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16. Abstract

The objective of this project was to develop a custom toolbox for monitoring and troubleshooting operational issues and faults at signalized intersections and diamond interchanges, and for providing a mechanism to facilitate signal timing optimization using third-party optimization programs. This report describes work conducted by Texas A&M Transportation Institute (TTI) researchers to achieve the above objectives, which resulted in three software modules: (1) a monitoring module that uses National Transportation Communications for ITS Protocols (NTCIP) messages to monitor and record real-time statuses of events in a traffic controller and logs collected and processed data for later use, (2) an analysis module that generates various easy-to-interpret reports to allow assessment of controller event data, and (3) an update module that reads optimized signal timing from a selected universal traffic data format (UTDF file) and uses NTCIP messages to download these timing data to a controller. The report also describes in-lab and field testing that researchers conducted to verify the operations of these modules.

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DEVELOPMENT OF NTCIP-BASED PORTABLE TRAFFIC SIGNAL EVALUATION SYSTEM

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Nadeem A. Chaudhary, P.E. # 66470.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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INTRODUCTION

BACKGROUND

In a 2007 report, the National Transportation Operations Coalition (NTOC) gave an overall D grade to the nation's traffic signal systems (*1*). Among the individual scores, proactive management, operations at isolated signals, and signal operation in coordinated systems received individual grades of D−, C, and D, respectively. In addition, traffic monitoring and signal maintenance received grades of F and C−, respectively, and detection systems received an F. The report cited lack of resources as a major cause of these low grades, and recommended five core areas of investment to improve the grade to an A. These core areas include proactive traffic monitoring and data collection, and routine signal timing updates. A recent update to the NTOC report showed minor improvement to some of these scores (*2*). Overall, a nationwide grade of D+ is still low. However, there are improvements in two areas. Results of assessment show a significant improvement of 7 points in the score for signal timing practices, mostly accounted for by agencies operating more than 150 traffic signals. The overall grade for traffic monitoring and data collection remains an F. These results underscore the need for continued and sustained efforts by transportation agencies to produce desired improvements in the health of the nation's signal systems.

Like most agencies dealing with traffic signals, the traffic operations departments in most Texas Department of Transportation (TxDOT) districts have a limited number of trained personnel responsible for maintaining and operating traffic signals in their respective jurisdictions. Because traffic signals in each jurisdiction are often spread across large geographic regions, it is not feasible for TxDOT staff to manage them without automating the process of monitoring and troubleshooting signal operations.

TxDOT has long recognized the need for, and invested in the development of, tools to assist its staff in monitoring and maintaining their signal systems. These tools include Progression Analysis and Signal System Evaluation Routine (PASSER™) signal timing optimization programs (*3*, *4*, *5*) and traffic signal monitoring and troubleshooting systems (*6*, *7*). The first of these tools was a prototype system that Texas A&M Transportation Institute (TTI) researchers developed. This system used a personal computer to interface with a signal cabinet and custom software to record real-time phase and detector status (*6*). It also provided an offline capability to calculate measures of effectiveness (MOEs) from logged real-time data. These MOEs included:

- Cycle time.
- Time to service.
- Queue service time.
- Duration of green, yellow, and red indications for enabled phases.
- Number of vehicles entering the intersection during each interval.
- Yellow and all-red violation rates.
- Phase failure rate.

Some of these measures required special 6 × 6 detectors located downstream and upstream of the stop bar. TTI researchers also tested the prototype system at two field locations. In a follow-up TxDOT project, the researchers developed a portable traffic signal performance measurement system (TSPMS) (*7*). TSPMS interfaces with a TS-2 cabinet via serial ports on Enhanced Bus Interface Units (BIUs) to record real-time phase and detector events in the controller. In addition, this system logs preempt and coordination statuses. TSPMS also includes an offline module to generate several MOEs listed below:

- Average phase time; phase failures; queue clearance time; time to service; counts on green, yellow, and red; and split utilization during coordinated operations for all enabled phases.
- MOEs for preempt data include the type of preempt, time of preempt, and the duration of preempt for each day.
- Detector failure data include type of detector failure and the time at which the detector failure occurred.

Researchers applied TSPMS at two intersections by collecting data for over a month and demonstrated how this system could be used to troubleshoot controller operations. Despite demonstrated benefits over TTI's original prototype signal monitoring system (*6*), TSPMS posed the following two challenges to its application:

- First, it required swapping of standard BIUs in the controller cabinet with enhanced BIUs prior to its use.
- Second, it required the user to manually input timing and coordination data used in the controller.

TxDOT initiated this project to overcome some of these limitations and develop a traffic signal monitoring and evaluation toolbox that uses National Transportation Communications for ITS Protocols (NTCIP) to provide an easier-to-use and standardized toolbox (*8*, *9*).

STATE OF TXDOT PRACTICE AND NEEDS

The research team interviewed members of the TxDOT monitoring committee for this project and other selected agency staff to identify the state of current agency practices related to traffic signal operations, maintenance, and management. These TxDOT staff represented districts with responsibilities from a few dozen traffic signals to several hundred. The objective of this task was to update the findings of a similar survey that TTI researchers conducted in 2004 (*10*). The following list highlights key TxDOT practices related to traffic signals, some of which vary from district to district:

- TxDOT staff prefers to use traffic volumes for evaluating signal operations but due to lack of resources often ends up utilizing data that are three to five years or more older.
- No district has a routine signal evaluation program. Some districts want to retime signals as frequently as every two to three years, but lack of resources does not permit such frequent updates. Districts generally initiate evaluation studies because of user (citizen, local police, school district staff, etc.) complaints, which are the primary means of

identifying problems at traffic signals. Some districts provide feedback to the user who reported a problem after resolving it.

- Center-to-field communications capabilities in various districts range from no communications to isolated signals, closed loop systems with center-to-field dial-up communications through the field master, and full Ethernet-based communications to individual controllers.
- Troubleshooting and resolving the root causes of operational problems such as malfunctioning detectors, and operational problems such as unacceptable queues or wait times require field trips. District staff generally makes minor in-field adjustments to phase times, splits, and offsets as needed.
- Even though TxDOT staff is familiar with several signal timing optimization programs, in-house use of these program is not common and most signal retiming tasks are subcontracted.
- Most districts use TxDOT-approved U.S. National Electrical Manufacturers Association controllers from multiple vendors. In addition, districts have operational controllers running different versions of firmware, depending on when a controller has been installed or updated. Newer controllers (installed or upgraded within the past 10 years) have NTCIP-compliant firmware. These controllers also have Ethernet ports, which may not be in use due to lack of center-to-field communications. However, NTCIP compliance does not matter because districts primarily rely on vendor software, which use proprietary communication protocols.
- TxDOT staff does not use built-in performance measurement features available in traffic controllers. Staff unfamiliarity with these features, which vary from vendor to vendor, is the primary reason for not using these facilities.
- TxDOT districts primarily use loops and/or video cameras for detection. The use of other technologies such as radar- or magnetometer-based sensors is also increasing. Furthermore, some districts prefer to use only video-based detection, while others rely heavily on loop-based systems. Where used, loop-based detection design consists of long (6 × 20 or 6 × 30) stop bar loops. Some districts use 6 × 6 setback loops (100 ft to 150 ft upstream of the intersection) either alone or in conjunction with stop bar loops.

  Districts also use detectors as appropriate. The most common practice is to use a single stop bar detection zone across multiple lanes, generally implemented by using a common lead-in cable. At diamond interchanges using four-phase operation, the interior through approaches do not have any detection. Also, coordinated phases in a coordinated system may not have any detection. In video-based systems, each phase has a single detector, which may consist of several zones tied together. Note that reliable traffic volumes cannot be obtained from long stop bar detectors and approach-based detection consisting of multiple loops or detection zones linked to a common channel.
- Districts use a wide range of control strategies, including:
  - Actuated operation.
  - Three- and four-phase operation at diamond interchanges.

- Time-of-day control with a combination of coordinated and free operation.
- Traffic responsive control.
- Traffic adaptive control on a limited scale.
- Use of signal priority to accommodate pedestrians in a coordinated system where cross-street split times are less than the required pedestrian times.

The interviewed TxDOT committee members indicated that for the product of this research to be useful to them, it should be:

- Applicable to isolated or coordinated signalized intersections and diamond interchanges.
- Easy to use by less-skilled personnel.
- Support controllers from different vendors to provide standardization.
- Provide features to assist them with key steps required for troubleshooting issues at traffic signals and keeping their operations as efficient as possible.

These steps include:

- Monitoring traffic signal operation and identification of operational issues and problems.
- Data collection, data processing, and analysis to identify root causes of identified problems.
- Optimization of traffic signal timing. This step may be as simple as manual tweaking of signal timings, or using a signal timing optimization program.
- Entering new timing parameters in the controller(s).
- Monitoring and fine-tuning of the system.

PROJECT ACCOMPLISHMENTS

To achieve project requirements of this project, researchers developed two portable toolboxes, each consisting of an off-the-shelf field-hardened laptop together with three custom software modules installed on it. The researchers developed the following three custom software modules in this project:

- A monitoring module that uses NTCIP messages to monitor real-time operation of a signal controller. It obtains and records real-time statuses of detectors, phases, channels, and alarms. It also conducts real-time processing of these data and saves processed data for offline analysis.
- A module for offline analysis of data recorded by the monitoring module. This module allows the user to select one or more days for which data were collected and produces user-selected MOE reports.
- An update module that uses NTCIP messages to update signal timings in a controller. This module reads signal timing parameters saved from a signal timing optimization

program in a universal traffic data format (UTDF) (*11*), and allows the user to download it to a selected controller.

Using NTCIP for communicating with a traffic controller provides two advantages. First, it allows standardization where tools can be used with any brand of traffic controller, regardless of the type of cabinet it is installed in. Second, it allows the automatic uploading of any needed controller configuration data, rather than having the user enter it.

ORGANIZATION OF THIS REPORT

This report documents work conducted to achieve the desired objectives. It contains four chapters, including this chapter and three appendices. Chapter 2 describes toolbox development process, including toolbox specifications, overview of NTCIP standards and toolbox software modules developed in this research. Chapters 3 and 4 are devoted to descriptions of in-lab and field testing of the NTCIP Portable Traffic Signal Evaluation System (NPTSES). The four appendices provide additional information.

TOOLBOX DEVELOPMENT

TOOLBOX SPECIFICATIONS

At the onset of this project, researchers developed toolbox specifications to formalize TxDOT requirements. The following subsections provide these specifications.

Applicability

The toolbox will be applicable to signalized intersections and signalized diamond interchanges operating in free and coordinated modes of operation. The toolbox can be connected to a single intersection or interchange for an adequate period to achieve its objectives. Although designed for use at one field location at a time, the toolbox should support application to coordinated signal systems consisting of multiple intersections and interchanges.

User-Friendliness

The toolbox should be portable, TxDOT employees with different education and experience levels should be able to easily use it, require minimal data entry from the user, allow saving of site-specific configuration data for later use, and require minimal training.

Communications with Controllers

The toolbox should be able to communicate with compliant controllers using NTCIP-based standard messages through a serial or Ethernet port. Furthermore, the toolbox should be able to upload all needed static and real-time data from a controller. Static data of interest include:

- Ring-barrier structure.
- Timing data for all enabled vehicle phases (i.e., minimum and maximum times), identification of any phases assigned to overlaps, and pedestrian phases (i.e., Walk, Flashing Don't Walk, and Don't Walk).
- Signal coordination data (cycle length, splits, offset, and phase sequence) for all patterns.
- Detector mapping data, including primary and switch phase assigned to each detector and other optional data such as NTCIP volume and occupancy options.
- Channel configuration data.
- Phase sequence data for all available rings.

Real-time data of interest for monitoring purposes includes current phase status, current detector status, current channel status, and statuses of various alarms that provide information about the operating mode at any given time. These alarms provide information about whether the controller is running free, running a coordinated pattern, operating under a programmed flash, transitioning from one pattern to another, disrupted by a preempt, or flashing because of a fault. The toolbox should be capable of storing up to one month's worth of such data on the hard disk.

Data Gathering and Online Processing Capabilities

Of all real-time data identified above, detector status is the most sensitive to latencies because detector actuations occur over very short periods. Actuation times for a detector are dependent on detection zone length and vehicle speeds. For this reason, traffic controllers poll the status of each detector every 100 milliseconds (one-tenth of a second) or faster. Previous research related to NTCIP-based polling (*12*) has shown that there is no significant difference in phase status information between 100- and 250-millisecond polling frequencies. However, detector status information obtained every 250 milliseconds has noticeable discrepancies as compared to polling conducted every 100 milliseconds. Therefore, researchers selected a desired target of 100 milliseconds between successful polling instances. Note that this time includes communications delays and time needed to process received data.

Report Generation Capabilities

The toolbox should provide reports beneficial for troubleshooting and identification of operational or hardware problems. Table 1 provides a list of such MOEs. To the extent possible, the toolbox should provide these MOEs in graphical format.

Table 1. Definitions and Reporting Format of Performance Measures.

Measure	Definitions	Reporting Format
Minimum Green	The observed green duration of a phase is equal to the phase minimum green specified in the controller unit.	Number of minimum greens observed per hour or identified for each cycle.
Time to Service	The time from when a call was first registered on a phase detector to the onset of the green for that phase.	Average time to service observed per hour or per cycle.
Queue Service Time	The duration in which the phase detector is continuously occupied from the onset of green to when the constant call on that detector is terminated.	Average queue service time observed per hour or per cycle.
Max-out (Phase Failure)	The phase detector is occupied when the green is terminated.	Number of max-out per unit time identified for each cycle.
Phase Duration	The observed green duration of a phase.	Average phase time observed per hour or per cycle.
Occupancy on Red	The duration in which the phase detector is occupied during the red time.	Average % of time the detector is occupied on red duration per hour or per cycle.
Occupancy on Green	The duration in which the phase detector is occupied during the green time.	Average % of time the detector is occupied on green duration per hour or per cycle.
Vehicle Counts during Green and Red	Number of vehicle actuations observed during the green indication and during the red indication	Number of vehicle counts on green indications and on red indication for each hour and or for each cycle.
Pedestrian Calls per Hour	The number of pedestrian phases activated either due to push buttons or by a recall function.	Pedestrian phases activated for each pedestrian phase for each hour of the day.
Preempt Activity	The observed number of preempts for each preempt.	The number of preempts for each preempt for each day.

Interface with Optimization Software

Several signal timing optimization programs exist (*2*, *4*, *5*, *11*), each of which uses a different native format for data entry and output. Researchers selected UTDF for use in this project because it is fully supported by Synchro (*11*), and partially supported by PASSER II (*2*) and PASSER V (*5*).

All signal timing optimization programs, including those mentioned above, provide signal timing reports that can be readily transferred to controllers. However, data obtained from a controller is not easy or straightforward to input to an optimization program, which requires that any volume data be supplied according to directional movements. A controller database does not have any information about detector-to-movement mapping to allow direct use of any volumes collected from detector, even if they are good. Detector design and number of detectors assigned to a phase also make it difficult to develop a generic mapping algorithm. After investigating the pros and cons of providing a toolbox interface for a user to enter data needed for mapping detector volumes to a format ready for use by an optimization program, researchers decided that it would be best not to include this feature in the toolbox. Instead, they decided to include the following two functional specifications:

- Include logic in the monitoring module to calculate detector specific volumes using detector actuations. This will allow a user to use volume data as appropriate.
- Include logic to read UTDF output and download selected timings to a controller using NTCIP objects.

NTCIP TOOLBOX DEVELOPMENT

Next, researchers developed the three software modules for the toolbox and installed these modules on two field-hardened laptops purchased for delivery to TxDOT at the end of this project. For reference purpose, researchers decided to use the NTCIP Portable Traffic Signal Evaluation System as the generic name for each module, followed by a hyphen and a letter to identify the specific module. The remainder of this report uses the following names identified below for the three modules:

- Monitoring module: NPTSES-M.
- Analysis module: NPTSES-A.
- Update module: NPTSES-U.

As stated previously, NPTSES-M and NPTSES-U use NTCIP protocols to communicate with a controller. Researchers used a commercial ActiveX application programming library to interface these modules with NTCIP-compliant traffic signal controllers (*13*). This library consists of a set of functions that supports creating and sending NTCIP commands (set, get, traps, block commands), and receiving and parsing NTCIP responses. The library supports the following protocols and interfaces:

- SNMP.
- TCP/IP.

- UDP/IP.
- Null.
- PMPP.
- Ethernet.
- RS-232.
- V-Series Dial-up Modems.
- CDPD.

The NTCIP library comes with a license that permits distribution of user applications developed using the library without any royalty fees. NPTSES-M uses the Get command to request static and dynamic data from the controller. NPTSES-U uses the Get command to obtain static data from a controller, and the Set command to send new signal timing information to a controller. Get and Set commands use standard object identifiers (OIDs) to access specific parts of a controller's database.

Overview of NTCIP Standards

Two NTCIP protocols are of interest to this project. These include NTCIP 1201–Global Object Definitions and NTCIP 1202–Object Definitions for Actuated Traffic Signal (ASC) Controller (*8*, *9*). NTCIP 1201 defines objects common to multiple field devices (i.e., signal controller, ramp controller, and dynamic message signs). These objects include a day-plan table and a time-base-schedule table. NTCIP 1202 defines the objects that are unique to ASC. The bulk of the communications between NPTSES and a controller uses NTCIP 1202 objects. Reading and writing data (using Get and Set commands) from and to a NTCIP-compatible device require the use of unique OIDs, which depend on locations of objects on the International Standards Organization (ISO) tree structure or hierarchy.

As described in the NTCIP Guide (*14*), all OIDs for transportation devices start with level 1.3.6.1.4.1.1206.4.2 (*iso.org.dod.internet.private.enterprises.nema.devices*) in the naming tree. The two devices of interest in this project are ASC (Device 1) and Global (Device 6). Therefore, objects of Interest in this project start with OIDs:

- 1.3.6.1.4.1.1206.4.2.1 for ASC objects.
- 1.3.6.1.4.1.1206.4.2.6 for global objects common to multiple NTCIP compatible devices.

The OIDs for objects applicable to various NTCIP devices can be deciphered by examining the Management Information Base (MIB) contained in the standards documents for these devices (*8*, *9*). The MIB for a device is a text file, which identifies names of objects, their definitions, access permissions (i.e., Read Only, Read/Write, Not Accessible), and data type/structures. Appendix A provides lists of Global and ASC OIDs of potential interest, that the research team identified by reviewing relevant NTCIP standards and other documents (*8*, *9*, *15*).

Monitoring Module

When executed, NPTSES-M assumes that it is physically connected to a controller (via Ethernet or serial cable) and immediately attempts to establish a connection to it using data saved in the base configuration file saved in the installation directory. If it is unable to establish communication, an error message appears. Upon the user's acknowledgment, NPTSES-M displays the configuration screen to allow the user to make any needed changes to the connection configuration. When a user makes changes, the program requires the user to save the configuration file, exit the program, and then rerun it.

