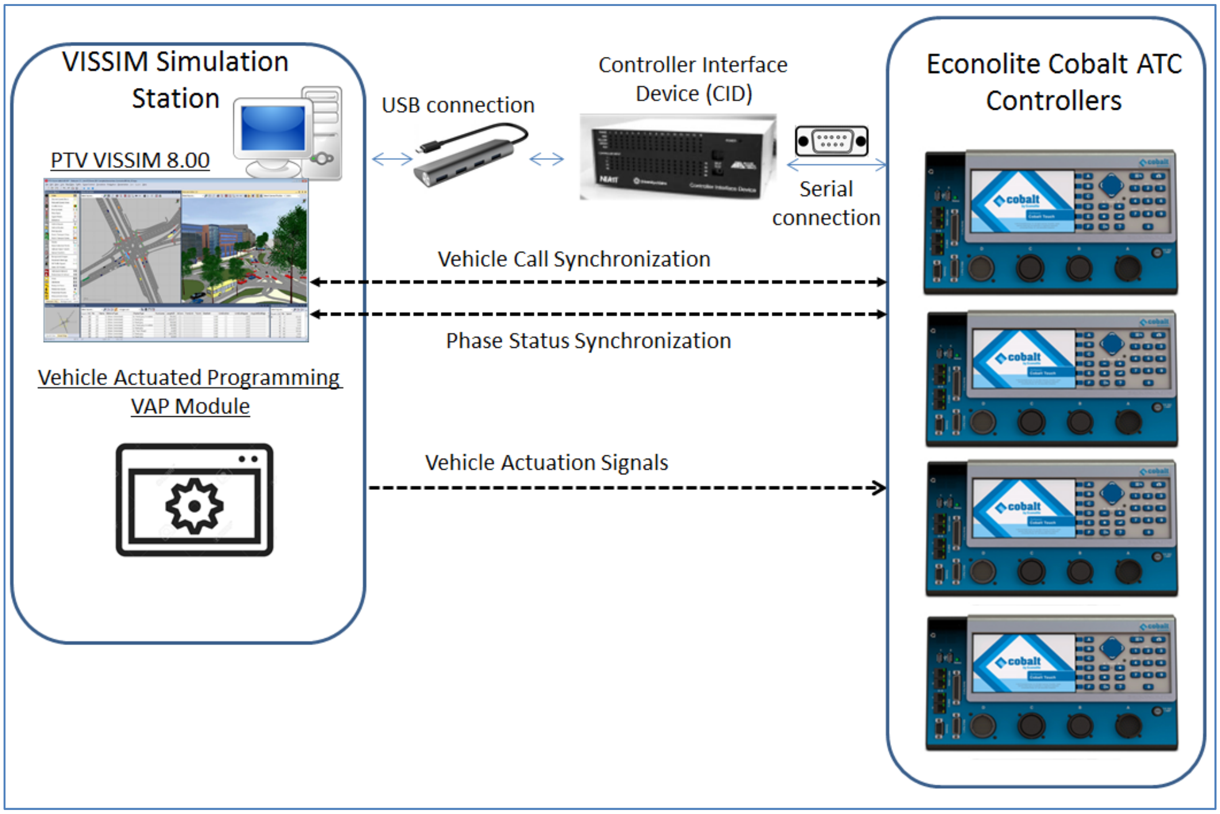


Figure 5. HILS system components

2.2.1. VISSIM Simulation Model

The microscopic simulation model is responsible for “moving” generated vehicles through a developed network following a known and scientifically approved kinematic model. Vehicle position is instantaneously recalculated at a predefined update frequency, also known as simulation speed. The simulation speed used in this process is setup as 1 simulation second per second of time, which allows real time synchronization of the microsimulation model and signal controller. Vehicle acceleration is recalculated in response to signal indications obtained from the CID and adjacent vehicles in the network. As presented earlier, traffic volumes and turning movements were determined during the data collection process and were adequately replicated in the PTV VISSIM microsimulation model. Appropriate detector states are updated during each simulation interval. Vehicle detection is obtained through presence detectors in VISSIM and vehicle detection signal is also transferred through CID and delivered to the controller where it is recognized as a call for the assigned signal phase. Each signal phase has a channel ID in VISSIM. The channel ID information is used by the Vehicle Actuated Programming Module (VAP) to properly establish the detector to controller assignment for the whole simulation network. This way, each detector provides a call for the assigned intersection controller it belongs to, and each signal head in VISSIM reflects the signal changes from the assigned TS2 intersection controller.

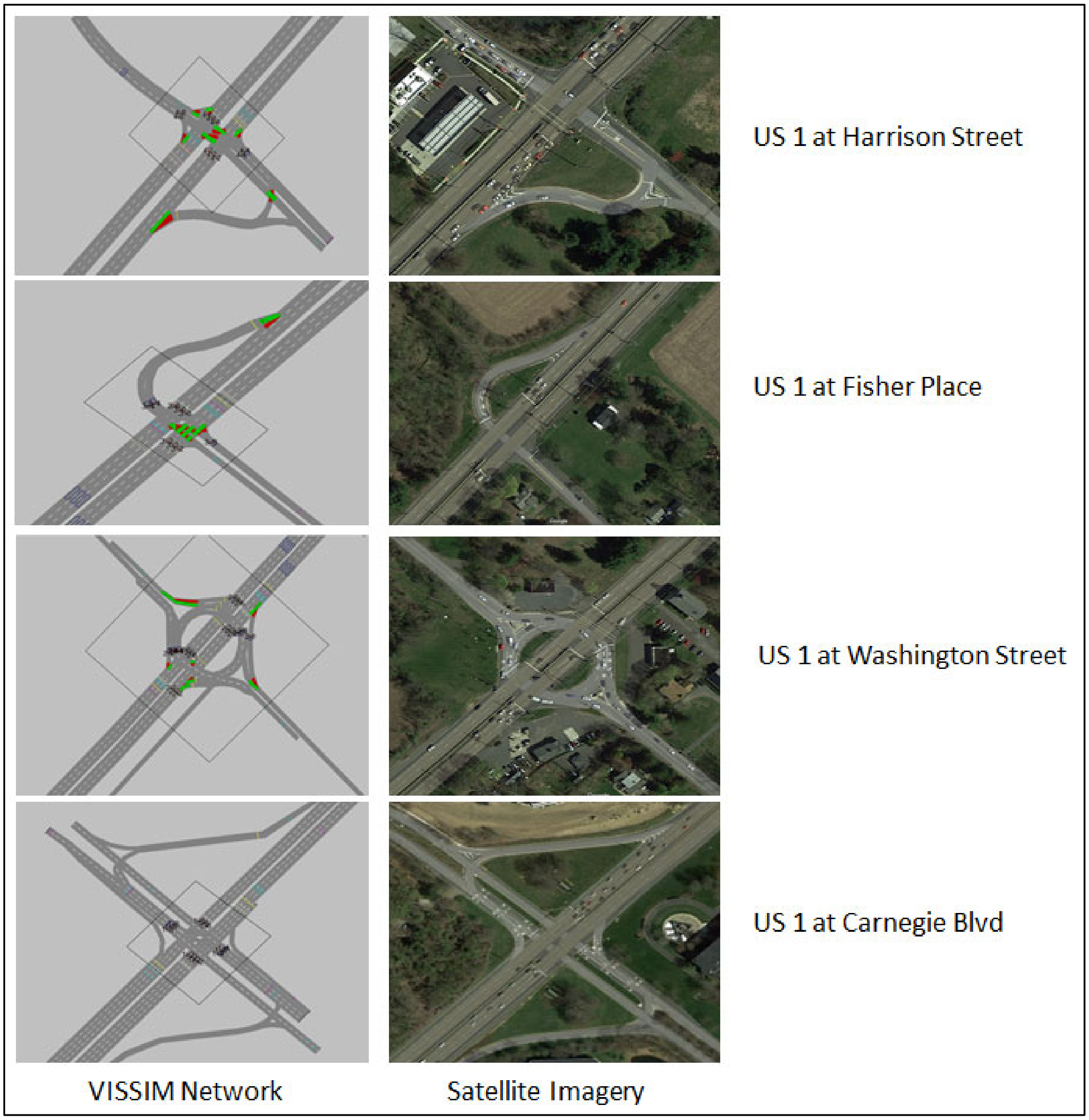


Figure 6. VISSIM Network for Observed Intersections on US 1

2.2.2. Controller Interface Device (CID)

The CID devices developed and produced by the National Institute for Advanced Transportation Technology (NIATT) (13) serves as a bridge between the simulation computer running the PTV VISSIM microsimulation program and the traffic controller. The main role of the CID is to transfer data from the computer to the traffic controller through traffic controller inputs, and it act as the interface between the traffic controller and the microsimulation computer. Once the traffic controller responds to the data received, the resulting control signals are transferred back to the microsimulation program on the computer. Since the whole setup runs in real time, the signal status and vehicle call are synchronized on both the controller and computer side as shown in Figure 7.