If NPTSES-M is able to successfully connect to the controller, it obtains the maximum number of phases, phase groups, overlaps, detectors, detector groups, channels, channel groups, phase sequences, rings, and preempts supported by the subject controller. The program needs this information because various controller brands have different upper limits for these parameters. Then, it obtains all programmed data for these parameters from the controller's database. These data include phase settings for all enabled phase, and detector data (primary and switch phase assignment, optional NTCIP volume and occupancy setting, etc.). Then, it saves all uploaded information on the hard disk in various files, and displays a subset of uploaded data on various screens that users can select using tabs on the display screen. While doing so, it displays a system log showing the current action. Finally, it starts collecting real-time data and continues to do so until stopped by the user. During this stage, it stops displaying its actions on the system log window. Furthermore, it keeps the main program screen minimized. This allows the program to monitor controller operation more efficiently by preventing the display process to steal a significant portion of core processing unit time.

NPTSES-M allows the user to select events (i.e., phase status, detector status, and channel status) from which to collect/save data. During the real-time data collection phase, NPTSES-M records statuses of selected events. It also optionally uploads one-minute NTCIP volumes and occupancies for detectors with these features enabled in the controller. In addition, it conducts real-time processing of this data for offline analysis to be conducted later. This additional processing includes calculation of 15-minute and hourly volumes from detector actuation. NPTSES keeps all daily data in the computer's memory and writes daily files on the hard disk once at midnight. It also writes all unsaved data to the hard disk when the user terminates the program. Figure 1 through Figure 5 illustrate various data screens. The user can view statuses of other controller events by activating additional screens by selecting desired options (Intersection Status, Channel Status, Ped Status, Detector Status, and Overlap Status) from the Display menu.

As illustrated in Figure 1, the main configuration screen provides for entering site-specific identification information, controller type, and parameters for configuring connection type. This screen also allows the user to save configuration for a site to a specific named file for later use.

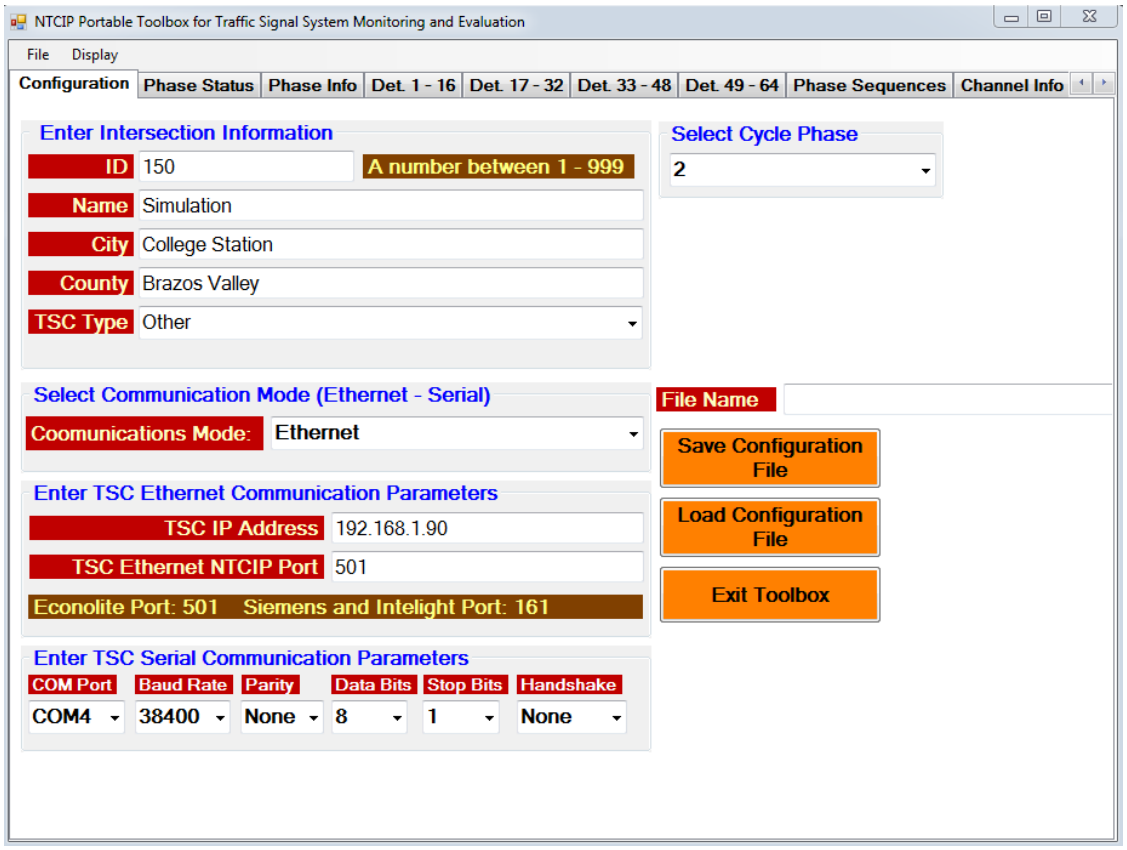


Figure 1. NPTSES-M Configuration Screen.

As illustrated in Figure 2, the phase status screen shows the current real-time status of enabled phases, the duration of current status for each phase, unit status, and coordination status. A phase duration field shown in magenta indicates that the associated detector has an active call. In this illustration, all phases have active calls. Phase information screen (Figure 3) displays data programmed for each enabled phase, including minimum and maximum times, gap settings, and concurrent phases.

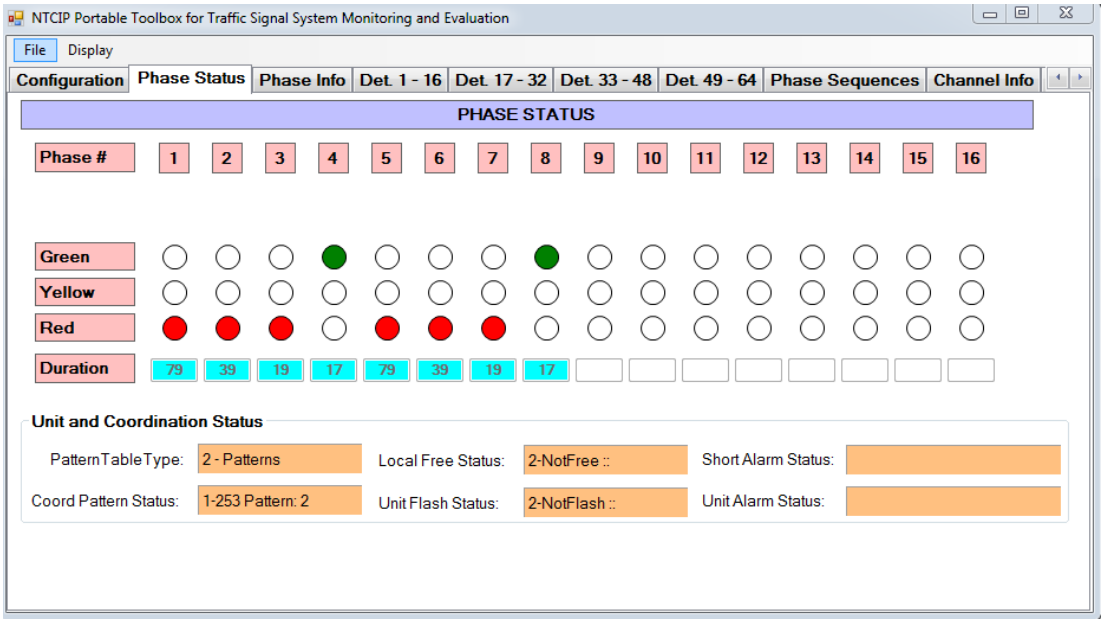


Figure 2. Phase Status Screen.

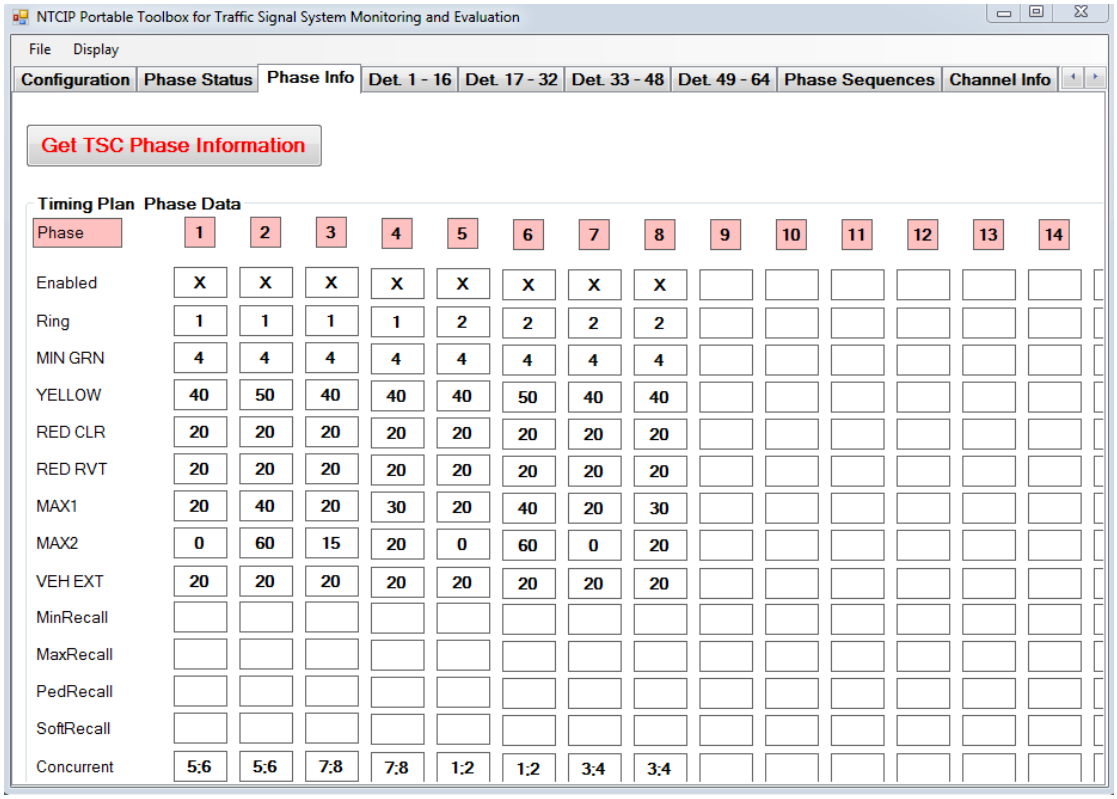
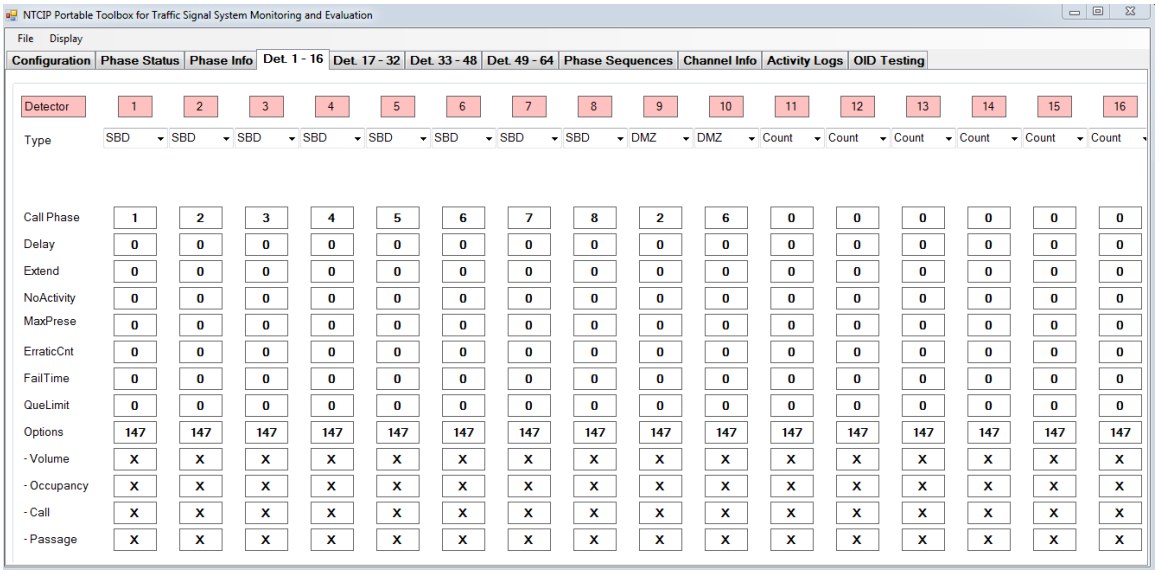


Figure 3. Phase Information Screen.

Figure 4 illustrates data uploaded by NPTSES-M for the first16 detectors. These data include detector type (only used for reference purposes), primary phase it calls, and other detector settings. The program provides three additional screens for displaying data for up to 64 detectors. Figure 5 shows the uploaded phasing sequence data.



Detector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Type	SBD	SBD	SBD	SBD	SBD	SBD	SBD	SBD	DMZ	DMZ	Count	Count	Count	Count	Count	Count
Call Phase	1	2	3	4	5	6	7	8	2	6	0	0	0	0	0	0
Delay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extend	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NoActivity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MaxPrese	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ErraticCnt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FailTime	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QueLimit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Options	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147
- Volume	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Occupancy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Call	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
- Passage	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 4. Detector Information Screen.

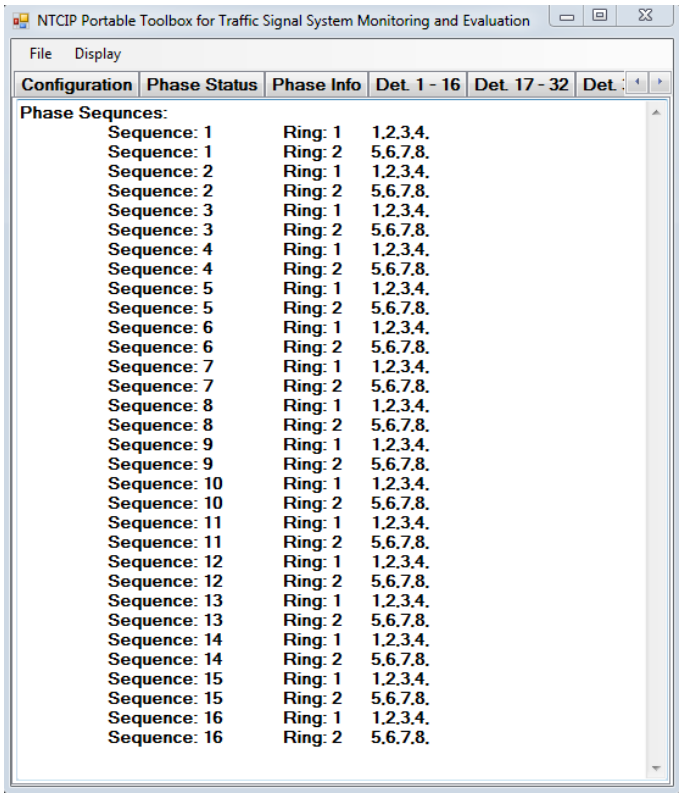


Figure 5. Phase Sequence Information.

The user should note that MPTSES-M supports application to controllers with any number of phases, channels, and detectors allowed in a controller, but limits displaying these data to 16 phases, 16 channels, and 64 detectors. For most TxDOT applications, these limits on displayed data should not pose any problems.

Analysis Module

NPTSES-A provides for offline analysis of data that the monitoring module had saved. On the main screen, it asks the user to select one of the supported report types. As illustrated in Figure 6, these report types include hourly MOEs, time-period, preempt, detector failure, and pedestrian detector reports. These reports may not be available in case MPTSES-M did not collect any data. In most cases, the user will be able to generate hourly MOE reports and time period reports. The Next Screen button (arrow located at the bottom of the figure) becomes active once the user selects a report type. Clicking on this arrow takes the user to the next screen containing two buttons for loading phase information and associated data that the monitoring module had saved.

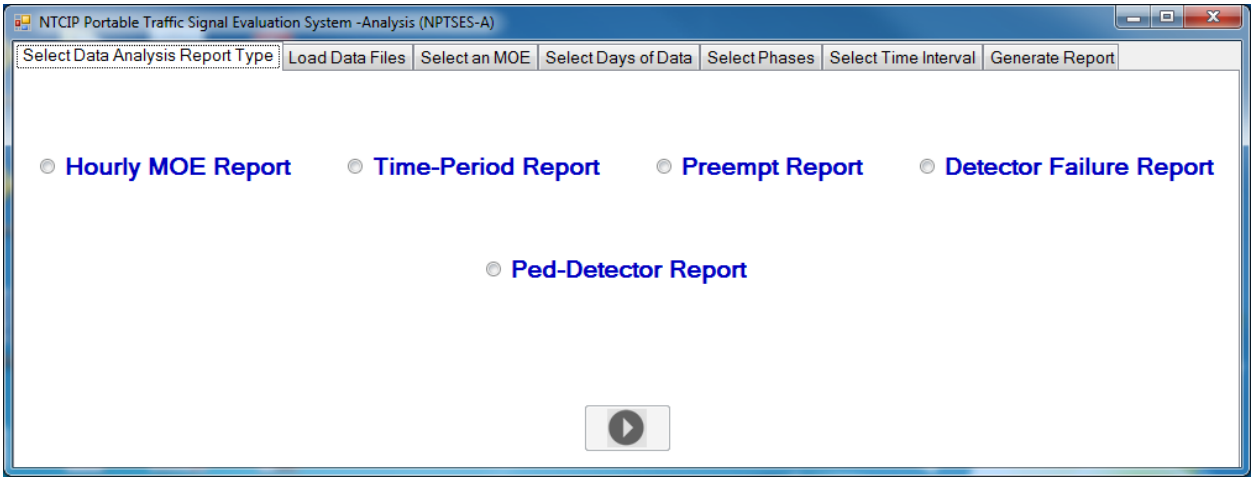


Figure 6. Main Screen of NPTSES-A.

The next step is to load a phase file, which contains static phase data. If the user ran the monitoring module for multiple days, selecting any one of the available files is sufficient. However, multiple files can be selected. The next step is to load one or more files from available data files for the site. Figure 7 illustrates the two steps where the user selected one phase file and four data files for generating Hourly MOE report. Here, each of the four data files contains MOEs for one day of data collection. After this step, the user clicks on the right arrow (located at the right bottom corner) in Figure 7 to move to the next step, where NPTSES-A requires the user to select one of the available MOEs (Figure 8) for which the user desires to generate a report. In the following two steps, the program asks the user to select one or more days (up to four in this case) and one or more phases.

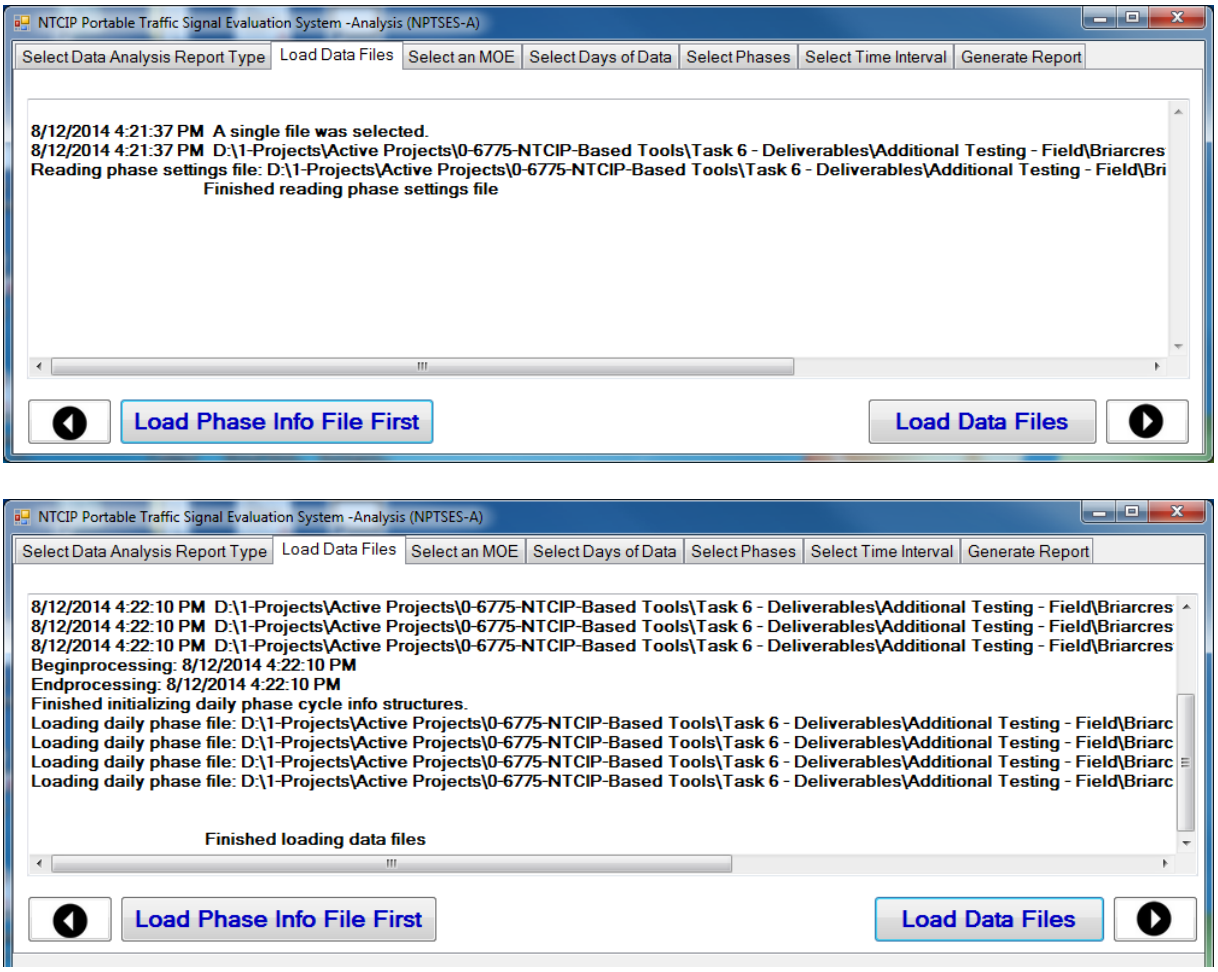


Figure 7. Selecting and Loading Data Files.

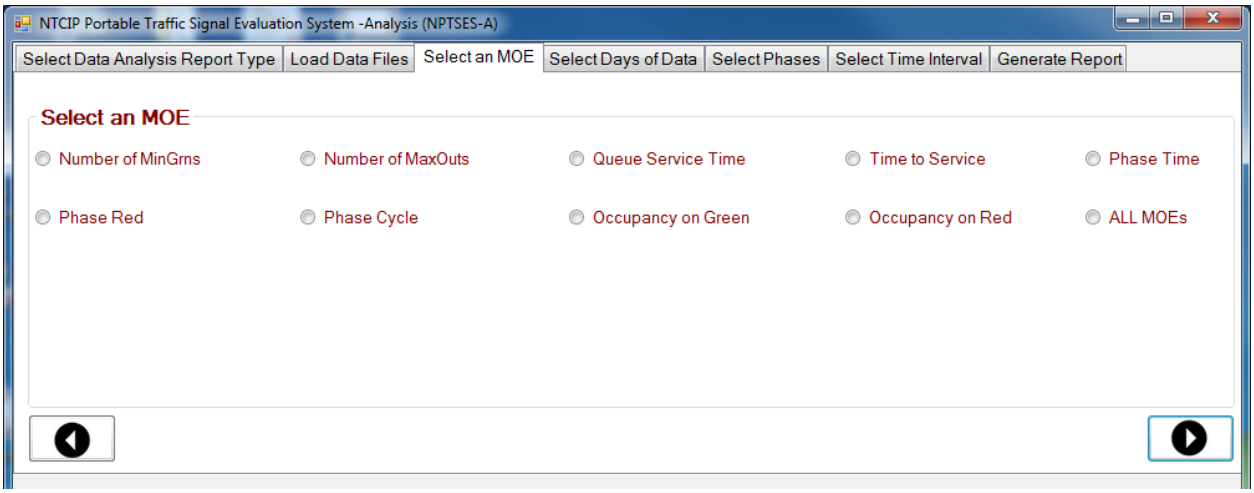


Figure 8. MOE Selection Screen.

The number of phases the program allows the user to select depends on whether he/she selected one day or multiple days. For multiple day reports, the user can select only one phase. In the next step, the user clicks a button at the bottom right of the screen to generate the desired report. Figure 9 shows a plot of average hourly phase times for Phase 2 for all four days selected in this case. In addition, it shows the average of these times. In this case, the average phase time is not appropriate because two of the four selected days are weekend days while the other two are weekdays. To generate these reports (plots), MPTSES-A makes use of Microsoft® Excel, which allows the user to delete any unneeded data. This specific case is a diamond interchange, which runs under free mode at night and switches to a coordinated operation before the morning rush hours. The reader will note that the phase times (actually splits) are more consistent between 8:00 a.m. and 7:00 p.m. when the system is using a coordinated pattern.

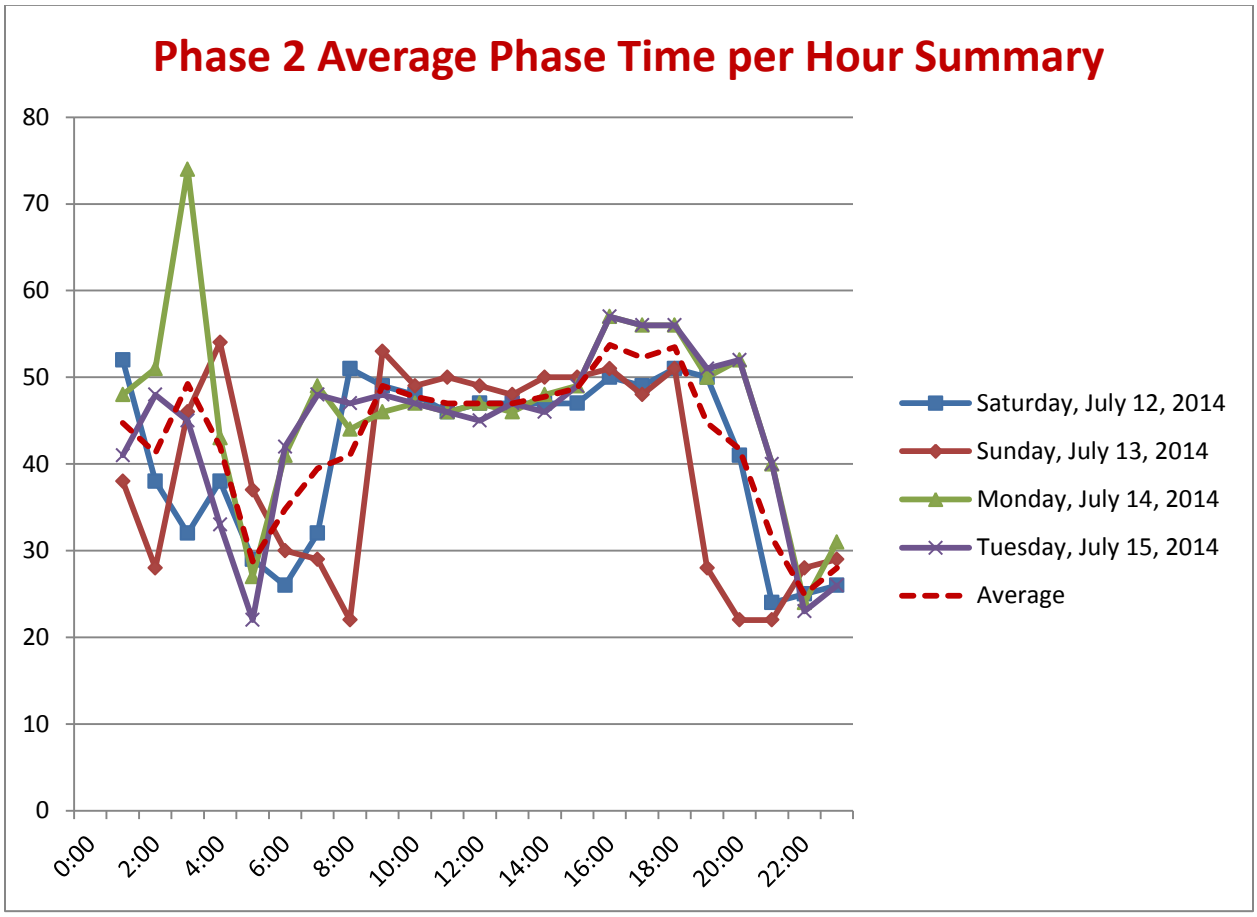


Figure 9. Average Hourly Phase Time for Phase 2 during Four Days.

Figure 10 illustrates that when the day selection is restricted to a single day, the program allows the report to include all user-selected phases; in this case, all six phases at the diamond interchange.

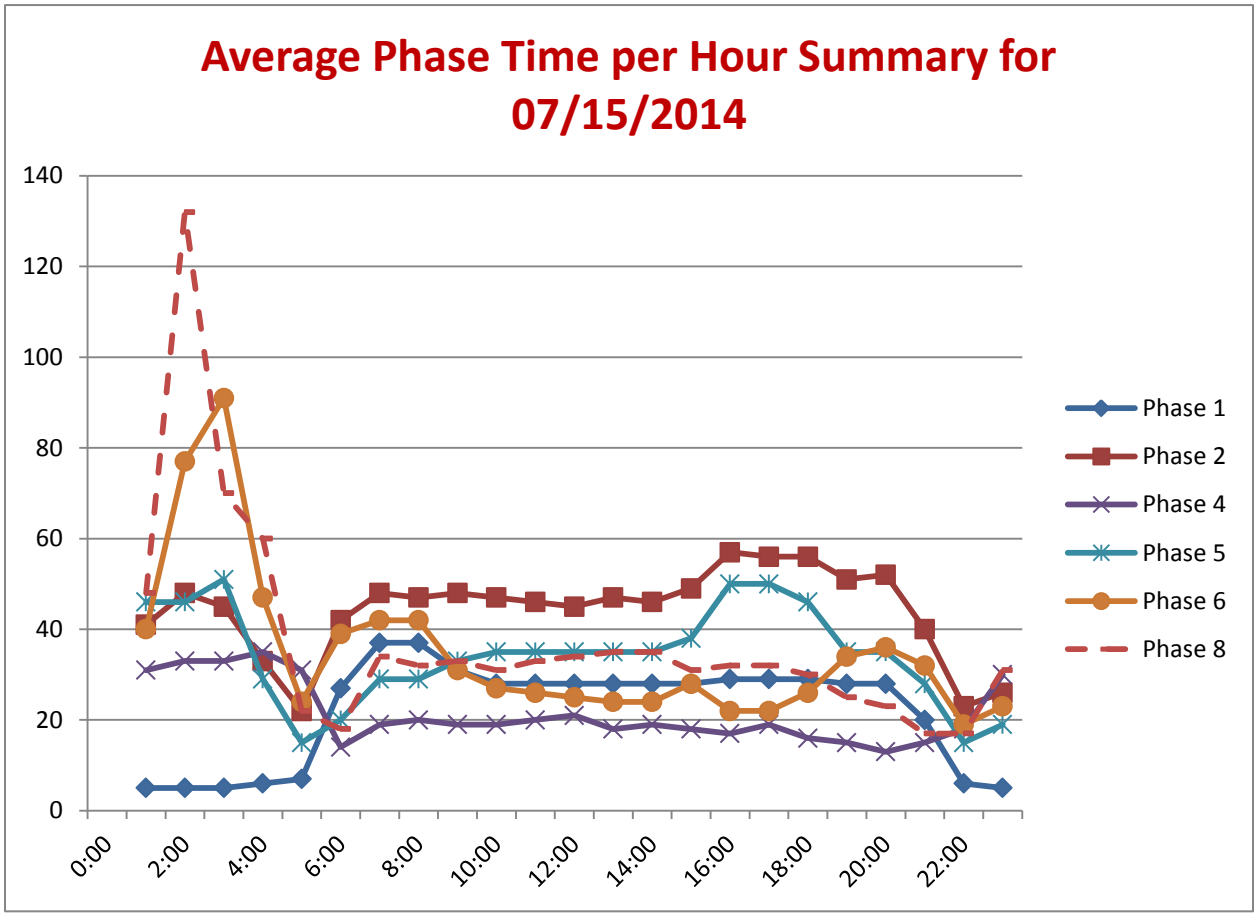


Figure 10. Average Phase Times for All Six Phases for One Selected Day.

When the user asks the program to generate all MOEs at once, the program restricts selection of phases to one. Figure 11 illustrates two of the three MOEs from such a report. The user will note that even though average times for Phase 2 during early morning hours are very high, the number of max-outs is low. This is an indication that long times for Phase 2 during this period are the result of the signal dwelling in Phase 2 and not because of high demand. Selection of other hourly MOEs results in a similar report.

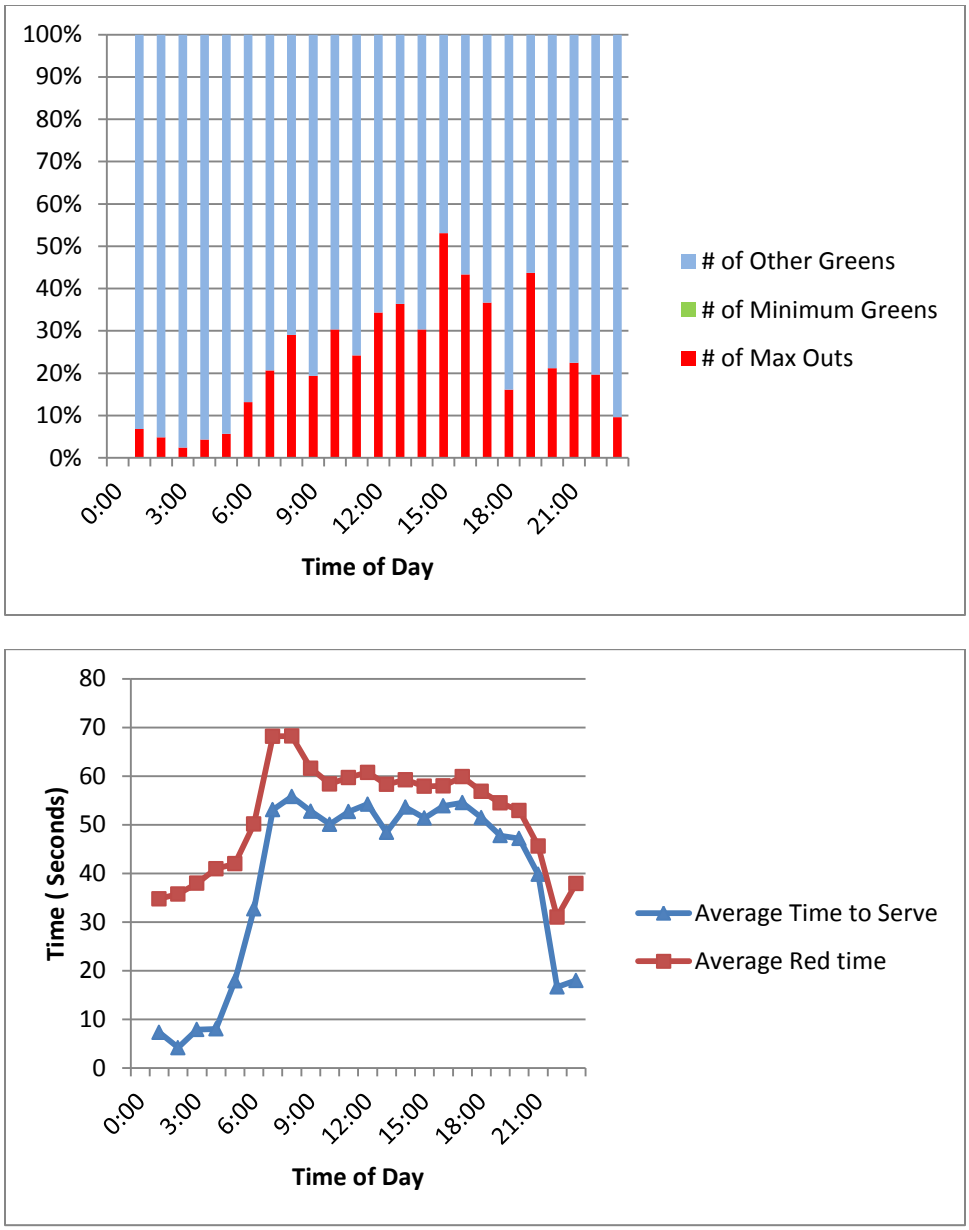


Figure 11. Two of Three MOEs for Phase 2 When User Selected All MOEs Option.

Update Module

NPTSES-U reads timing data from a UTDF file and allows users to download this data to a controller using NTCIP objects. Like the monitoring module, it can connect to a controller via Ethernet or serial port. However, it does not matter what type of connection a user chooses because communication speed is not critical in this case. NPTSES-U user interface provides access to various data screens via named tabs located at the top. The first screen that NPTSES-U displays allows the user to select a UTDF file. The second screen has a button, clicking on which causes the program to read the content of the selected file. At the completion of this process, the program shows the number of signalized intersections included in the data file, the identification number

that the optimization program used for the first intersection, and timing data for this signal. If the file contains more than one signal, the user can select another intersection from the dropdown list. Appendix B provides more information about the format of the UTDF file. Figure 12 shows a screen for a UTDF file for a single-intersection case. The next screen allows the user to connect NPTSES-U to a controller using a similar configuration screen as the monitoring module. As soon as NPTSES-U establishes a connection with the controller, it uploads a subset of controller database pertinent to timing data and displays it on the next screen together with the basic timing data read from the UTDF file. The objective of displaying data from both sources is to allow the user to verify data consistency before downloading new data. The user should note that there is no way to reverse the download action. Figure 13 illustrates this screen, which has four buttons to allow downloading of selected data or all data at once.