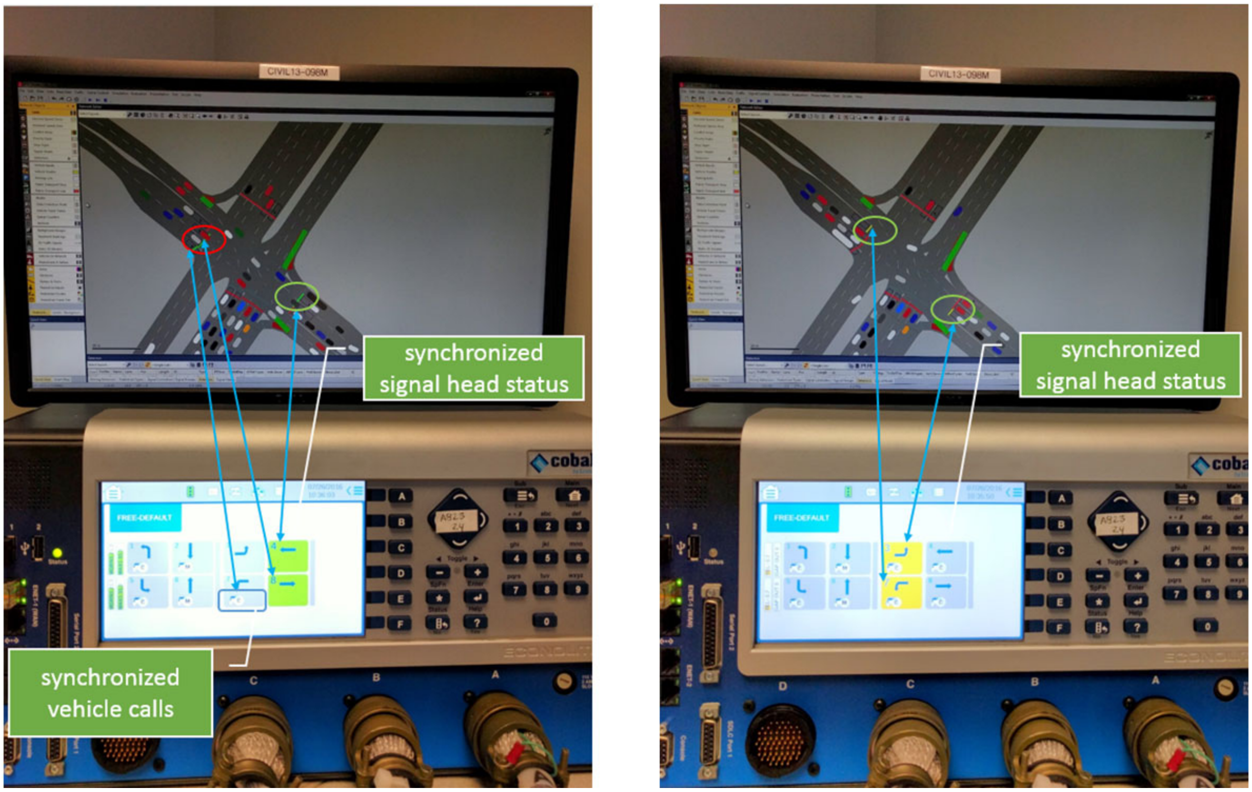


Figure 7. Synchronization between VISSIM and Econolite Cobalt

The CID can communicate with any NEMA TS2 controllers through a RS485 serial data line communication (SDLC) interface and has a separate power supply. There are three connectors on the CID side and three NEMA type TS2 compatible harness connectors on the controller side. The CID solution includes USB drivers for Windows, which provides easy system implementation with most microsimulation programs running on the Windows platform. This version of the CID has a total of 64 input-outputs, which provides high-level capabilities necessary for the large scale simulation tasks.

Figure 8. NIATT Controller Interface Device with Econolite Cobalt ATC Controller

2.2.3. Econolite Cobalt ATC Controllers

A total of four Econolite Cobalt ATC controllers were used in this project with each intersection being controlled by its own controller. The signal controllers communicate with Traffic Management Software and other controllers in the network over TCP/IP protocol. All the controllers are equipped with seven-inch touchscreen interfaces, allowing appropriate adjustment and monitoring of the device status. This version of the TS2 controller has a wide variety of features such as: preemption, coordination, detector configuration, data logging, time-base applications, and various signal status features. The controller can use the total of 16 phases, 8 concurrent groups in four timing rings and 16 pedestrian phases. The main feature of this controller type is that is supports ATCS implementation which will be described in the next section of this report.

2.3. Task 3: Integration of ATCS and HILS

To adequately integrate the HILS system described in the previous section with ATCS Software, all the controllers with assigned static IP addresses need to be connected using a communication switch. This allows data transfer between the ATCS database that is located on a separate server unit (Figure 9) and individual controller databases. When working in coordination or adaptive mode, this data transfer between the two databases runs continuously. Such a networking aspect of the system is used in the real world application for most of the ATCS solutions, and it allows the traffic management software to make changes on the controller settings while providing instantaneous monitoring of the system in real time. The Integrated Adaptive system developed at the NJIT research laboratory comprises four Cobalt controllers with corresponding CID boxes and it can be integrated with various types of traffic management software. The system layout is illustrated in Figure 11 and will be described in more detail in the next section of this report.

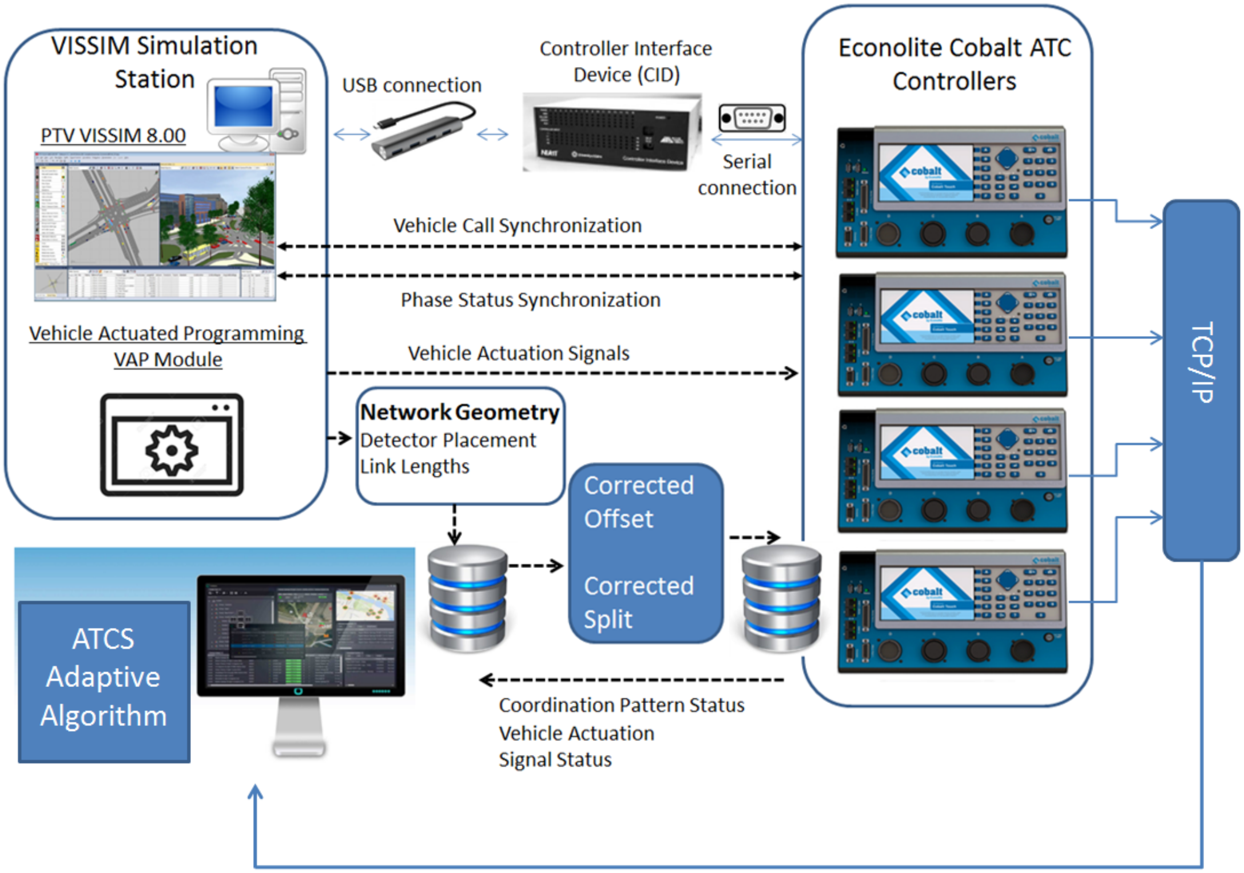
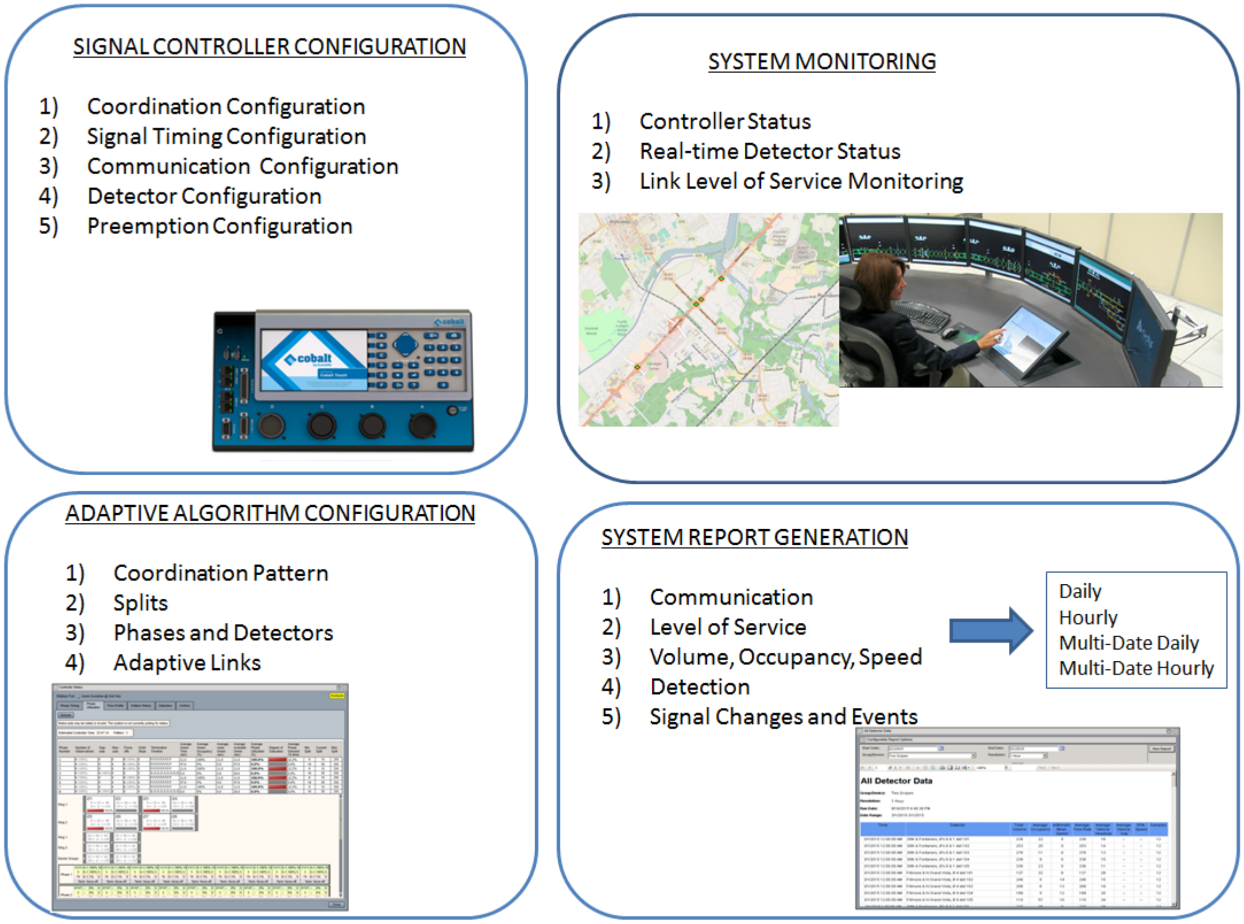