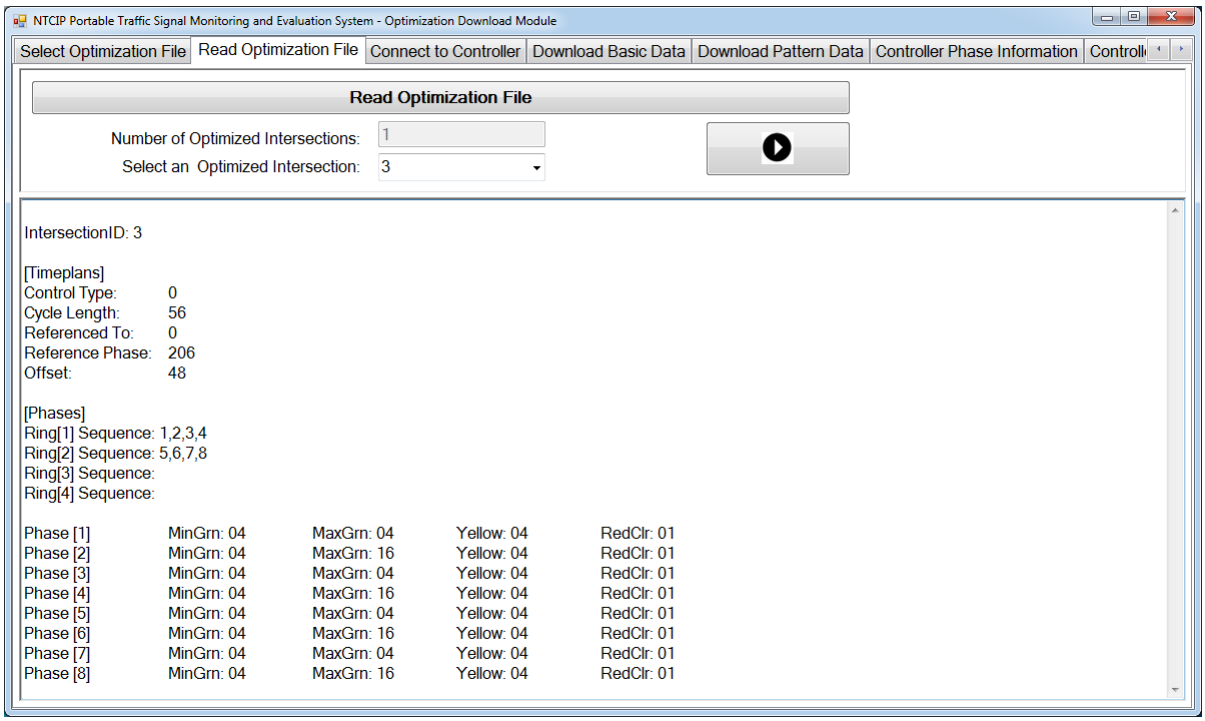


Figure 12. Timing Data Read from a UTDF File.

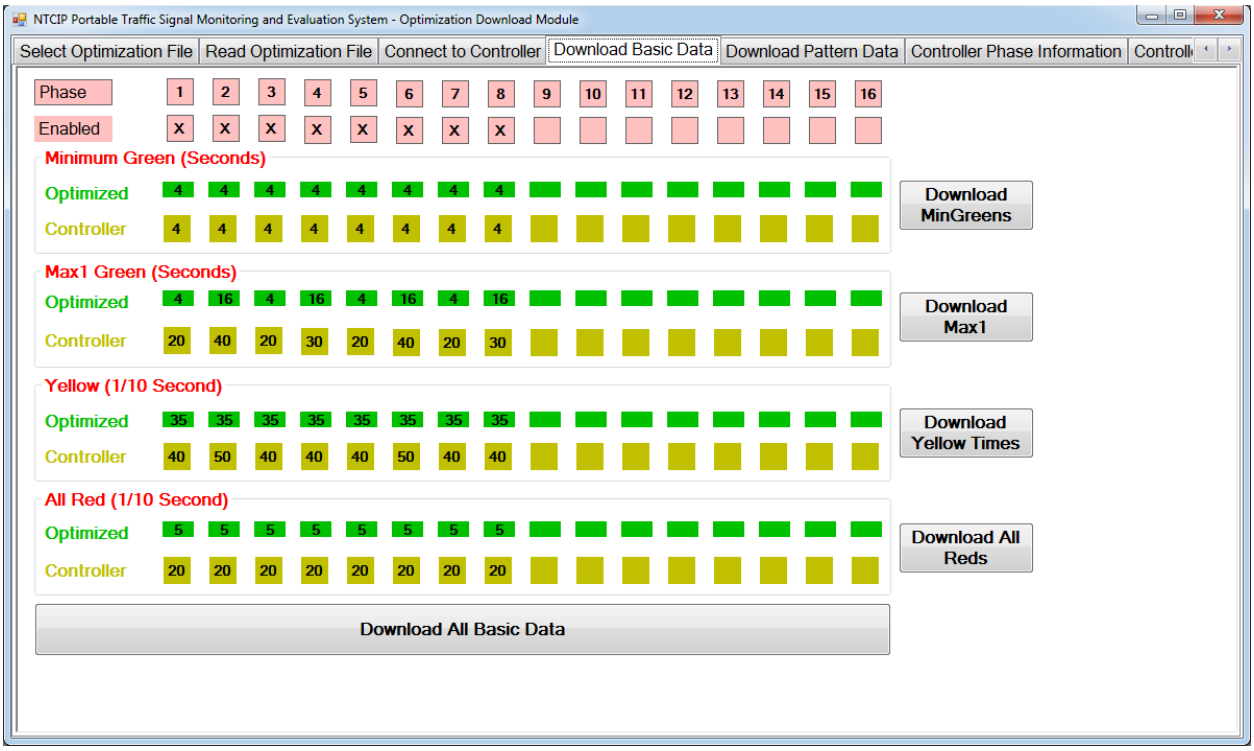


Figure 13. Basic Timing Data from a UTDF File and Controller Database.

Figure 14 shows the Download Pattern Data Tab. This screen displays optimized pattern data read from the UTDF file for the selected signal and allows the user to download this data to the controller. The program compares the optimized phasing sequence read from the UTDF file against phasing sequences programmed in the controller and identifies the appropriate sequence number. In this illustration, Sequence 1 (Ring 1: 1-2-3-4 and Ring 2: 5-6-7-8) in the controller matches the optimized phase sequence. At the top of the screen, the user can enter a valid pattern number and click the Get Pattern Data button to load controller pattern data corresponding to the selected pattern.

Figure 15 illustrates data read from a sample UTDF file against controller data for Pattern 3 for one of the test controllers used in this project. Clicking the Download Pattern Data button on this screen will cause NPTSES-U to write the new data to the selected pattern. Consequently, existing data in the associated split table (in this case, 3) will be overwritten along with the remaining pattern data.

The remaining two screens display basic timing data and phase sequence data programmed in the controller for reference purposes. Figure 16 and Figure 17 illustrate these screens.

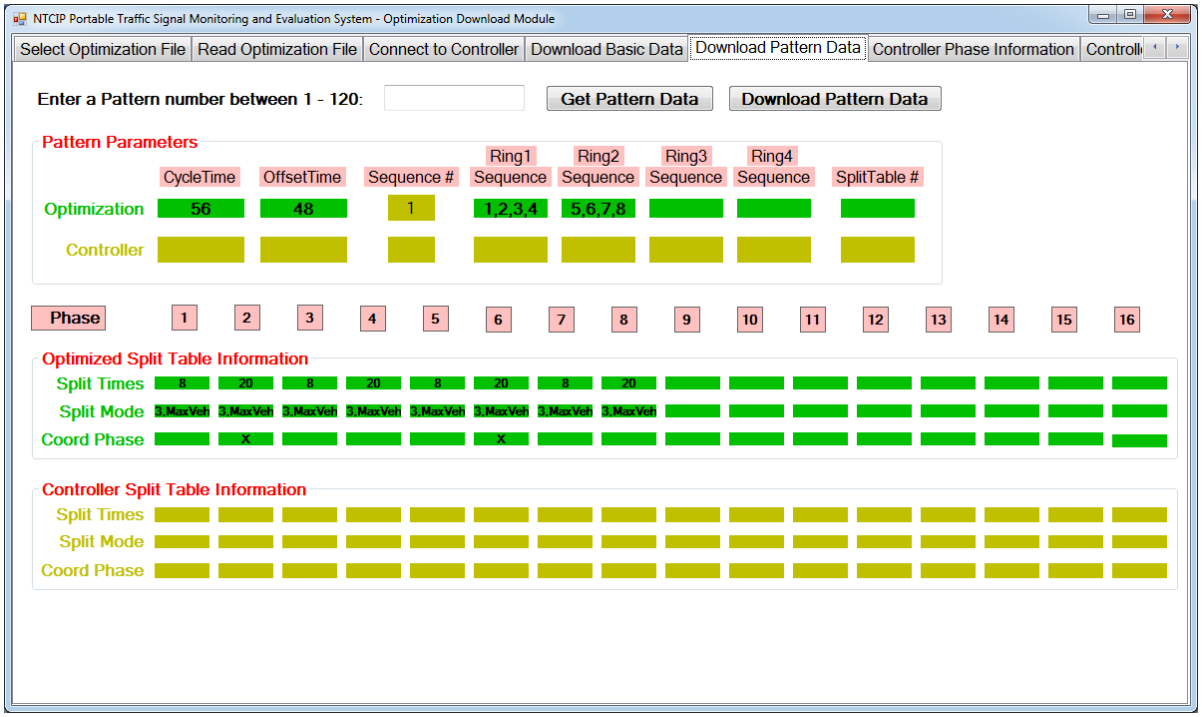


Figure 14. Pattern Data Screen.

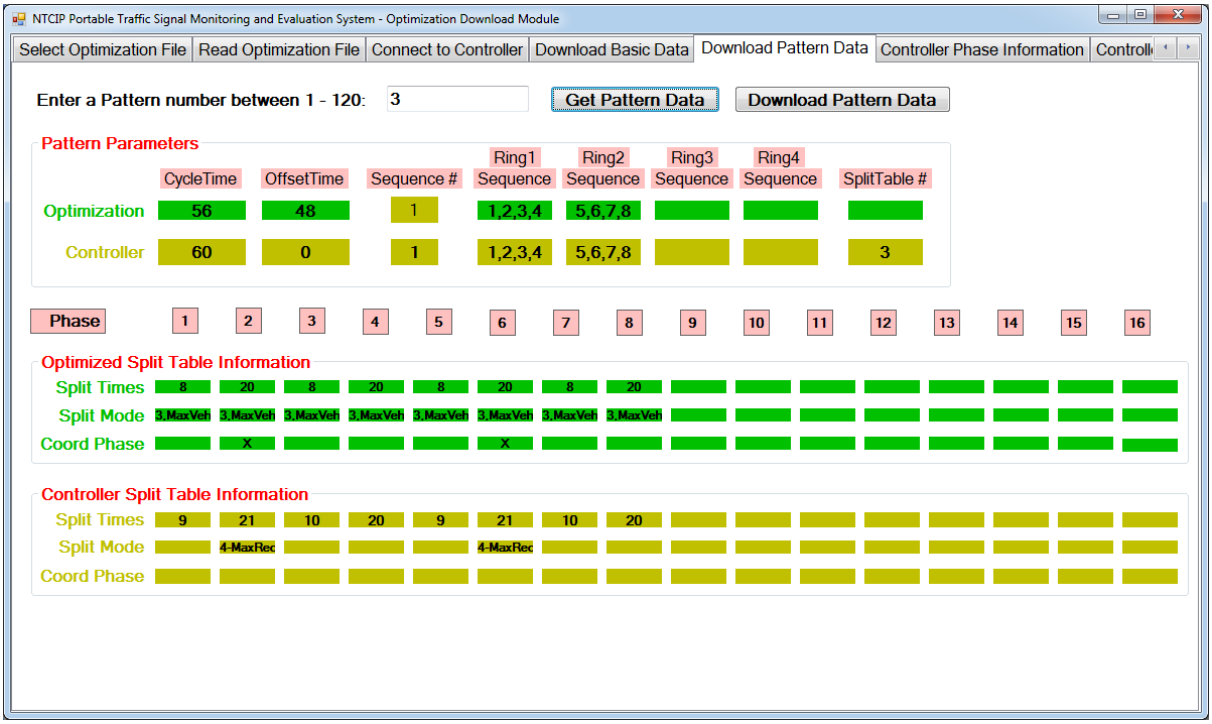


Figure 15. Screen Illustrating Patterns Data from a Sample UTDF File against Controller Data.

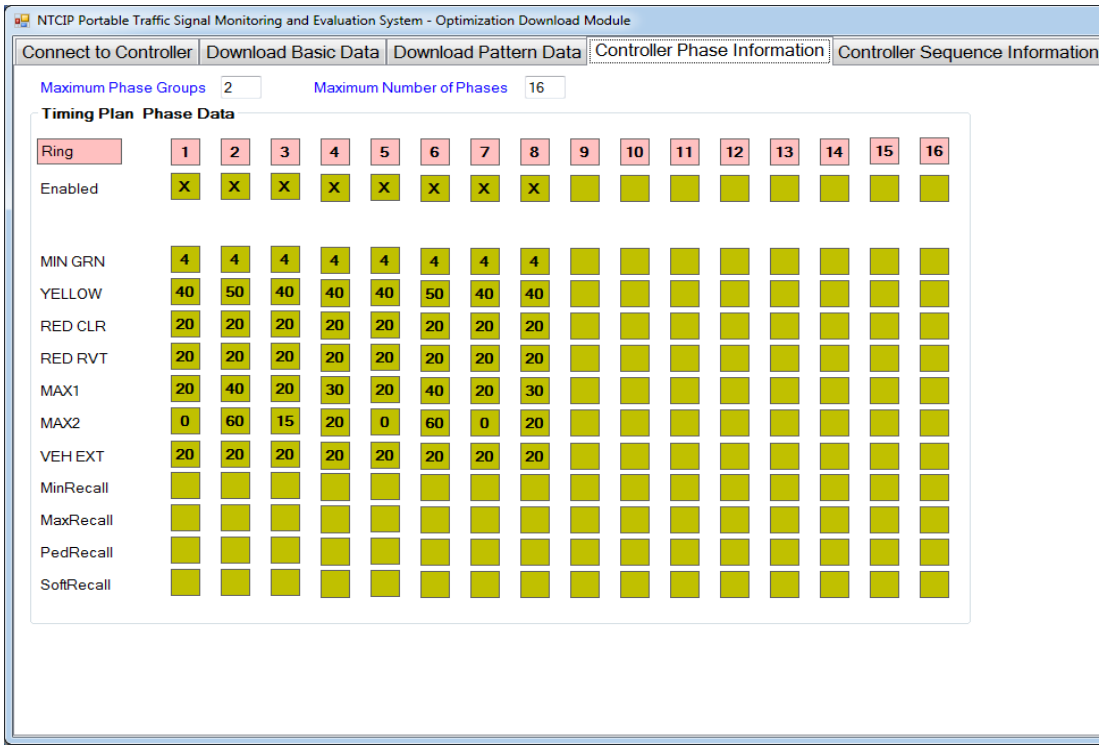


Figure 16. Phase Data Read from the Controller.

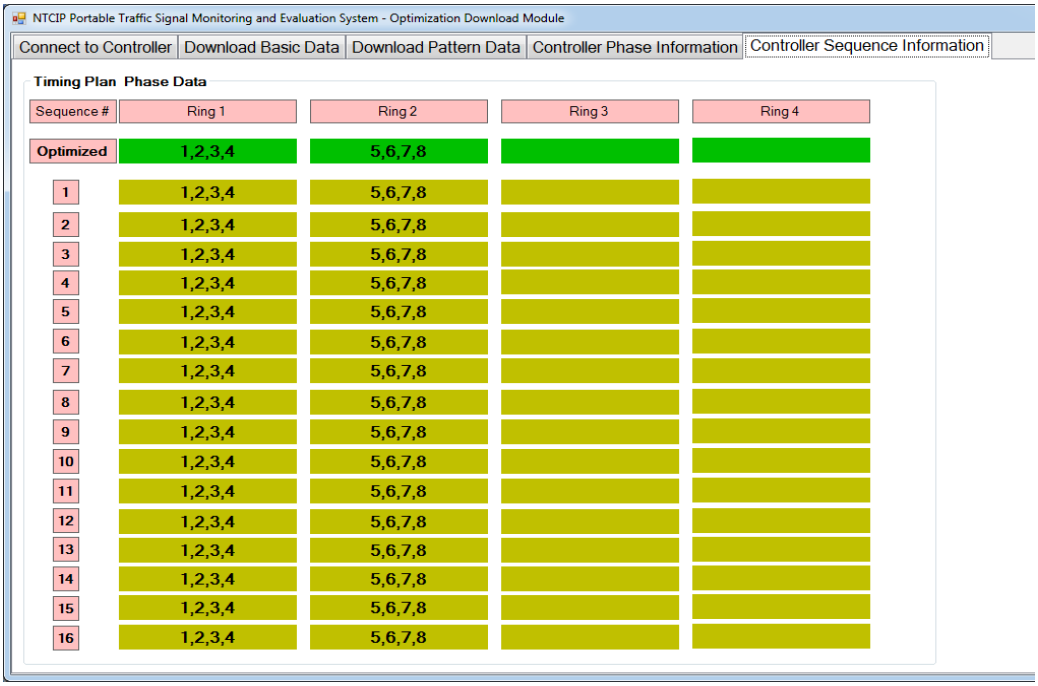


Figure 17. Phasing Data Programmed in the Controller.

IN-LAB TESTING

INTRODUCTION

Throughout the development and refinement of the three toolbox modules, the researchers performed continual tests to ensure that they operated as intended. Initial tests used the software-in-loop (SIL) controller, followed by hardware-in-the-loop (HITL) tests, and finally field tests at several locations. As the development work progressed, researchers continued to rely on all three types of tests, with a focus on HITL-based and field tests, to ensure that any software refinements and bug fixes did not introduce additional bugs.

SIL-BASED TESTING

SIL-based tests used an Econolite™ soft controller for first-level testing of any new or revised software code. In this testing, researchers primarily tested NPTSES-M and NPTSES-U modules. Researchers conducted most of this testing on the computer used for software development, where the software module being developed was running in debug mode. In this testing, the toolbox interfaced with the software version of a real controller, both running on the same computer with communications between the toolbox and the soft controller established through the computer's IP address. As illustrated in Figure 18, this testing allowed the researchers to verify quickly and visually that the toolbox was correctly using the NTCIP Get and Set commands.

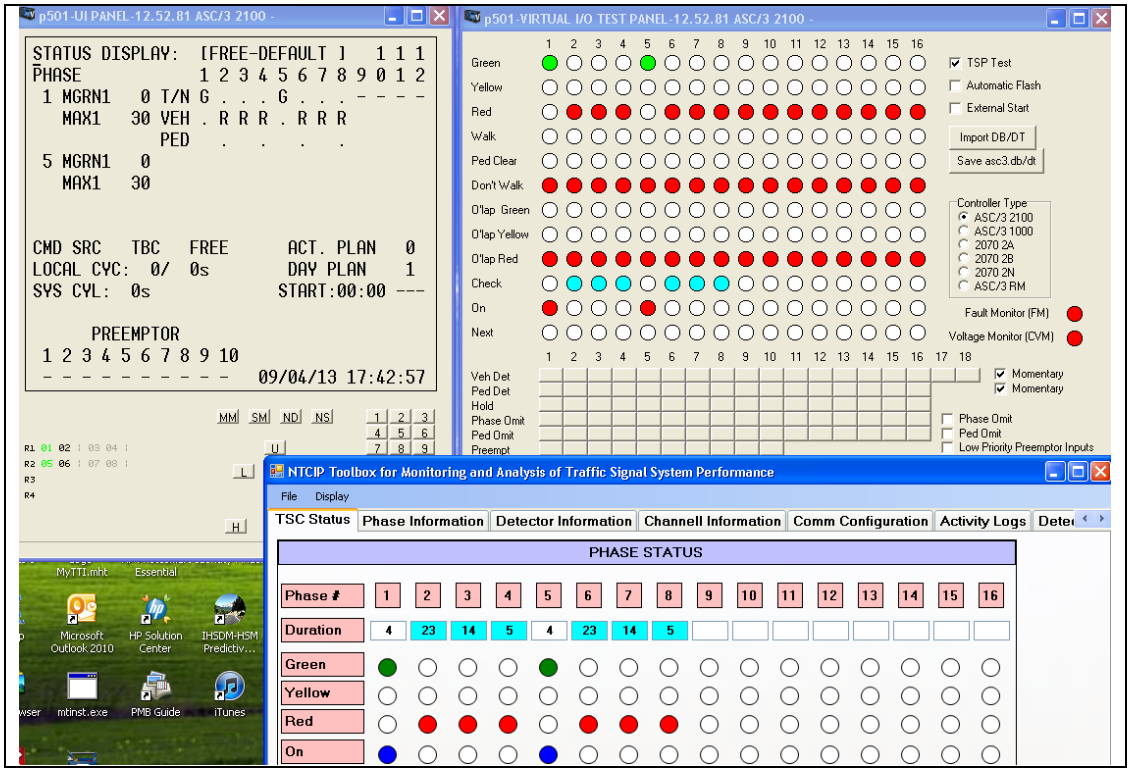


Figure 18. Toolbox Testing Using Econolite Soft Controller.

Researchers also added a communication delay logging/viewing feature in NPTSES-M to evaluate time required to get real-time statuses of various controller events. Figure 19 shows an earlier version of the screen used to monitor communications delays, which are low because both NPTSES-M and the software controller resided on the same computer.

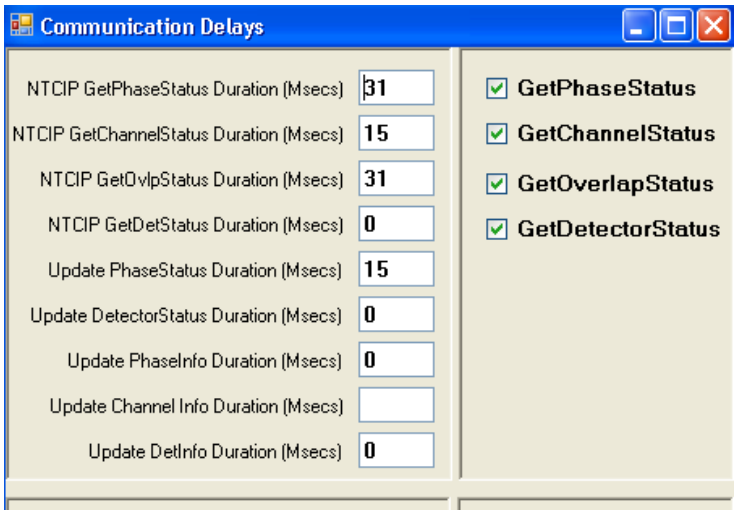


Figure 19. Built-in NPTSES-M Delays Analysis Screen.

INITIAL HITL-BASED TESTING

HITL-based testing of NPTSES consisted of several stages, all done on a field-hardened laptop computer and connected to one of the test controllers via Ethernet or serial port, to run NPTSES-M and NPTSES-U modules. The initial stage did not involve any other process. It allowed the research team to evaluate the communication and data exchange functionality of NPTSES-and NPTSES-U modules. This testing proved that the toolbox can physically interface with real controllers using both serial and Ethernet ports. The testing also showed that serial-based NTCIP communication is not fast enough for real-time monitoring of controller events.

NPTSES-U testing at this stage also included its ability to read timing data from UTDF files and download to controllers. This testing used UTDF files that the research team created for several cases, including:

- A single intersection cases with permissive left-turn-only phases.
- A single intersection case with protected/permissive left turns.
- A two-intersection coordinated system.
- A three-phase diamond interchange.
- A four-phase diamond interchange.

Researchers used the following controllers in this testing phase:

- Naztec 980, NTCIP Version 61.4i.
- Naztec ATC, Version 76.8F, Build 3418.
- Siemens ITS M50, Version EPAC 300w/NTCIP OS # 4.02f.
- Econolite, ASC/3-2100, Version Beta 02.52.81, Configuration N3000.
- Intelight ATC X-1, Model Max T, Version 1.7 Demo.

Naztec 980 only supports serial-based communications. When available (as in the case of the tested controller), the Ethernet port on this model uses serial over IP communication protocol, which does not offer any advantage in terms of communication speed. All other controllers are capable of full Ethernet communications.

PREPARATION FOR EXTENDED NPTSES TESTING

This phase of testing involved corridor simulation (CORSIM) to provide simulated traffic actuations to a real controller. In preparation for this testing phase, researchers created the following test cases:

- A single intersection test case to evaluate toolbox application to an intersection running free under different traffic loadings.
- A two-intersection test case to evaluate application of the toolbox to a coordinated intersection.
- Two diamond interchange test cases—a tight diamond and a wide diamond—to evaluate the application of the toolbox to diamond interchanges operating under 3-phase and 4-phase control.

However, the bulk of this testing uses the single intersection case described here in detail. This test case represented a four-legged single intersection with high-speed approaches in the east-west direction and a minor-street in the north-south direction. The major street is a four-lane highway with left turn bays, while the minor street is a two-lane highway with left-turn bays. One key objective of this exercise is to simulate typical detector configurations using a single base test case. This simulation model includes detectors for generating actuations needed for actuated operations as well as system detectors to collect traffic counts. This test case has the following detector configuration:

- All stop bar detectors, including those in left-turn bays, are 60 ft long.
- Detectors in left-turn bays call left-turn phases.
- Detectors in through lanes call through phases. Through detectors on each major approach are on a single channel.

- Dilemma zone detectors were placed in all main lanes and located at distances of 320 ft, 430 ft, and 540 ft from the stop bar. All dilemma zone detectors on an approach were configured to call the through phase on a single channel.
- System detectors were configured upstream of the stop bar detectors in all lanes including turn bays. However, each system detector was configured to be on a unique channel to allow collection of accurate count data

Typical dilemma zone and system detectors are 6 ft long. However, the CORSIM simulation model, which uses a time step of one second, cannot correctly model such short detectors because it often misses vehicle detections occurring between two time steps. To overcome this problem, researchers took the following measures after making several calibration runs:

- Selected approach speeds of 30 mph.
- Increased sizes of these detectors to 35 ft.

Figure 20 illustrates the single intersection test case. This illustration does not show system detectors on major approaches since they are located farther upstream of the dilemma zone detectors.

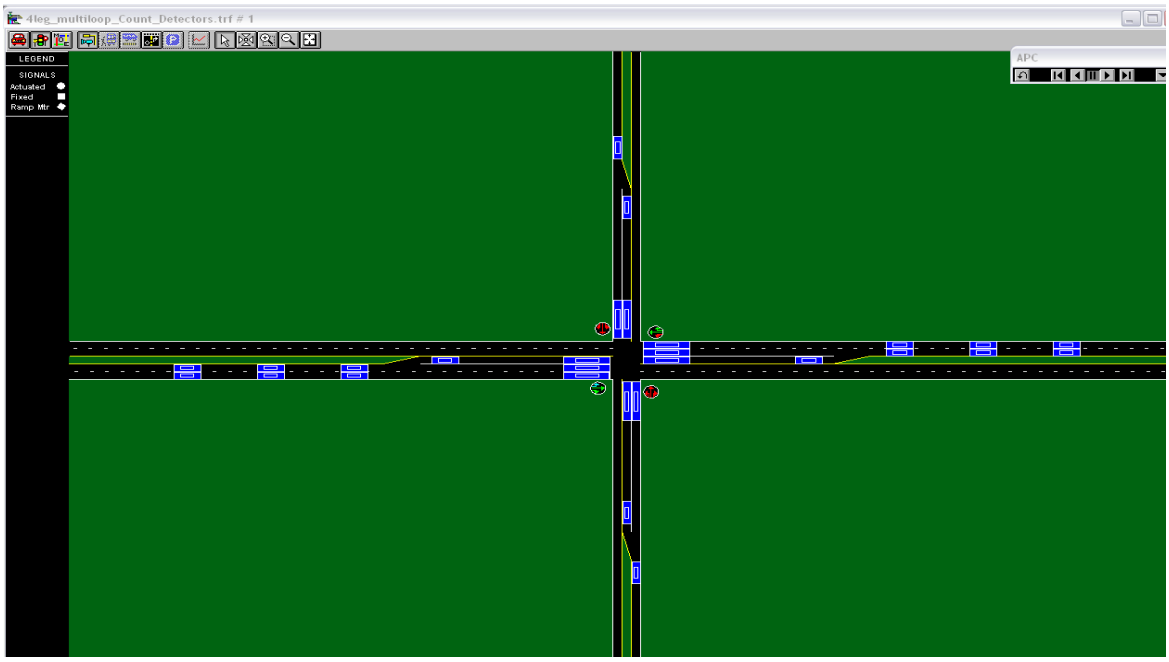


Figure 20. Illustration of the Single Intersection Test Case in CORSIM.

Table 2 provides detailed information and mapping of simulated detectors to controller channels for this test case. The other simulation test cases, which are configured similarly, do not have system and dilemma zone detectors.

Researchers programmed an Econolite controller for use in a simulated environment by entering the data identified in Table 3 through Table 6. In addition, they programmed Preempt 1 for

testing NPTSES-M when a controller is under a preempt call. Researchers generated these calls manually as described later.

Table 2. Configuration of Detectors for the Single Intersection Simulation Test Case.

Simulation Detector	Controller Channel	Detector Type	Assigned Phase	Detector Location Description
1	1	Stop Bar	1	Westbound left
2	2	Stop Bar	2	Eastbound through
3	3	Stop Bar	3	Northbound left
4	4	Stop Bar	4	Southbound through
5	5	Stop Bar	5	Eastbound left
6	6	Stop Bar	6	Westbound through
7	7	Stop Bar	7	Southbound left
8	8	Stop Bar	8	Northbound through
9	9	Dilemma Zone	2	Eastbound
10	9	Dilemma Zone	2	Eastbound
11	9	Dilemma Zone	2	Eastbound
12	10	Dilemma Zone	6	Westbound
13	10	Dilemma Zone	6	Westbound
14	10	Dilemma Zone	6	Westbound
17	11	System Detector	None	Westbound left turn lane
18	12	System Detector	None	Northbound left turn lane
19	13	System Detector	None	Eastbound left turn lane
20	14	System Detector	None	Southbound left turn lane
21	15	System Detector	None	Eastbound outside lane
22	16	System Detector	None	Eastbound inside lane
23	17	System Detector	None	Westbound outside lane
24	18	System Detector	None	Westbound inside lane
25	19	System Detector	None	Northbound approach
26	20	System Detector	None	Southbound approach

Table 3. Base Timing Plan.

Parameter	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
Minimum	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Walk		4.0		6.0		4.0		6.0
PCL		15		17		15		17
Veh Ext	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Max 1	20	40	20	30	20	40	20	30
Yellow	4.0	5.0	4.0	4.0	4.0	5.0	4.0	4.0
All-Red	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Table 4. Scheduled Events.

Event	Action Plan	Start
1	2	7:00
2	3	12:00
3	4	18:00
4	1	22:00

Table 5. Action Plans.

Action Plan 1		Action Plan 2		Action Plan 3		Action Plan 4	
Pattern	Flash	Pattern	1	Pattern	2	Pattern	Auto
		Sequence	1	Sequence	2	Sequence	1

Table 6. Phase Splits for the Two Patterns.

Split	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
1	18	54	19	29	18	54	19	29
2	20	40	20	30	20	40	20	30

Table 7. Coordination Patterns.

Pattern	Cycle	Offset	Split Pat	Action Plan	Sequence	Ring 1	Ring 2
1	120	63	1	2	1	1234	5678
2	110	24	2	3	2	2134	5678

EXTENDED TESTING OF NPTSES-M

As shown in Figure 21, the environment for testing NPTSES-M consisted of the toolbox, a desktop computer, a traffic controller, a TS2 Testbox, and appropriate cables configured as follows:

1. Toolbox connected to the controller via Ethernet or serial port.
2. TS2 Testbox connected to the controller via SDLC port.
3. A desktop computer, connected to the Testbox through a serial port, for HITL-based testing.

The research team conducted testing of NPTSES-M in the following three stages:

1. Verification of the correctness of static and real-time data that NPTSES-M uploaded.
2. Use of TTI's Snooper program (Figure 22) to manually activate various detector calls, preempt calls, phase omits, and phase hold signals to the controller and visual verification that NPTSES-M correctly obtains statuses of resulting controller events.
3. HITL-based computer simulations using TSIS-CORSIM™ for various lengths of time ranging from an hour to 30 hours.

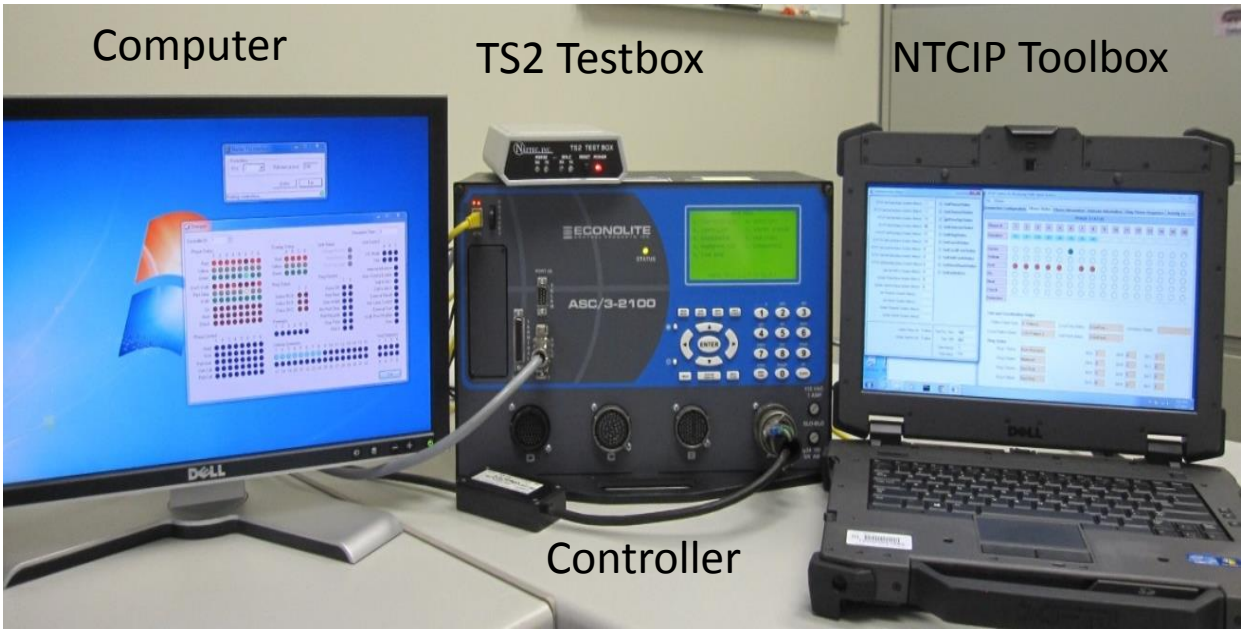


Figure 21. Environment for Testing of the Monitoring Module.

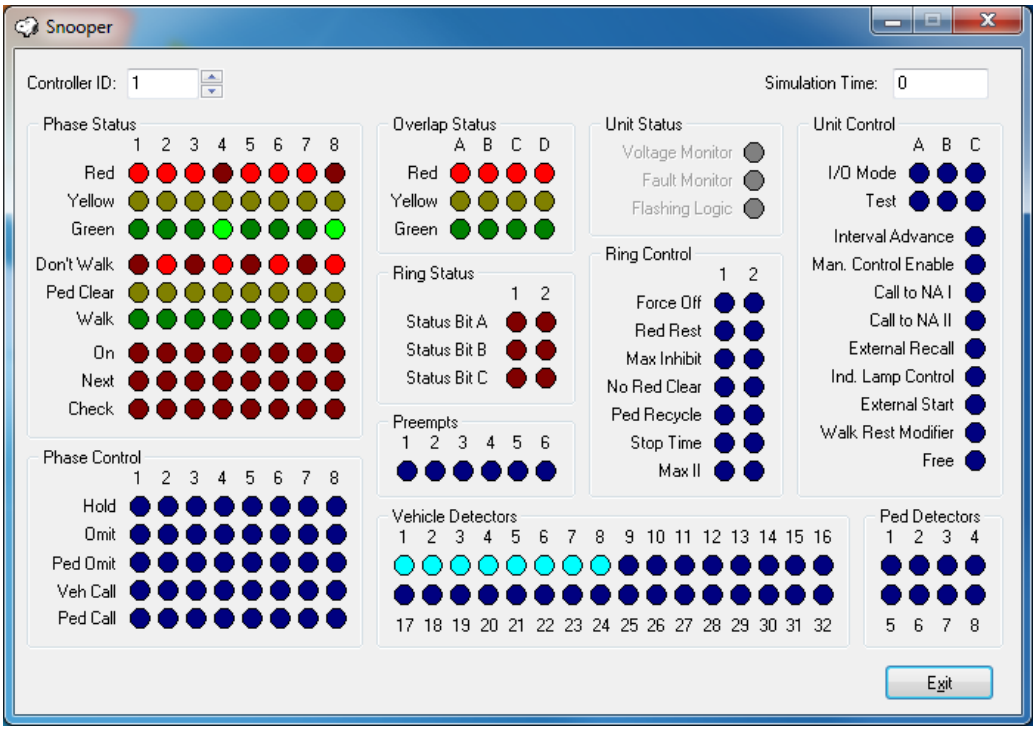


Figure 22. Snooper Interface.

This testing identified several issues including some controller-brand specific issues reported to the project monitoring committee in a technical memorandum. In subsequent months, researchers made appropriate revisions to the NPTSES-M and NPTSES-U modules to address all the identified issues. As part of these revisions, the researchers extended the delay monitoring feature of NPTSES-M (see Figure 23 and compare it with Figure 19).