Figure 9. Overall System Architecture of HILS with Integrated ATCS module

2.3.1. Traffic Management Software

Typical traffic management software has four major components for the system configuration, monitoring, report generation, and adaptive algorithm configuration. The signal controller configuration can be conducted on both the software and controller (hardware) side. After the database synchronization is finished, all configuration changes are applied to both sides of the system. System monitoring is achieved through either the signal status or data logging interfaces and includes signal status, controller mode, synchronization status, and various data illustration graphs (e.g. occupancy, speed, volume for selected time period or update frequency). Report generation is usually conducted on an hourly, daily, and multi-date basis for different measures of effectiveness (MOEs), signal changes, and communication performance.



SIGNAL CONTROLLER CONFIGURATION

1) Coordination Configuration
2) Signal Timing Configuration
3) Communication Configuration
4) Detector Configuration
5) Preemption Configuration

SYSTEM MONITORING

1) Controller Status
2) Real-time Detector Status
3) Link Level of Service Monitoring

ADAPTIVE ALGORITHM CONFIGURATION

1) Coordination Pattern
2) Splits
3) Phases and Detectors
4) Adaptive Links

SYSTEM REPORT GENERATION

1) Communication
2) Level of Service
3) Volume, Occupancy, Speed
4) Detection
5) Signal Changes and Events

Daily
Hourly
Multi-Date Daily
Multi-Date Hourly

Figure 10. Centracs Adaptive System Features and Functions

3. Case Study

The methodology described in the previous section of this paper was applied for the Centracs Adaptive System implementation. The HILS system developed for evaluation of different traffic control technologies was utilized for this task.

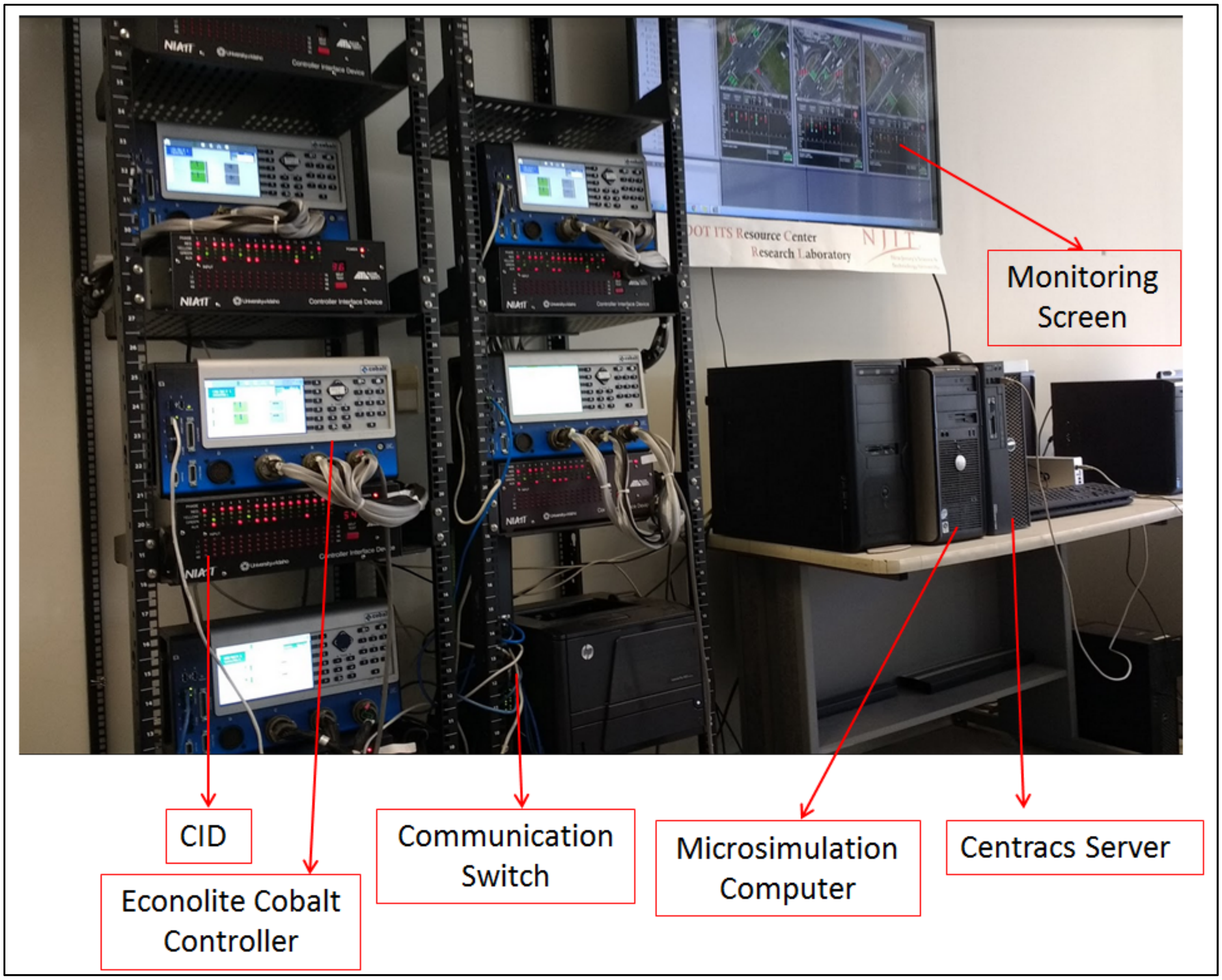


Figure 11. Integration of Centracs Adaptive and HILS system at NJIT Research Facility

During system integration at NJIT, the following tasks were completed:

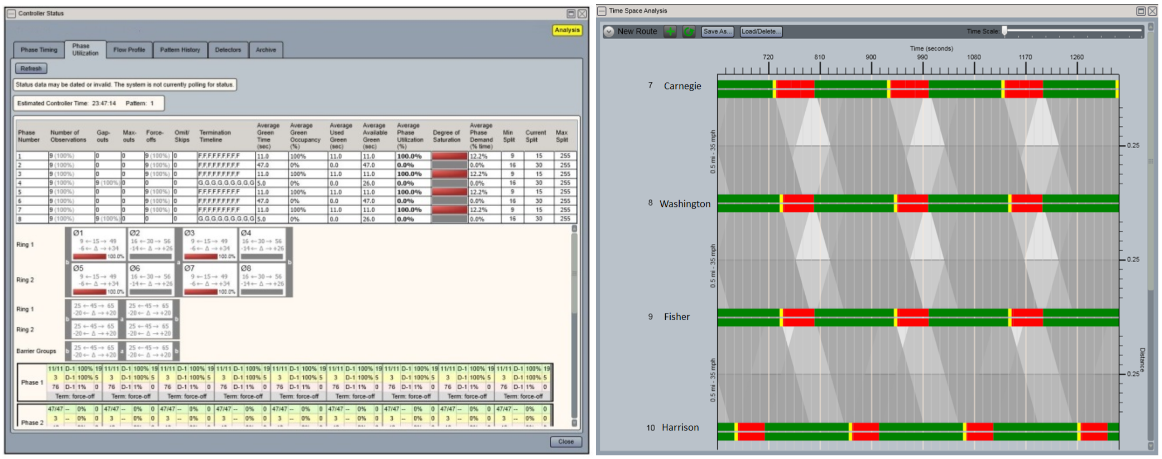
1. Centracs database and software installation
2. Configuration of the networking and communication protocols
3. System detector configuration and detector adjustment

4. Configuration of the controller coordination patterns and action plans
5. Road network geometry coding in Centracs (including controller to link and detector to link assignment, link lengths, detector placement)
6. Centracs Adaptive Algorithm configuration (verification of patterns, splits, and sequences)
7. Data logging and report generation adjustment

Figure 12. Screenshot of the Controller Real-Time Monitoring in Centracs

3.1. Centracs Adaptive Algorithm

An adaptive algorithm utilizes vehicle detection and road geometry data to provide a more efficient signal timing pattern. Some of the most frequently observed benefits are the ability of the system to adapt to unexpected changes in real-time traffic conditions, improvement in travel time reliability, keeping progression at all times of the day, reduction in congestion, and the improved effectiveness of traffic signal timing. The major goal of this project was to utilize the HILS environment for Centracs Adaptive algorithm testing. The initial signal timing was obtained from the Synchro dataset documenting current signal, applied in the field for an observed period of the day. The key parameters of the signal timing pattern include; split, cycle length, phase, and offset. This initial pattern is altered by the Centracs Runtime Refiner in accordance with prevailing traffic conditions produced by the VISSIM microsimulation model. The Runtime Refiner is the component of the adaptive algorithm that recommends the most optimal values of cycle length, offset, and split and sends them to the traffic controllers for immediate adjustment. Figure 13 illustrates the results obtained by the Centracs Adaptive algorithm. Recommended split, cycle, and offset values can be seen from the controller status window. In addition, there are many different measures of effectiveness calculated from the historical data such as: average phase utilization, green occupancy, and degree of saturation, which provides an appropriate insight into the effectiveness of the current algorithm configuration.



Status data may be dated or invalid. The system is not currently polling for status.

Estimated Controller Time: 23:47:14 Pattern: 1

Phase Number	Number of Observations	Gap-outs	Max-outs	Force-offs	Omit/ Skips	Termination Timeline	Average Green Time (sec)	Average Green Occupancy (%)	Average Used Green (sec)	Average Available Green (sec)	Average Phase Utilization (%)	Degree of Saturation	Average Phase Demand (% time)	Min Split	Current Split	Max Split
1	9 (100%)	0	0	9 (100%)	0	F,F,F,F,F,F,F,F,F	11.0	100%	11.0	11.0	**100.0%**	🟥	12.2%	9	15	255
2	9 (100%)	0	0	9 (100%)	0	F,F,F,F,F,F,F,F,F	47.0	0%	0.0	47.0	**0.0%**	▬	0.0%	16	30	255
3	9 (100%)	0	0	9 (100%)	0	F,F,F,F,F,F,F,F,F	11.0	100%	11.0	11.0	**100.0%**	🟥	12.2%	9	15	255
4	9 (100%)	9 (100%)	0	0	0	G,G,G,G,G,G,G,G,G	5.0	0%	0.0	26.0	**0.0%**	▬	0.0%	16	30	255
5	9 (100%)	0	0	9 (100%)	0	F,F,F,F,F,F,F,F,F	11.0	100%	11.0	11.0	**100.0%**	🟥	12.2%	9	15	255
6	9 (100%)	0	0	9 (100%)	0	F,F,F,F,F,F,F,F,F	47.0	0%	0.0	47.0	**0.0%**	▬	0.0%	16	30	255
7	9 (100%)	0	0	9 (100%)	0	F,F,F,F,F,F,F,F,F	11.0	100%	11.0	11.0	**100.0%**	🟥	12.2%	9	15	255
8	9 (100%)	9 (100%)	0	0	0	G,G,G,G,G,G,G,G,G	5.0	0%	0.0	26.0	**0.0%**	▬	0.0%	16	30	255

Figure 13. Example of the Centracs Adaptive Algorithm Calculation Results

3.2. Configuration for HILS

All necessary parameters for the selected testbed on US1 were collected during the configuration of the adaptive algorithm and they include:

- **Existing signal timing pattern**: As mentioned before, this dataset was obtained from Synchro model reflecting the current signal timing setup on US 1, between Harrison St and Carnegie Center Boulevard.
- **Coordinator configuration**: During this task, the offset reference point, force-off conditions, and the transition type were configured. Coordination is an important component of the adaptive system and the system settings need to be verified by the Centracs adaptive algorithm in order to be applied during the operation.
- **Link and detector assignment**: This feature allows the adaptive algorithm an ability to establish the controller to link assignment. During the configuration process, the user needs to specify the length of each link and which detector and controller is assigned to it.

3.3. Detector Adjustment

Vehicle detection in the HILS environment is performed using presence detectors from VISSIM. Just as in real world scenarios, the detector occupancy time is used to estimate individual vehicle speed. With respect to that, the accuracy of the speed detection can be adjusted using:

- Trap length, which represents the length of a presence detector in VISSIM (Figure 14)
- And average vehicle size in a Centracs algorithm configuration

Algorithm Name: Adaptive

Signal Controller: 10 - US1 @ Carnegie

Detector Number	ll ase	Phase Utilization	Flow Profiling	Upstream Controller	Downstream Controller	Distance Upstream	Detector Length	FreeFlow Speed	Time To Fl
1		☐	☐	Not Specified	Not Specified	16 Feet	10 Feet	0 MilesPerHr	0
2		☑	☑	Not Specified	9	1161 Feet	30 Feet	55 MilesPerHr	74
3		☐	☐	Not Specified	Not Specified	16 Feet	6 Feet	0 MilesPerHr	0
4		☑	☑	Not Specified	10	400 Feet	30 Feet	55 MilesPerHr	25
5		☐	☐	Not Specified	Not Specified	16 Feet	6 Feet	0 MilesPerHr	0
6		☑	☑	9	Not Specified	2000 Feet	30 Feet	55 MilesPerHr	127
7		☐	☐	Not Specified	Not Specified	16 Feet	6 Feet	0 MilesPerHr	0
8		☑	☑	Not Specified	10	400 Feet	30 Feet	55 MilesPerHr	25
9		☐	☐	Not Specified	Not Specified	16 Feet	6 Feet	0 MilesPerHr	0
10		☐	☐	Not Specified	Not Specified	16 Feet	6 Feet	0 MilesPerHr	0
11		☐	☐	Not Specified	10	16 Feet	6 Feet	0 MilesPerHr	0

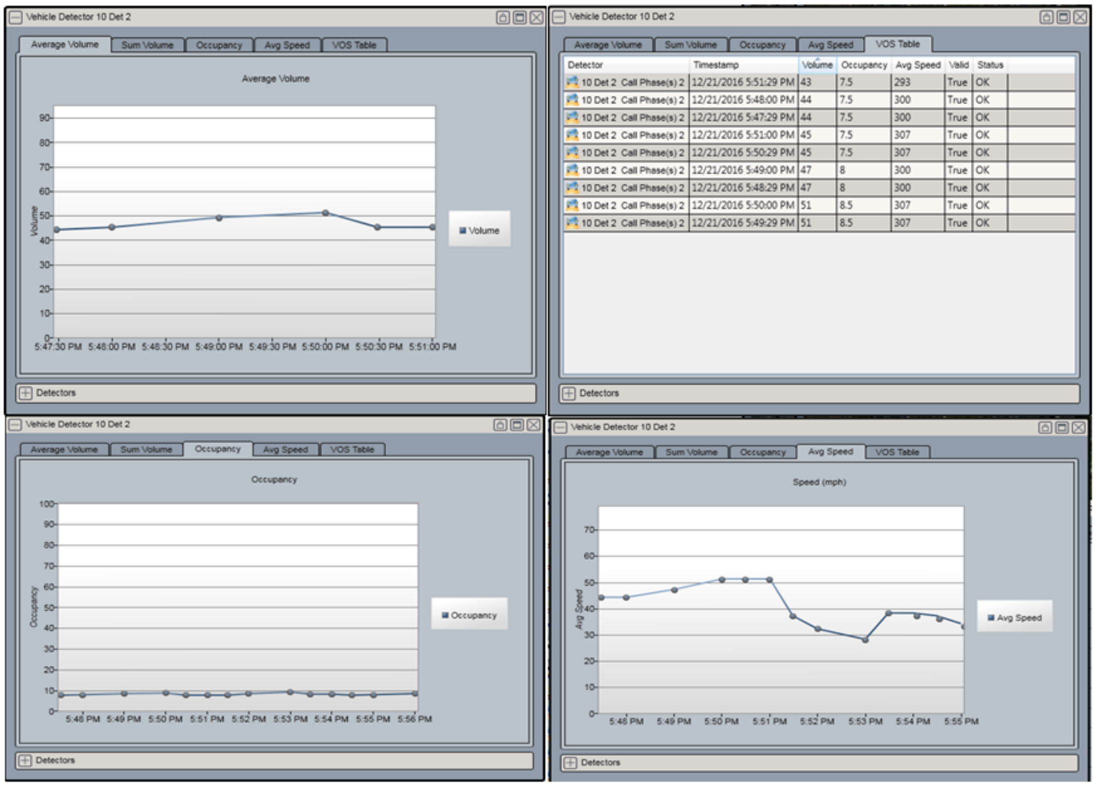
Pattern Table Type: Patterns

Figure 14. Trap length illustration in VISSIM (left) Centracs detector parameter settings (right)

Another very important detector setting is the distance of the detector from the stop line. Centracs configuration guidelines specify the recommended detector location to be in the middle of the upstream link which provides the most accurate link speed and volume information. After evaluating different parameter setups, detector length in VISSIM of 30 feet, and average vehicle length of 14.75 feet with mid-block detector position, provided the most accurate detector readings.

3.4. Data Collection

Data collection in Centracs can be obtained using a detector screen for each individual detector or detector group. The Detector Status screen includes five tabs of data. As the detectors reply to poll requests from the system (usually once per minute), data will start to be shown on the tabs and data tables will be generated. The first four tabs contain graphs; the VOS Table tab shows the volume, occupancy, and speed data used to make the graphs, in tabular format. For supported detector types, the Status column shows any existing detector faults (otherwise, this column shows “OK”); the Valid column shows whether the system considers the volume, occupancy, and speed data from this detector to be reliable (in the case of a detector fault, the system considers the data to be unreliable and does not include it in the graphs/calculations). Illustration of data collection results is presented in Figure 15 below.



Detector	Timestamp	Volume	Occupancy	Avg Speed	Valid	Status
10 Det 2 Call Phase(s) 2	12/21/2016 5:51:29 PM	43	7.5	293	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:48:00 PM	44	7.5	300	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:47:29 PM	44	7.5	300	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:51:00 PM	45	7.5	307	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:50:29 PM	45	7.5	307	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:49:00 PM	47	8	300	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:48:29 PM	47	8	300	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:50:00 PM	51	8.5	307	True	OK
10 Det 2 Call Phase(s) 2	12/21/2016 5:49:29 PM	51	8.5	307	True	OK

Figure 15. Data Collection Results from Centracs Detector Screen

3.5. Simulation Results

A side by side comparison of the base-case traffic control observed in the field and Centracs was conducted. The base-case signal operation was simulated using historical signal change data obtained during the data collection process. The signal timing setting for Centracs (e.g. cycle, split, offset, etc.) were assigned according to the parameters used in the field. Further analysis included the comparison of the delay and number of stops for all intersection approaches in the test corridor.

3.5.1. US 1 and Harrison Street Intersection Analysis

The Centracs signal control system achieved lower delay and number of stops. The cumulative reduction in delay of up to 400 seconds was observed on the north-bound approach in the simulation scenario where the Centracs signal control was used.

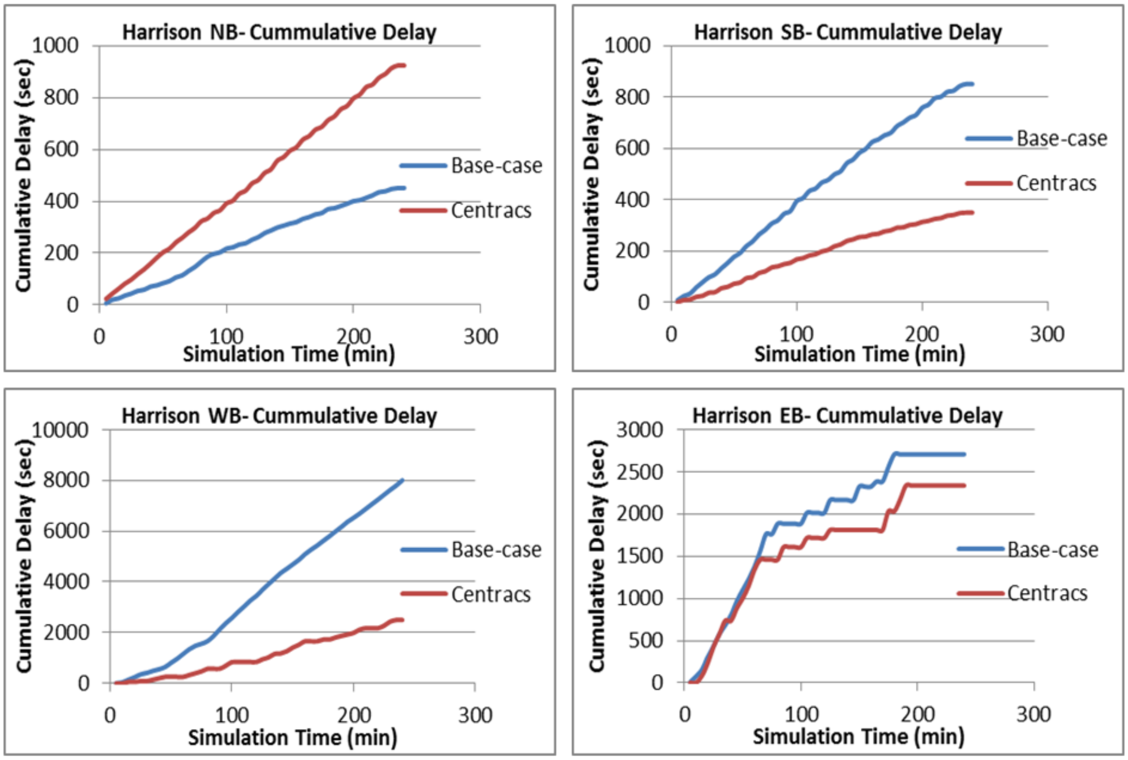


Figure 16. US1 at Harrison Street Cumulative Delay Plot

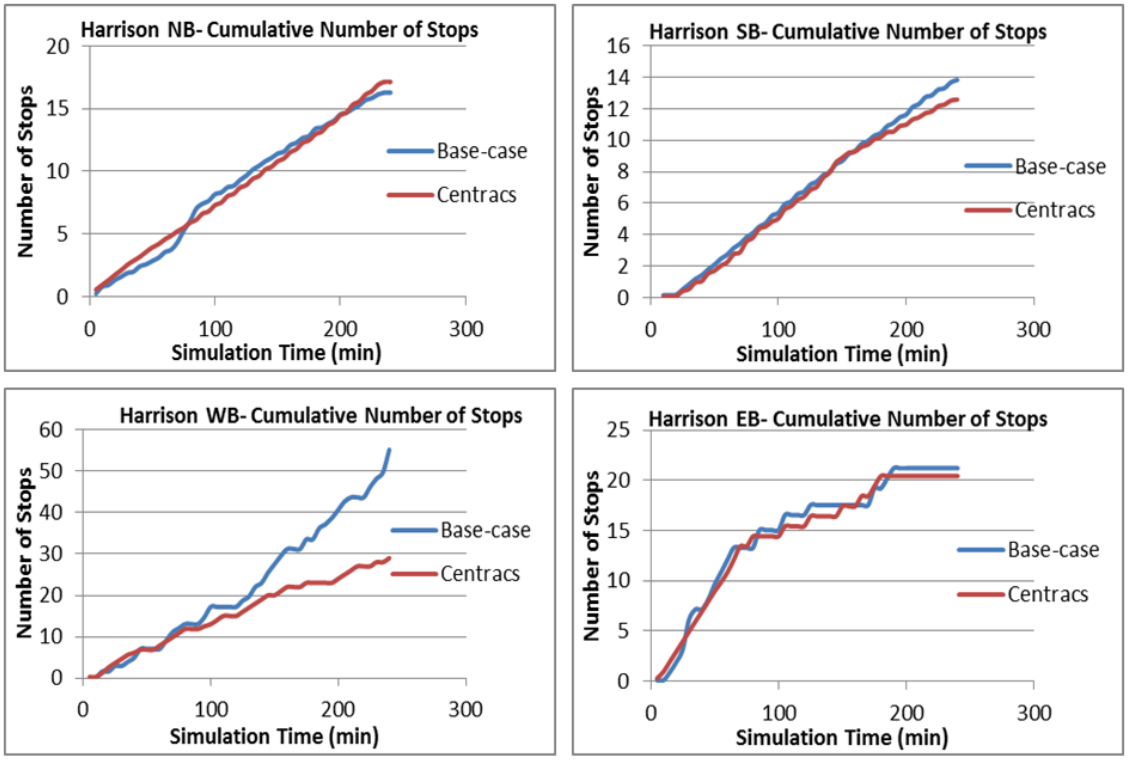


Figure 17. US1 at Harrison Cumulative Number of Stops

3.5.2. US 1 and Fisher Place Intersection Analysis

Similar delay and number of stops reduction was observed for the US1 at Fisher Place intersection. The southbound approach had the highest delay reductions in the scenario that included Centracs signal control, and the northbound approach had the highest reduction in number of stops.