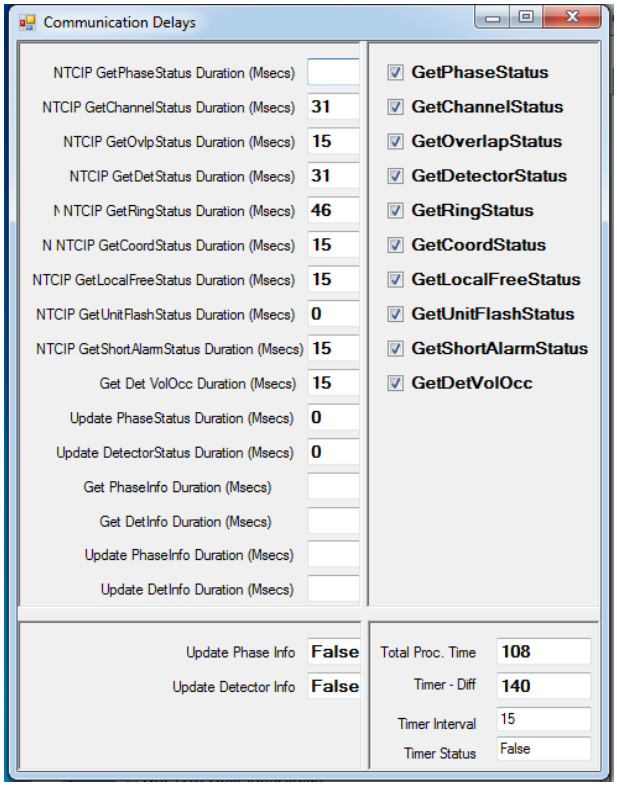


Figure 23. Status of Communication Delays.

Researchers also added a capability to upload NTCIP volumes and occupancies that the controller had collected internally. NPTSES-M automatically sets the polling interval of 60 seconds for uploading these data. However, the user must program the optional detector settings in the controller to allow internal collection of these data.

The first part of Stage 2 testing verified that the monitoring module correctly uploaded and displayed static data programmed in the controller. These data included, but were not limited to, basic signal timings (Figure 3), phasing sequences (Figure 5), and channel data.

TESTING OF NPTSES-A

The analysis module reads processed data that the monitoring module had written to the hard disk, and presents these in a graphic format for easy interpretation. It allows the user to select desired data files containing specific measures of effectiveness. In-lab testing of this module verified that it is correctly reading and processing data files that the monitoring module had written during HITL simulations. Figure 24, Figure 25, and Figure 26 provide illustrations of selected MOEs collected during a simulation run from midnight to 11:00 a.m. Note that the intersection operation switched from free to Pattern 1 (120-second cycle length) at 7:00 a.m. This change is reflected in these figures as an increase in average green times for Phases 2 and 6 as well as an increase in delay (that is, average time to service) for most minor phases. Percent phase utilization (left-side graph in Figure 26) for Phase 4 shows that it has reserve capacity.

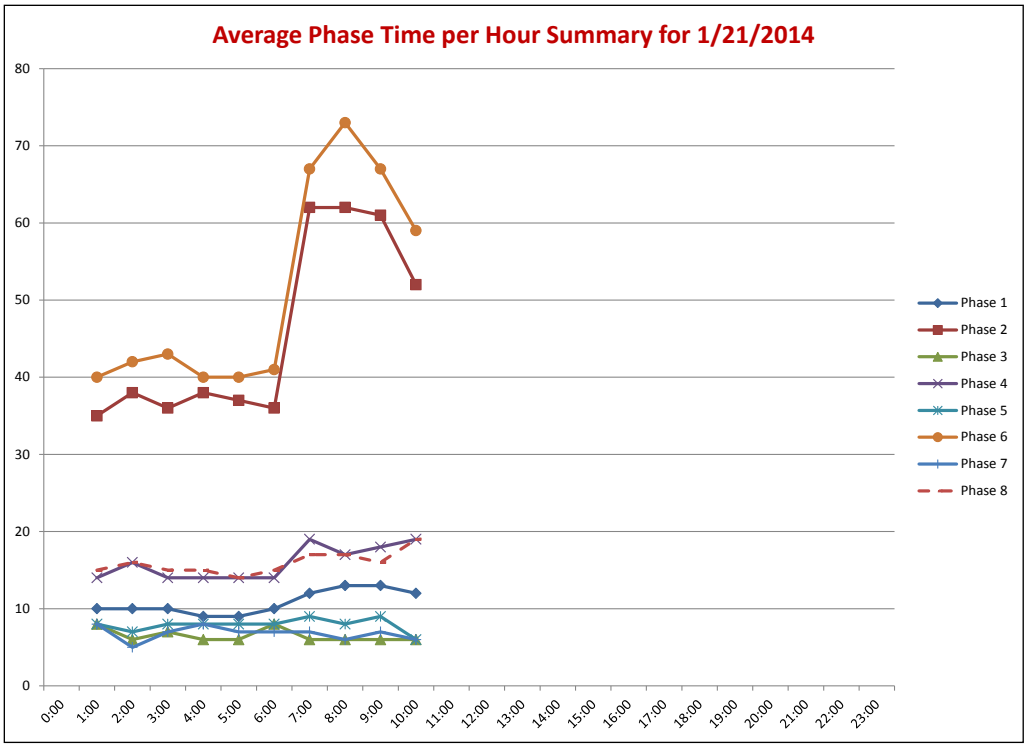


Figure 24. Comparison of Average Phase Lengths for Multiple Phases.

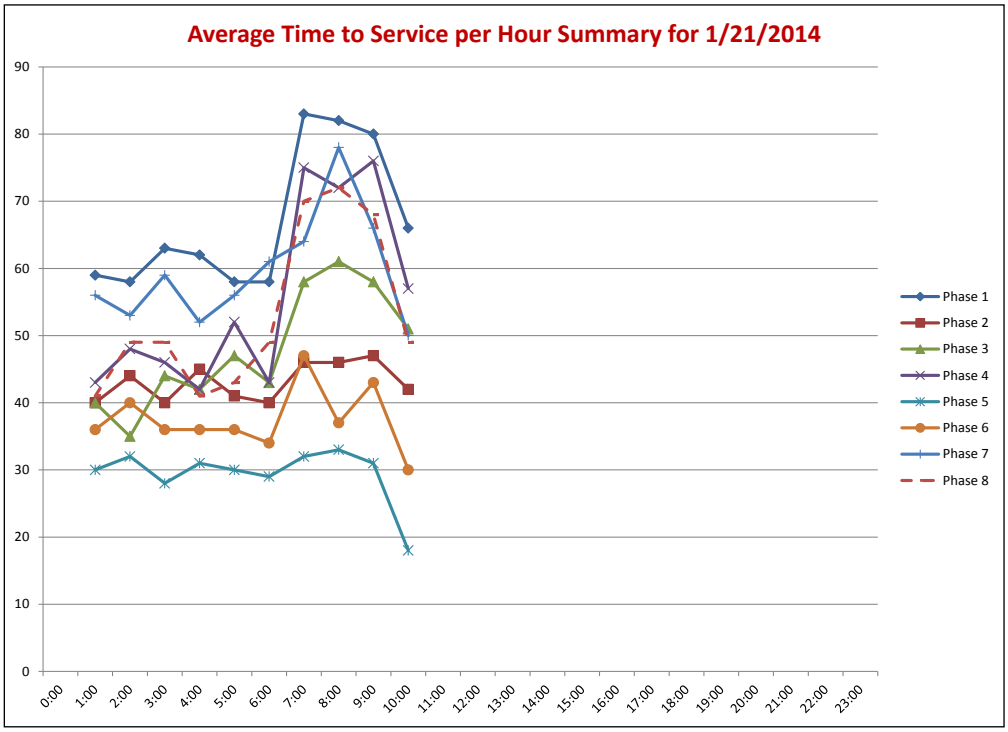


Figure 25. Comparison of Average Service Time for Multiple Phases.

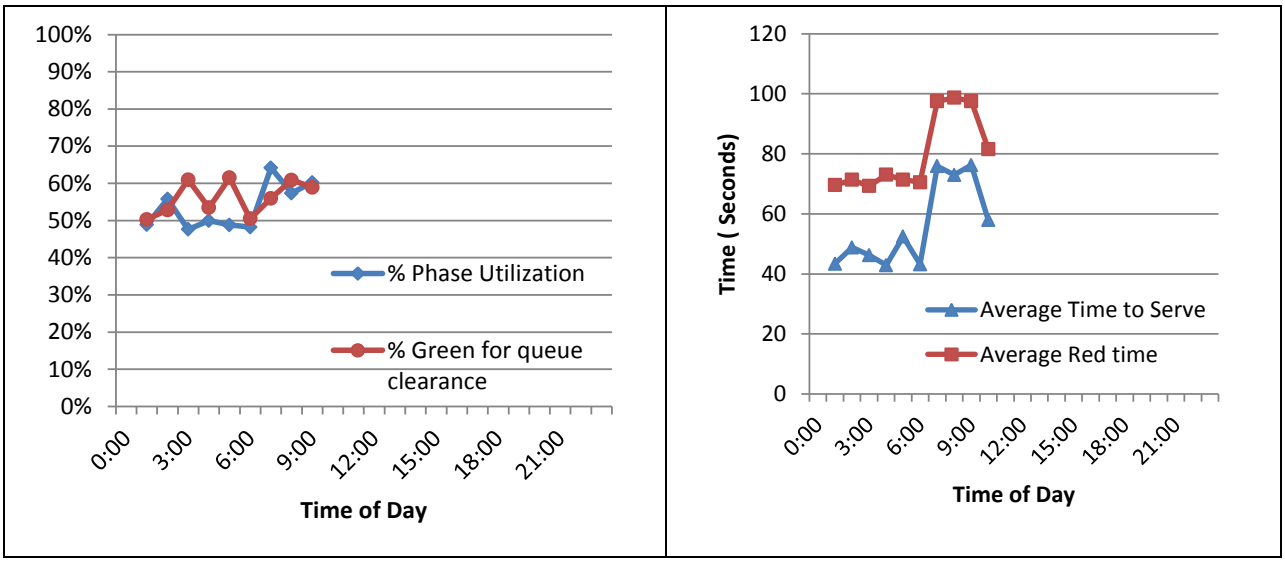


Figure 26. MOEs for Phase 4.

TESTING OF NPTSES-U

NPTSES-U reads signal-timing data from a UTDF file and allows the user to download these data to the controller using NTCIP messages. This stage of testing verified that NPTSES-U correctly reads and interprets UTDF files. Testing also verified that it is able to correctly load needed data from NTCIP-compliant controllers, and can correctly write timing data to a controller's database. An earlier chapter provided illustrations of screens for this module.

FIELD TESTING

INTRODUCTION

Project requirements dictated that the toolbox modules be tested at a minimum of three field sites with the following characteristics:

- Isolated intersection or isolated diamond interchange.
- Signal or diamond interchange running in a coordinated mode.
- An intersection with preemption and pedestrian activities.

Researchers selected the following sites to satisfy these requirements:

- A diamond interchange located at the intersection of SH 6 and Briarcrest Drive in Bryan, Texas. This location uses an Intelight® X-1 controller, which also provides time-based coordination with an adjacent signal system. Field testing at this site began on February 25 and continued for two weeks.
- A three-legged isolated intersection located at the intersection of US 79/190 and SH 36 in Milano, Texas. This intersection uses a Siemens® M50 controller. To allow field testing, the controller had to be reinitialized and rebooted to load NTCIP-compliant firmware that was stored in the controller memory but was not being used. This change also required manual onsite reconfiguration of the signal timing database in the controller. The controller also had to be reinitialized and rebooted to activate Ethernet-based communications. Toolbox testing at this site began on March 18 and continued for two weeks.
- A four-legged intersection located at FM 1960 and Stuebner Airline in Houston, Texas. This intersection used an Econolite® ASC/3 controller, runs in a coordinated mode, and experiences significant pedestrian activity. The toolbox was placed in the signal cabinet at this site on May 5 and retrieved on May 9.
- An isolated diamond interchange located at the intersection of FM 1960 and IH 45 in Houston, Texas. This location uses an Econolite ASC/3 controller to provide a four-phase diamond operation strategy. This site provides preemption to accommodate a nearby fire station. A second laptop was placed in the signal cabinet at this site on the afternoon of May 5 and retrieved on May 9. Upon retrieving the toolbox from this site, researchers discovered that the computer had automatically shut off the same day after a few hours of operation. An inadvertent power-saving setting on the operating system turned out to be the cause of this undesired result. Nonetheless, the toolbox was able to collect more than four hours of data. However, this duration was not sufficient to record any preemption events.
- In addition to the above in-field tests, researchers also conducted limited testing to evaluate if the toolbox could be used from a remote location. These tests were carried out on April 23 and involved remote connections to the following three controllers from the TxDOT District office in Houston:

- The first remote site is the intersection of FM 2920 and Alvin A. Klein Road in Spring, Texas. This site has an Econolite ASC/3 controller. Both monitoring and download modules were successfully connected to this site, and researchers were able to upload controller data that they collected. However, the communications speed was too slow for real-time monitoring using NTCIP-based messages, which often required over 2 seconds to complete each data collection cycle.
- This site consists of two closely spaced intersections (FM 2920 and Spring Cypress at Holzwarth Road in Spring, Texas). Here, an Econolite ASC/3 controller was used to provide signal control at the two intersections using several phases and overlaps. Testing at this site revealed that remote communications using NTCIP-based messages is too slow for real-time monitoring. At this location, one complete cycle to get statuses of phases, detectors, and channels took 2–3 seconds.
- FM 29202 Dowdell Road (Siemens M50 controller). The toolbox was unable to communicate with this controller. Like other controllers with center-to-field communications, this controller is also connected to a computer server at the district office. It appears that this version of the Siemens controller is not capable of simultaneous communications with multiple computers. However, this issue needs to be verified through the manufacturer.

During the April 23 visit to the Houston District office, the authors also demonstrated the steps that the update module (NPTSES-U) required to read an optimization output from Synchro and download new timings to a controller.

RESULTS OF FIELD TESTING

Evaluation of the toolbox, especially the monitoring module, revealed that it successfully gets most of the desired data from the three controllers (Econolite ASC/3, Siemens M50, and Intelight ATC) available at the above test sites. Field testing identified the following issues:

- The toolbox is not able to correctly get concurrent phase and phase sequence data from the Siemens M50 controller. The research team used NTCIP Exerciser, V3.3b7, to verify this controller's compliance with NTCIP 1202 standard, and found that the exerciser gets phasing sequence data correctly. The researchers then evaluated the toolbox code to identify the cause of this discrepancy. This investigation revealed the string of data that the controller returned in response to the toolbox request does contain the correct phase sequence data, but it is in a different format than all other controllers tested. The research team has identified and implemented a fix for this issue.
- The toolbox correctly obtains concurrent phase data from the Intelight controller, but returns no data for phase sequences. When the research team conducted tests using the NTCIP Exerciser, they obtained the same results. Upon inquiry, the vendor revealed that the subset of NTCIP protocol dealing with ring sequences has not been implemented at this time. To work around this issue, the vendor provided their proprietary object identifiers to obtain sequence data. The research team has already implemented a customized fix based on this information.

As stated earlier, remote communication using NTCIP objects is not fast enough to obtain status data in real time, but it can be used to download optimized timings to controllers from a remote location.

Appendix C provides Google® maps of the above test sites, and basic timing data and detector mappings that the monitoring module obtained from controllers at these sites. Note that the controller database does not contain any information about direction and movement assignments to phases. In addition, the controller database does not contain detailed information (such as location, size, how many lanes it covers, etc.) about detectors. Such information is useful and at times necessary to understand data that the toolbox collected and reported. For this reason, phase to movement assignments have been added to maps in Appendix C. The following sections provide analysis results for selected sites.

Diamond Interchange at FM 2920 and I-45

As stated in the previous section, unintended power management settings on the laptop computer used at this site caused an automatic shutdown after a few hours of operation. Nonetheless, some useful data were collected, a summary of which is described below. Note that the duration of data collection was not long enough to capture any signal preemption events.

The controller database at this location specifies 11 vehicle detectors that are assigned to call various signal phases (see Appendix C). Table 8 provides 15-minute counts that the monitoring tool had monitored from actuations (on and off statuses) of these detectors.

Table 8. 15-Minute Detector Counts from FM 2920 and I-45 Interchange.

	Detector 1	Detector 2	Detector 4	Detector 5	Detector 6	Detector 8	Detector 11	Detector 12	Detector 15	Detector 16	Detector 21
Time	**1**	**2**	**4**	**5**	**6**	**8**	**2**	**4**	**6**	**8**	**8**
12:30:00 PM	0	92	153	0	41	136	104	2	47	28	35
12:45:00 PM	0	76	145	0	32	133	133	0	46	26	35
1:00:00 PM	0	69	137	0	37	135	111	22	51	29	47
1:15:00 PM	0	79	135	0	55	115	107	15	63	27	31
1:30:00 PM	0	95	120	0	37	99	127	46	37	28	32
1:45:00 PM	0	68	143	0	20	116	109	20	39	26	31
2:00:00 PM	0	80	156	0	23	113	124	1	36	32	40
2:15:00 PM	0	81	132	0	24	289	120	3	32	20	41
2:30:00 PM	0	82	127	0	29	369	95	2	27	33	37
2:45:00 PM	0	78	131	0	27	287	98	0	38	25	29
3:00:00 PM	0	0	115	0	26	367	135	4	27	31	45
3:15:00 PM	0	48	136	0	28	280	125	2	26	23	41
3:30:00 PM	0	95	73	0	32	326	118	10	35	34	43
3:45:00 PM	0	65	151	0	13	147	104	1	32	38	54
4:00:00 PM	0	90	175	0	23	117	97	5	28	29	40
4:15:00 PM	0	67	140	0	24	96	86	0	22	31	59
4:30:00 PM	0	70	168	0	12	88	111	3	20	41	47
4:45:00 PM	0	57	164	0	2	39	127	2	2	35	44
5:00:00 PM	0	75	156	0	15	89	102	0	18	38	39
5:15:00 PM	0	87	153	0	11	109	85	21	17	40	39
5:30:00 PM	0	106	166	0	2	234	110	3	16	43	31
5:45:00 PM	0	93	157	0	0	131	99	0	19	54	32
6:00:00 PM	0	91	142	0	0	68	108	15	20	39	39

The first thing to note in the above table is that all counts for Detectors 1 and 5 are zero. This could be the result of either one of the following two factors:

- Detectors 1 and 5 do not physically exist.
- Both detectors have failed.

To verify detector failure, the monitoring tool generates a report containing detector diagnostics data that the controller had generated based on appropriate programming of detector diagnostics parameters in the controller. For this test site, however, the diagnostics file that the toolbox had generated was empty. Because this interchange has U-turn lanes on both frontage roads, and is operated using the Texas 4-Phase diamond interchange control strategy, Case 1 is the most likely scenario. However, confirmation of this assumption required in-field verification.

By itself, the phase to movement mapping obtained from field observations (see Appendix C) is not sufficient to understand the implications or quality of these counts. For further analysis, additional information is required such as detector type (stop bar, setback, etc.), effective size of detection zone (6 ft, 40 ft, etc.), and number of lanes that this detector covered.