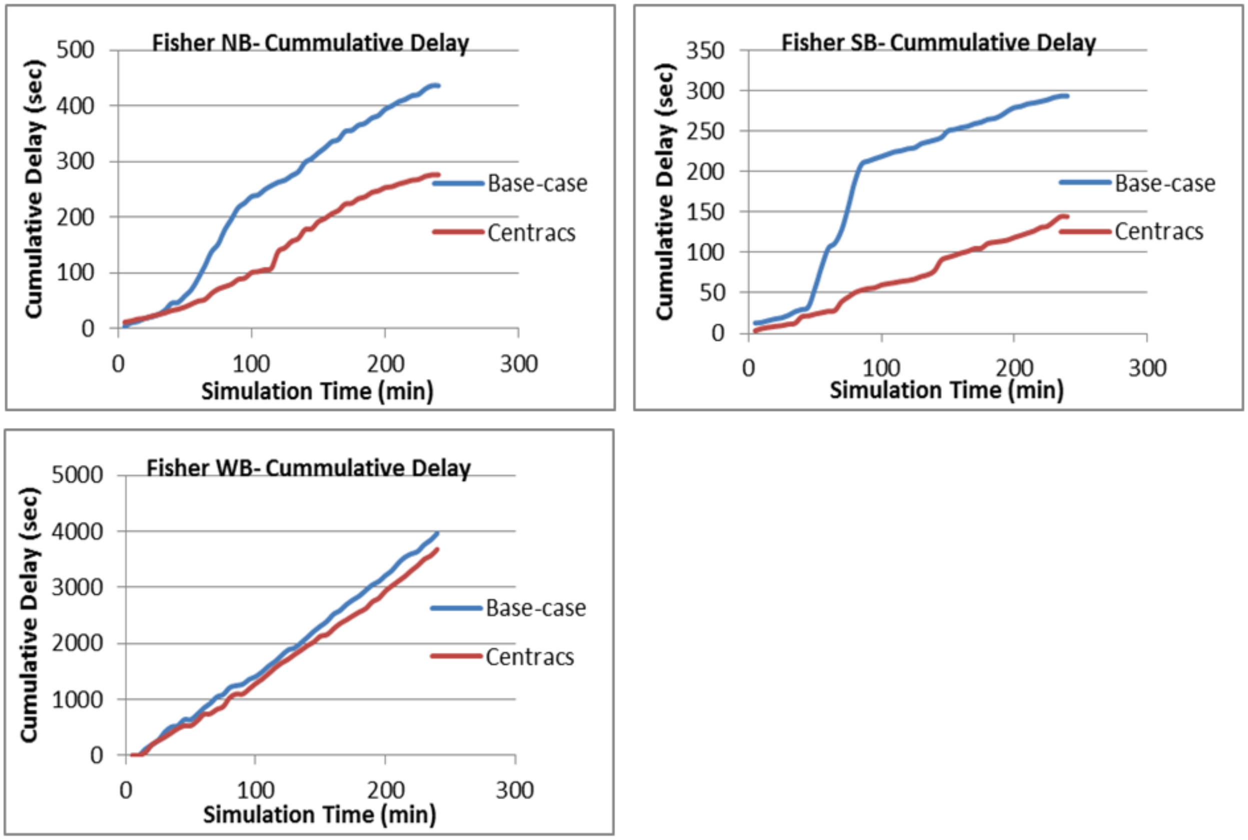


Figure 18. US 1 at Fisher Place Cumulative Delay Plot

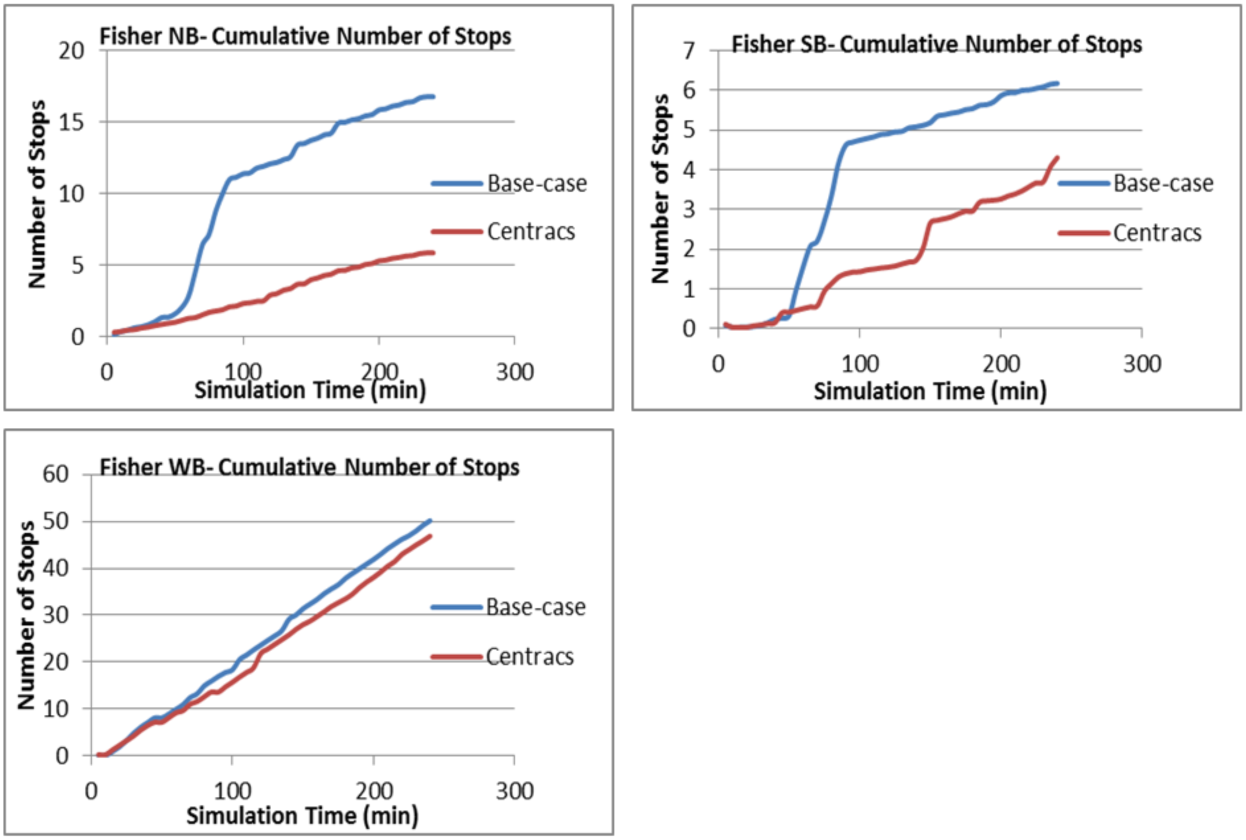


Figure 19. US1 at Fisher Place Cumulative Number of Stops

3.5.4. US 1 and Washington Street Intersection Analysis

The Washington intersection had the highest delay reductions on the westbound approach. The number of stops was also reduced for all the intersection approaches. Both measures of effectiveness confirmed the advantage of the adaptive algorithm and are illustrated in figures below.