Figure 27 through Figure 30 provide plots of counts that the monitoring module had recorded from detectors assigned to Phases 2, 4, 6, and 8. The reader will note the differences in the magnitude of counts among detectors assigned to the same phase. For Phases 4 and 8, these differences are large. In addition, there are significant differences in magnitudes of counts between detectors assigned to different phases. For comparison purposes, note that the highest 15-minute counts from detectors assigned to Phases 2, 4, 6, and 8 are approximately 135, 174, 63, and 369, respectively. Detector design information is needed to interpret these numbers and to determine any potential issues with these detectors.

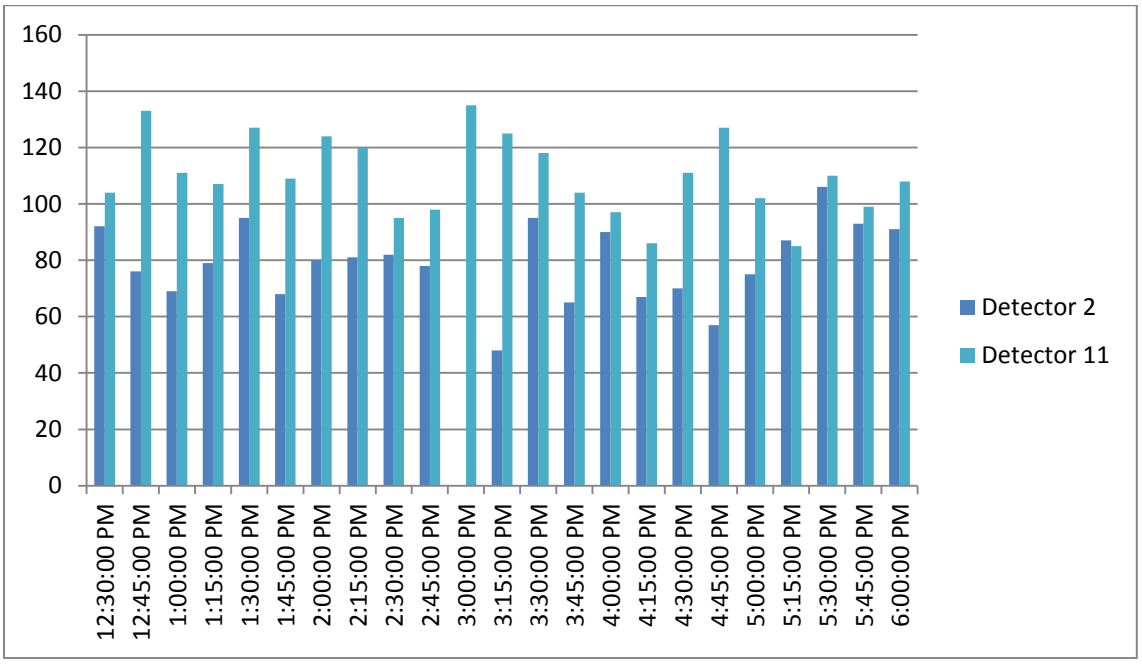


Figure 27. Counts from Detectors Assigned to Phase 2.

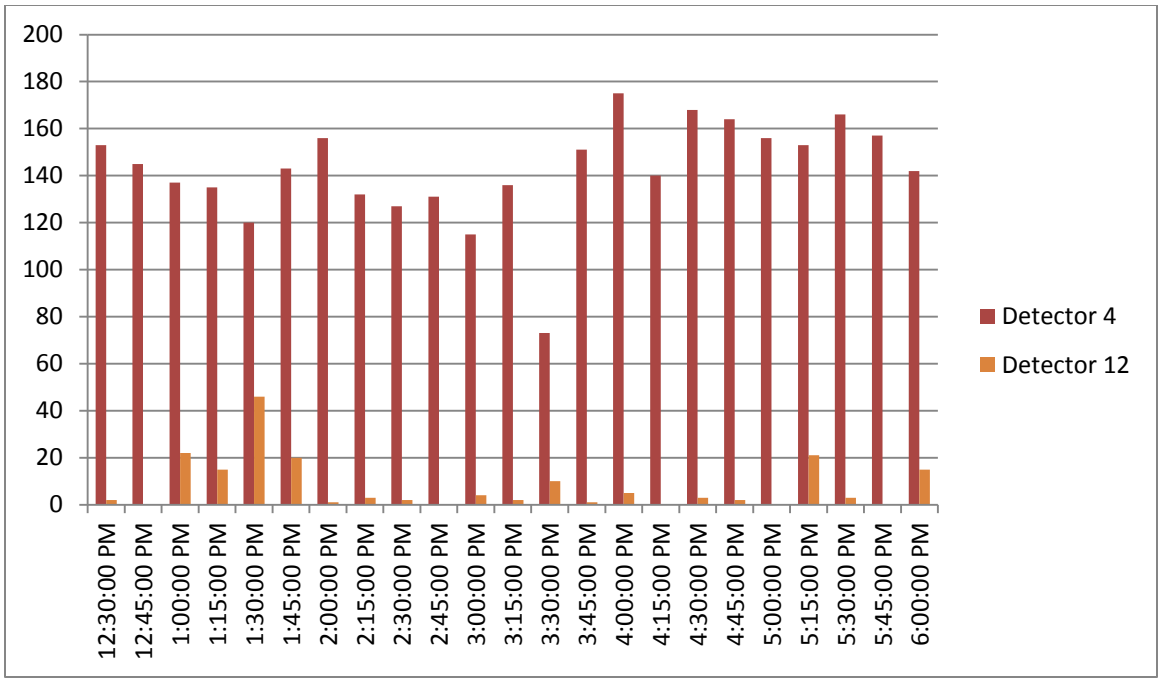


Figure 28. Counts from Detectors Assigned to Phase 4

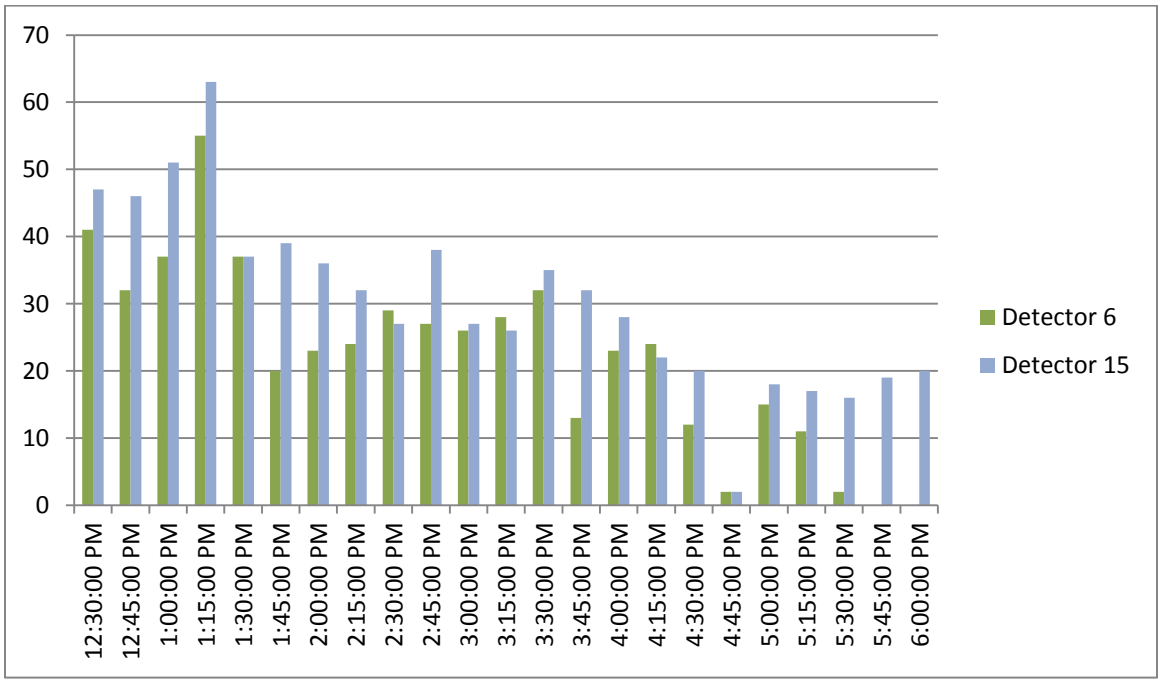


Figure 29. Counts from Detectors Assigned to Phase 6.

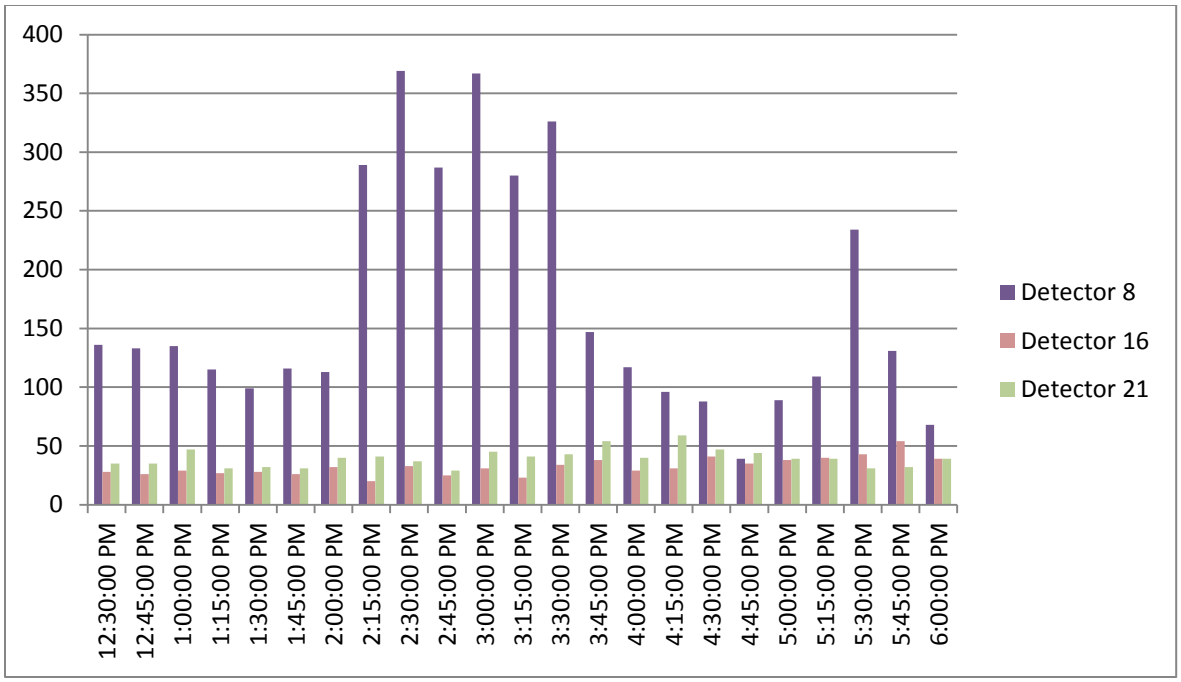


Figure 30. Counts from Detectors Assigned to Phase 8.

Figure 31 provides a plot of hourly average phase times for Phases 2, 4, 6, and 8, respectively, from these detectors. This information shows how the controller responded to changes in detected traffic conditions over the data collection period. Table 9 provides programmed minimum and maximum times for these phases.

Table 9. Phase Time Limits.

Phase #	Minimum	Maximum
2	15	45
4	7	45
6	15	60
8	7	45

When combined, the information in Figure 31 and Table 9 provide the following assessment about the operation of this signalized interchange:

- Except for Phases 2 and 8 between noon and 1:00 p.m., all phase times were mostly longer than their respective minimum times.
- For all phases, the actual phase times increased as time progressed, but the average phase times remained lower than the programmed maximum times, indicating that the programmed maximum times are adequate.

- Utilization of Phases 2 and 8 was around 50 percent each, indicating that both these phases have ample reserve capacity to handle any additional demand during this part of the day.
- Phases 4 and 6 faced higher demands than the other two phases. Maximum utilization rates of these phases were 87 percent and 75 percent, respectively.

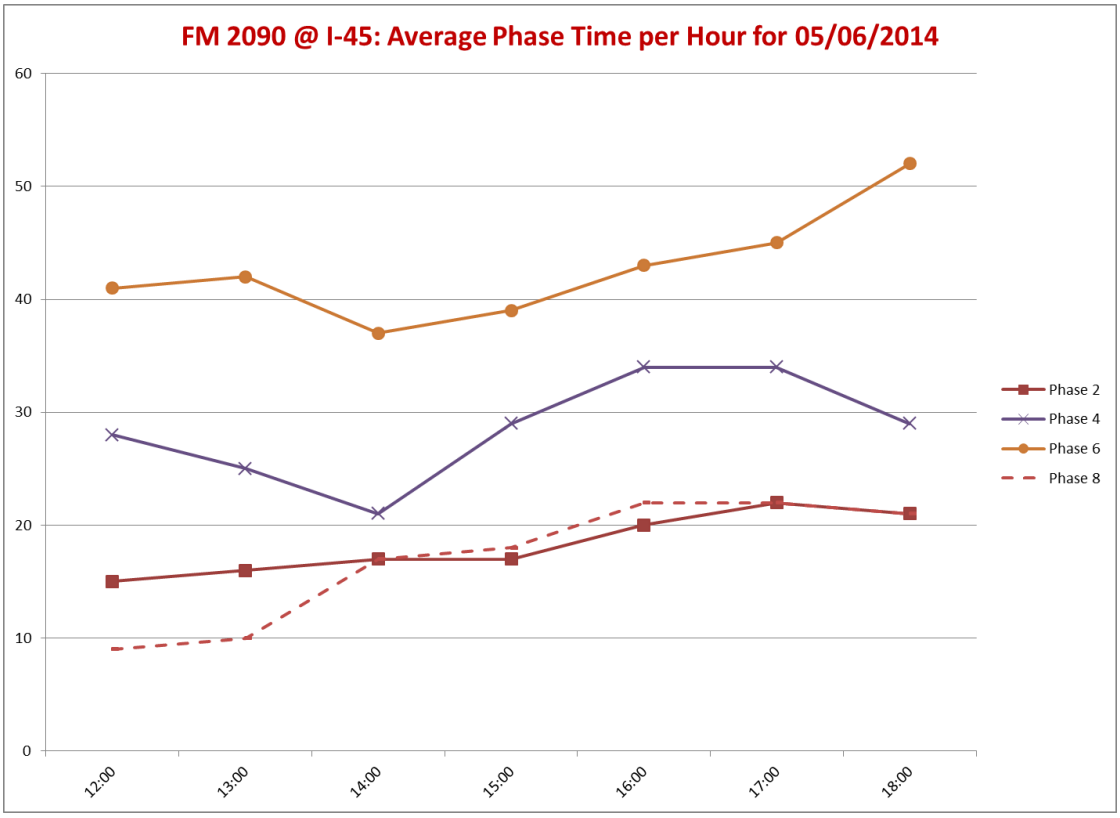


Figure 31. Average Hourly Phase Times for Phases 2 through 8.

The analysis module is also designed to provide several additional useful measures of effectiveness that require integration of the detector and phase events, a task that the monitoring module accomplished in real time. These measures include hourly statistics on the average number of max-outs (phase terminations while an associated calling detector was still occupied), queue service time, and time to service, which are based on real-time post-processing that the monitoring module had done. All of these reports had errors. The last section of this report addresses this issue.

Signalized Intersection at FM 1960 and Stuebner Airline

This intersection operates in actuated coordinated mode according to preprogrammed time-of-day (TOD) schedules, which are different for weekdays, Saturdays, and Sundays. At this intersection, Phases 2 and 6, serving through movements on FM 1960, were designated as the coordinated phases and operate under vehicle recall. Also, this intersection uses traffic signal priority (TSP) for accommodating pedestrians call for Phases 4 and 8, which have shorter splits than the time required for servicing actuated pedestrian calls. Using TSP allows transfer of time (up to a specified limit) from Phases 2, 6, and other main-street phases to accommodate pedestrians without forcing the system to go out of coordination.

The monitoring module successfully collected data at this site for the entire data collection period, which included two partial weekdays and three full (24-hour) weekdays. After retrieving the toolbox from this site, researchers used the analysis module to evaluate data collected from this site. This section presents the results of this analysis. For comparison purposes, Appendix B provides weekday TOD pattern data (time-of-day schedule, cycle length, splits, etc.) programmed in the controller at this location.

Figure 32 shows the measured average cycle time for all eight phases at this intersection. For any phase, one cycle is the time from the beginning of a green to the beginning of the next green. In this figure, note the large values of cycle times for main-street left-turn phases (Phases 1 and 5) between midnight and 5:00 a.m., indicating that both these phases activated fewer times than the rest of the signal phases. This is an indication of low or no demand for these phases. After 6:00 a.m., the cycle times for these phases were lower and more in line with the other phases. In this figure, the wide scale of the y-axis masked the variations in these times.

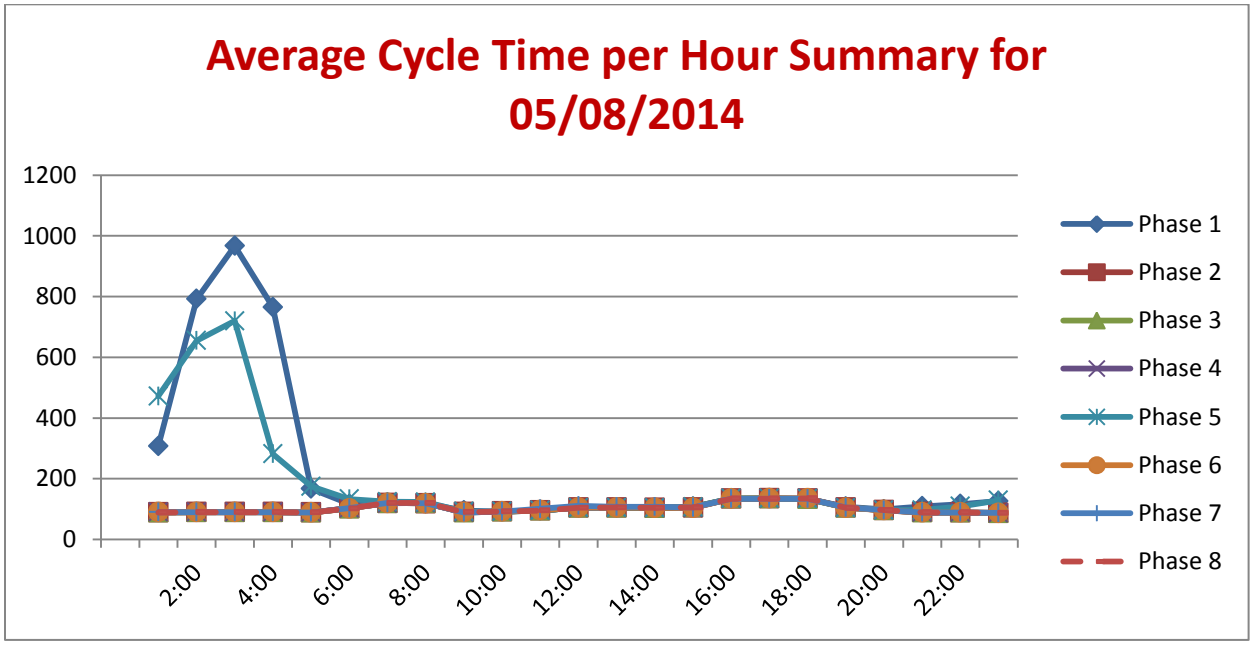


Figure 32. Average Hourly Cycle Times for Phases 1 through 8.