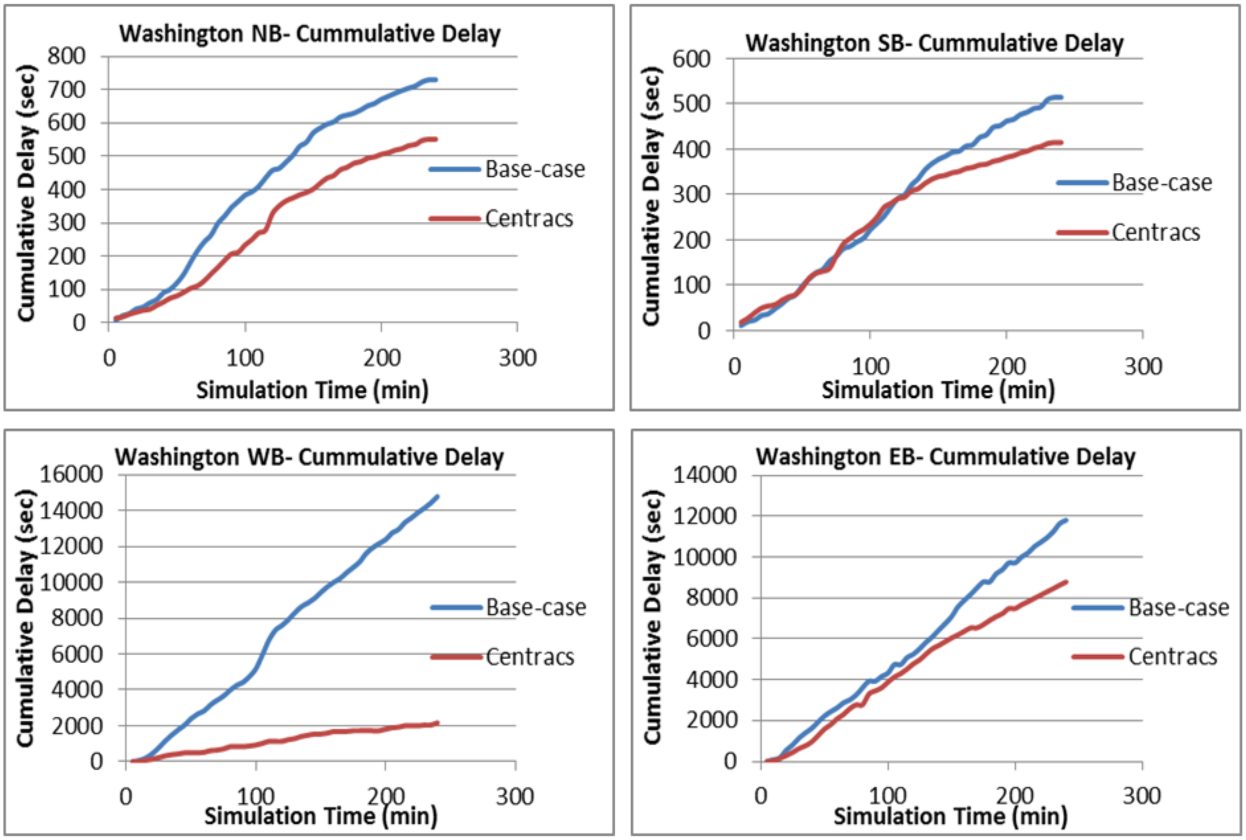


Figure 20. US1 at Washington Street Cumulative Delay Plot

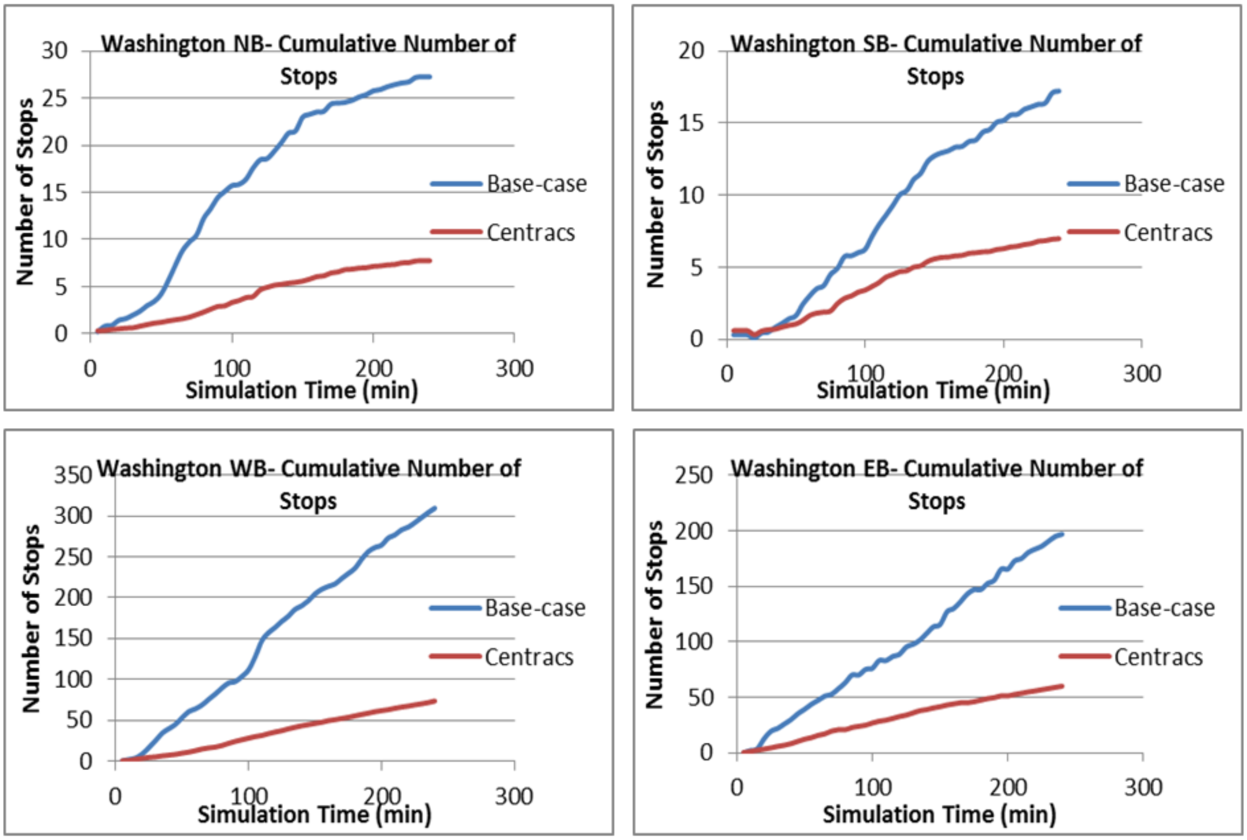


Figure 21. US1 at Washington Street Cumulative Number of Stops

3.5.5. US 1 and Carnegie Center Boulevard Intersection Analysis

Similarly, the delay and number of stops were detected for the Carnegie Center Boulevard intersection. Once again, the benefits of the adaptive algorithm were detected and are illustrated in figures below.

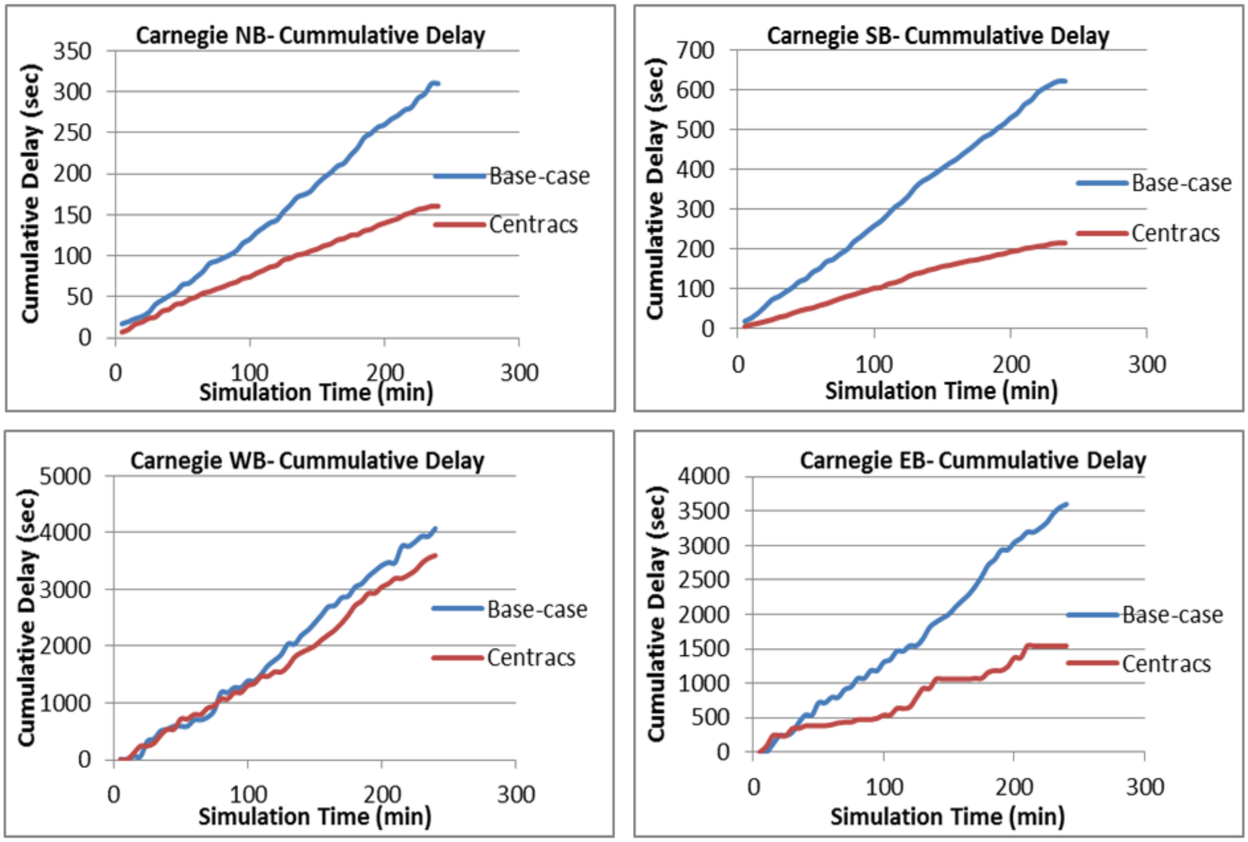


Figure 22. US1 at Carnegie Center Boulevard Cumulative Delay Plot

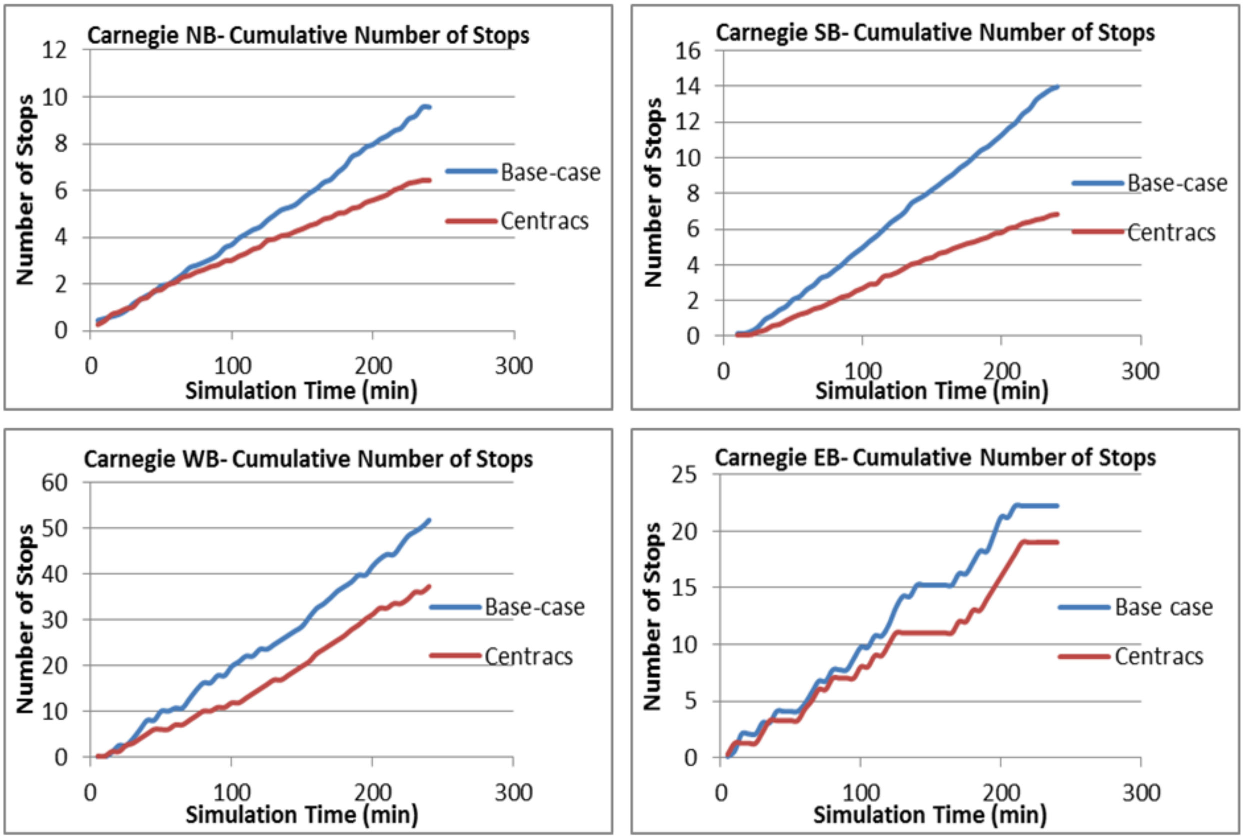
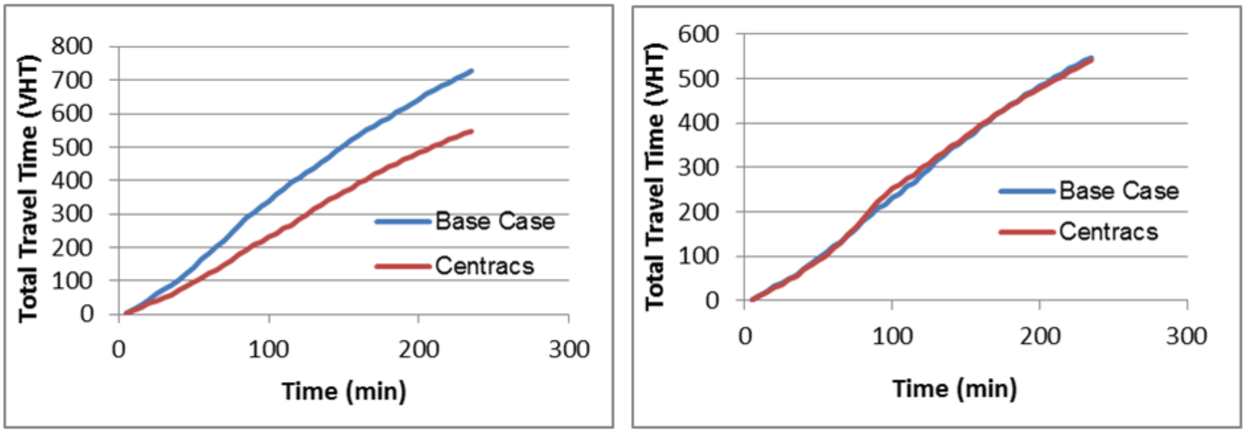


Figure 23. US1 at Carnegie Center Boulevard Cumulative Number of Stops

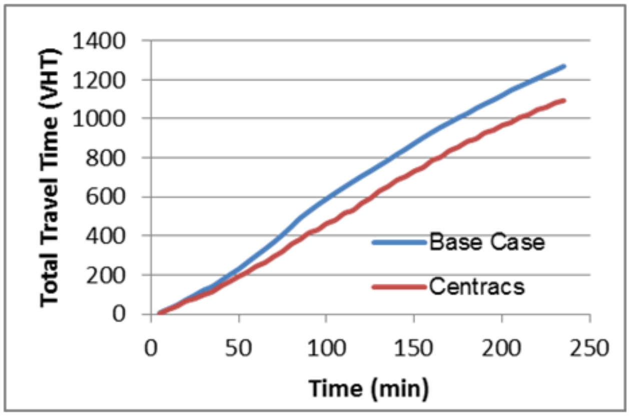
3.5.7. Corridor Level Performance

In addition to individual intersection analysis, the overall corridor performance was evaluated for the base case and the adaptive signal control. To that end, total travel time and corridor throughput were captured instantaneously for the whole simulation period. To adequately estimate overall improvement, vehicle hours of travel were computed as the product of the traffic volume (i.e. corridor throughput) and the average corridor travel time. While Centracs made a significant improvement on NB, some marginal improvement was achieved on the SB (Figure 24). Overall performance of the Centracs adaptive algorithm is illustrated in Figure 25, and it is clear that adaptive system reduced overall travel time by almost 200 vehicle-hours in total.



* VHT – Total vehicle hours traveled

Figure 24. Total Corridor Travel Time (NB left, SB right)



* VHT – Total vehicle hours traveled

Figure 25. Overall Corridor Travel Time

4. Conclusions and Recommendations

4.1. Conclusions

The NJIT research team developed a methodology for the evaluation of the adaptive signal control under HILS environment. HILS is widely used by various scientific and industry-related researchers and represents an accurate and safe method for testing the system capabilities in real time. Using the HILS environment, it is possible to test the traffic control system with immediate exposure to different traffic conditions that usually occur for only a few hours during the day. Another very useful capability of the HILS is that it allows for repetition of the experiments, which produces better accuracy and statistical significance of the test. PTV VISSIM microsimulation software offers development of the testbed that has the identical road and infrastructure geometry as the observed location, thus providing opportunity for the system validation and verification without affecting road users and pedestrians. The Centracs adaptive algorithm evaluated in this project uses vehicle detector data and TS2 NEMA type controllers with existing features and applications. Vehicle detection obtained from VISSIM and processed by CID devices has satisfying characteristics and it corresponds to those produced by the loop detectors. The best indicator of the successful detection accuracy is that the speed, volume, and occupancy data collected by Centracs and VISSIM do not contain significant differences.

4.2. Recommendations

The HILS environment setup presented in this project represent a valid tool for the evaluation of different signal control strategies. It is worth noting that such system can be successfully used for the training purposes providing an adequate hands-on experience. As all the changes in the signal control strategies can be instantly observed in the simulation this tool is recommended for the training and evaluation purposes.

4.3. Next Step

The HILS system described in this project has a capability of incorporating different controllers and different adaptive algorithm types. Combination of Centracs and Cobalt controllers represent just one out of many possibilities that can be used to establish adaptive signal control. NIATT’s Controller Interface Device (CID) gives the traffic engineer the opportunity to test any signal-timing plan that can be operated with either a NEMA or 170 traffic controllers, making HILS manufacturer and adaptive software independent. In addition, Centracs System shall provide database management with full upload, download and control to Econolite ASC/2, ASC/3 controllers, 2070 controllers running the Econolite ASC/2070, ASC/3 2070 or Eagle EPAC ver. 4.01D or ver. 4.01F controllers using NTCIP 1202 communications protocols. Oasis™ firmware, controllers and 170 controllers using Econolite ACT protocols can also be included in the Centracs Adaptive environment. The future extension of this project will include an evaluation of different connected vehicle (CV) applications in cooperation with adaptive and actuated signal control. As different CV applications mandated by the U.S. DOT are close to becoming a reality, the cooperation of these applications with existing signal strategies is necessary for their success. Different V2I and V2V applications are nothing new in the area of microsimulation. Therefore, HILS represents a perfect methodology for testing such sophisticated control strategies without endangering safety and the intersection for quality of service.

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