Figure 33 provides a plot of cycle time for Phases 2, 3, 4, 6, 7, and 8 only. Removing Phases 1 and 5 allows variations in cycle times for these phases to become more pronounced. Note that these cycle times generally match the programmed TOD cycle lengths (90-, 120-, 90-, 105-, 135-, 105-, and 90-second) under which the controller is supposed to be operating throughout the 24-hour period. Some variations are seen on this graph because the toolbox-calculated averages based on hour boundaries, but some pattern changes (i.e., 6:30 a.m.) occurred in the middle of the hour. In these instances, the plotted point for the hour containing the pattern change is based on the averages of two patterns. In addition, some variations may also be due to the impacts of transitions from one pattern to the next. Furthermore, note the deviation in the plot for Phase 7 between 10:00 a.m. and 2:00 p.m. This deviation, an increase in cycle time, is an indication of phase skipping due to lower demand for this phase during this period.

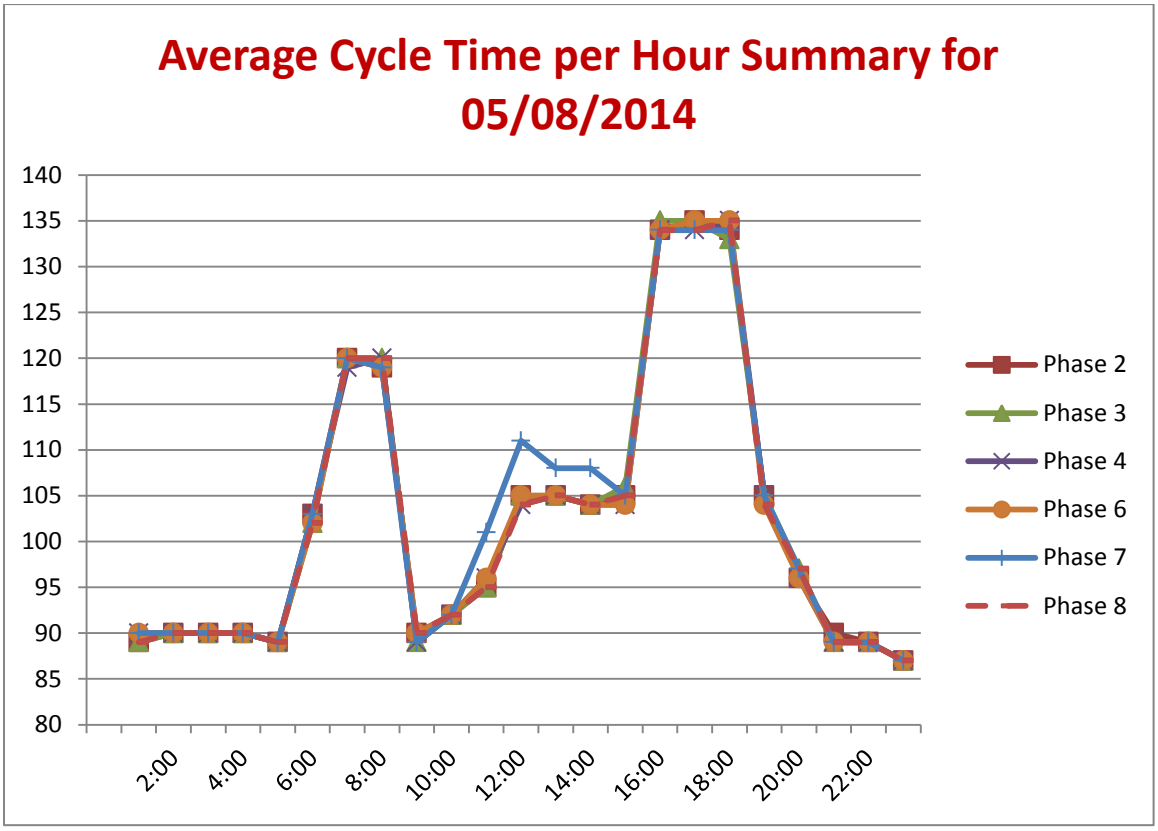


Figure 33. Cycle Times of Phases except Phases 1 and 5.

Figure 34 and Figure 35 show average phase times for Wednesday, May 7, and Thursday, May 8, 2014. Note that the two days exhibit very similar trends, but have some differences because no two days experience the same exact demand. For Phases 2 and 6, these variations are also an indication of pedestrian activities.

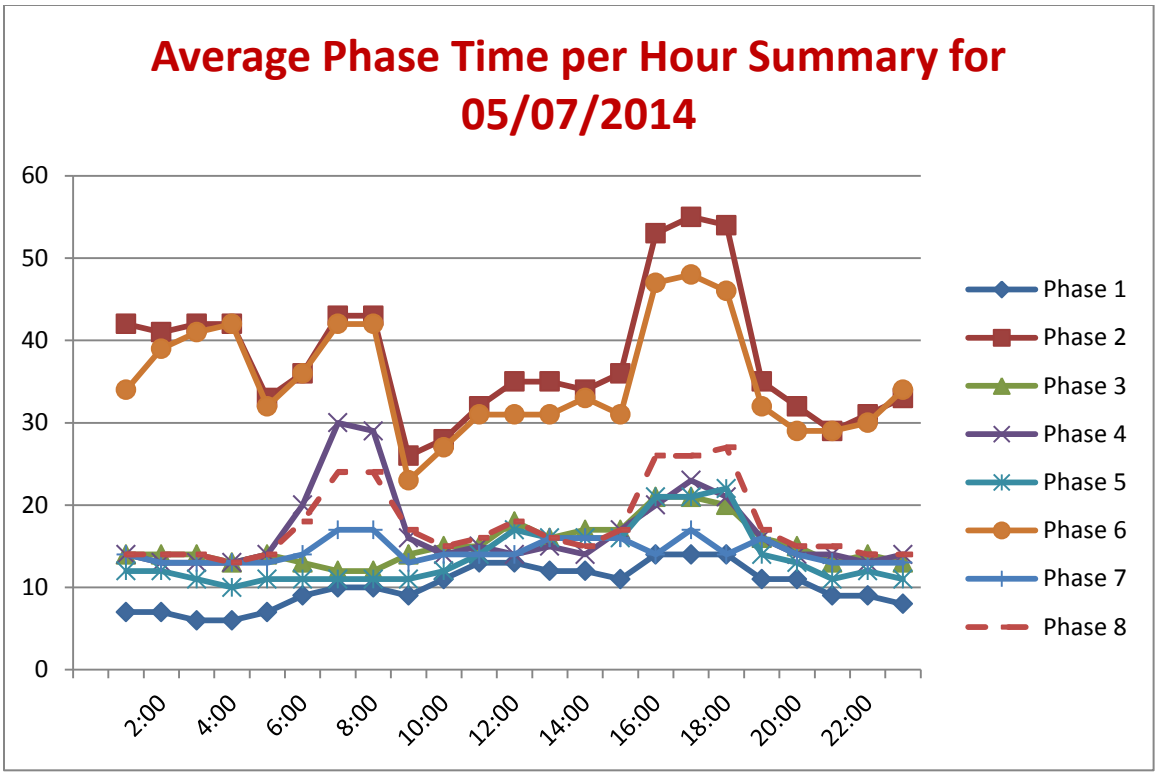


Figure 34. Average Green Times on Wednesday at the FM 1960 Site.

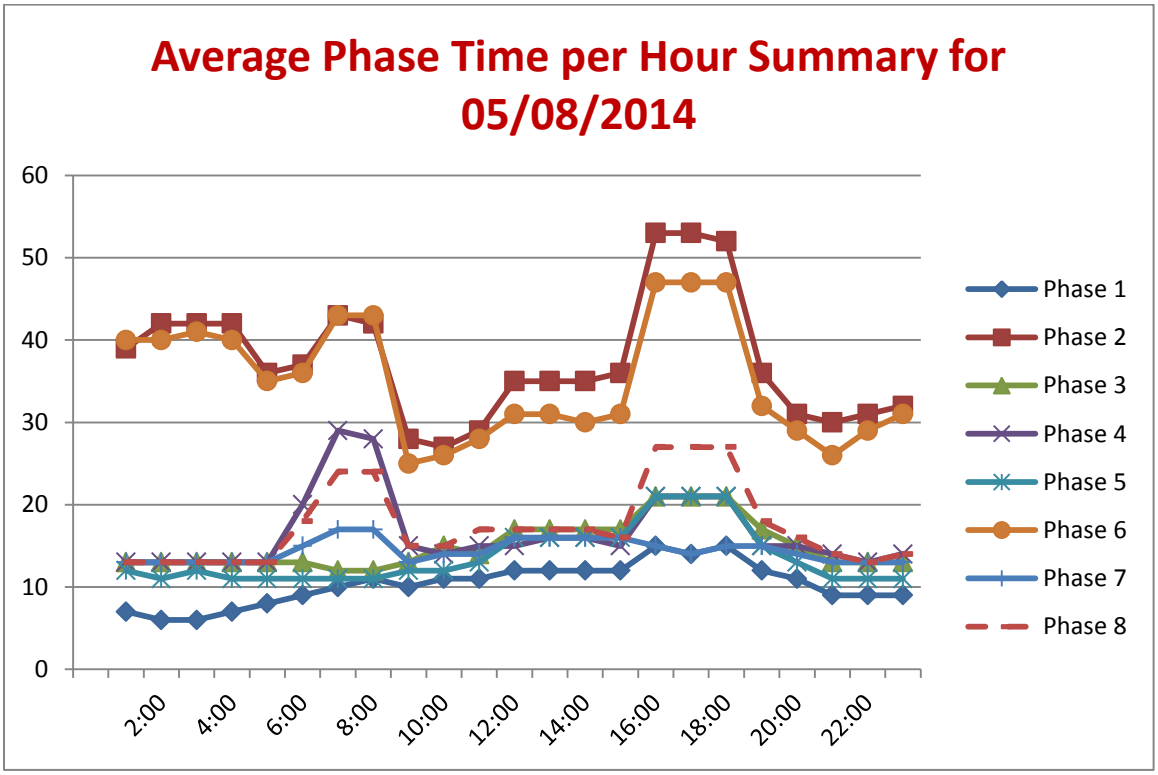


Figure 35. Average Green Times on Thursday at the FM 1960 Site.

The impact of pedestrian activities on the operation of coordinated phases is an item of interest when evaluating the operation of this intersection. Figure 36 shows zoomed-in plots of phase times for Phases 2 and 6. To allow easy assessment, TOD cycle lengths (black font) and corresponding splits (color-coded) have been manually added to the plots.

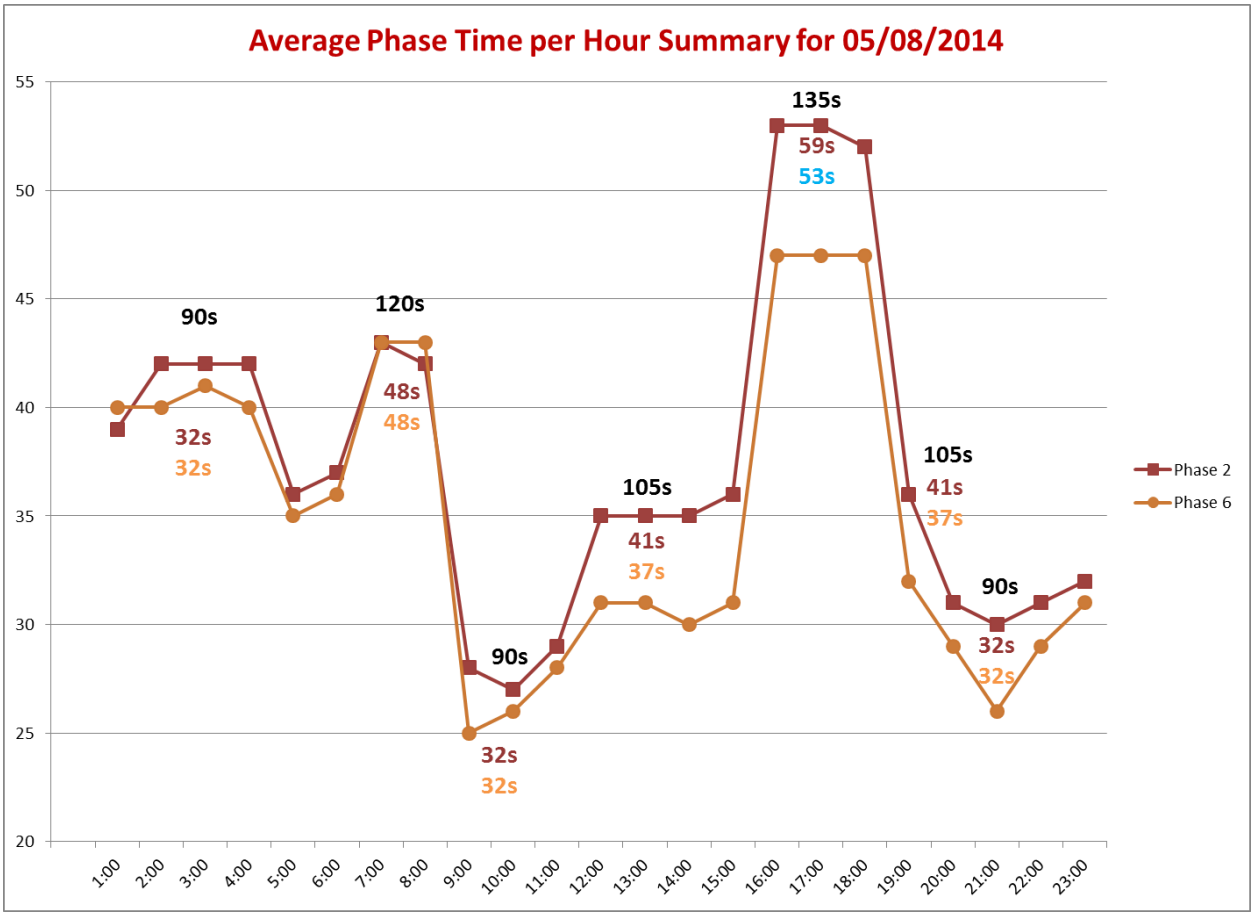


Figure 36. Actual Times of Phases 2 and 6 Compared to Programmed Cycle and Splits.

Figure 36 provides the following information:

- From midnight to 6:30 a.m., both phases received more than the allocated split times.
- From 6:30 a.m. through 9:00 p.m., the average phase times for both phases were 5–6 seconds less than the assigned splits. Thus, the pedestrian activity did have an impact on both coordinated phases, where the actual average time was lower that the assigned splits during most of the day.

Other performance measures, especially the number of times these phases terminated with active detector calls, would be a good indicator of the impact of pedestrian activities on the quality of service of coordinated phases as well as the adequacy of green splits. Similar to the measures obtained for the FM 2920 at the I-45 diamond interchange site, the additional measures that the analysis module reported were also incorrect or erroneous.

Field Test Summary and Resulting Actions

The previous sections provided analysis results for two field tests. The researchers obtained similar results for using data collected at the other field-test sites. One unexpected finding in all these cases was that the analysis module did not correctly calculate measures of effectiveness that are dependent on a combination of real-time status information from both phases and detectors. Upon investigation, the research team found that the source of problem was not in the analysis module, but a flaw in the monitoring module logic used for real-time post-processing, which integrates detector and phase data and writes this to a file that the analysis module will use. More specifically, this bug was the result of a flaw in detector-to-phase assignments used to link data from the two sources. The researchers corrected this flaw in the code and conducted additional field tests to verify correct operation of NPTSES-M. Because of time constraints, researchers conducted all of this testing at the test site located in Bryan, Texas.

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APPENDIX A: NTCIP OBJECT IDENTIFIERS

Table A1. Selected NTCIP Global Objects.

NTCIP 1201 OID	Object Name
1.3.6.1.4.1.1206.4.2.6.3	globalTimeManagement
1.3.6.1.4.1.1206.4.2.6.3.1	global.Time
1.3.6.1.4.1.1206.4.2.6.3.2	globalDaylightSaving
1.3.6.1.4.1.1206.4.2.6.3.3	timebase
1.3.6.1.4.1.1206.4.2.6.3.3.1	maxTimeBaseScheduleEntries
1.3.6.1.4.1.1206.4.2.6.3.3.2	timeBaseScheduleTable
1.3.6.1.4.1.1206.4.2.6.3.3.2.1	timeBaseScheduleEntry
1.3.6.1.4.1.1206.4.2.6.3.3.2.1.1	timeBaseScheduleNumber
1.3.6.1.4.1.1206.4.2.6.3.3.2.1.2	timeBaseScheduleMonth
1.3.6.1.4.1.1206.4.2.6.3.3.2.1.3	timeBaseScheduleDay
1.3.6.1.4.1.1206.4.2.6.3.3.2.1.4	timeBaseScheduleDate
1.3.6.1.4.1.1206.4.2.6.3.3.2.1.5	timeBaseScheduleDayPlan
1.3.6.1.4.1.1206.4.2.6.3.3.3	maxDayPlans
1.3.6.1.4.1.1206.4.2.6.3.3.4	maxDayPlanEvents
1.3.6.1.4.1.1206.4.2.6.3.3.5	timeBaseDayPlanTable
1.3.6.1.4.1.1206.4.2.6.3.3.5.1	timeBaseDayPlanEntry
1.3.6.1.4.1.1206.4.2.6.3.3.5.1.1	dayPlanNumber
1.3.6.1.4.1.1206.4.2.6.3.3.5.1.2	dayPlanEventNumber
1.3.6.1.4.1.1206.4.2.6.3.3.5.1.3	dayPlanHour
1.3.6.1.4.1.1206.4.2.6.3.3.5.1.4	dayPlanMinute
1.3.6.1.4.1.1206.4.2.6.3.3.5.1.5	dayPlanActionNumberOID
1.3.6.1.4.1.1206.4.2.6.3.3.6	dayPlanStatus

Table A2. List of ASC Object Identifiers.

NTCIP 1202 OID	Object Name
1.3.6.1.4.1.1206.4.2.1.1	phase
1.3.6.1.4.1.1206.4.2.1.1.1	maxPhases
1.3.6.1.4.1.1206.4.2.1.1.2	phaseTable
1.3.6.1.4.1.1206.4.2.1.1.2.1.1	phaseNumber
1.3.6.1.4.1.1206.4.2.1.1.2.1.2	phaseWalk
1.3.6.1.4.1.1206.4.2.1.1.2.1.3	phasePedestrianClear
1.3.6.1.4.1.1206.4.2.1.1.2.1.4	phaseMinimumGreen
1.3.6.1.4.1.1206.4.2.1.1.2.1.5	phasePassage
1.3.6.1.4.1.1206.4.2.1.1.2.1.6	phaseMaximum1
1.3.6.1.4.1.1206.4.2.1.1.2.1.7	phaseMaximum2
1.3.6.1.4.1.1206.4.2.1.1.2.1.8	phaseYellowChange
1.3.6.1.4.1.1206.4.2.1.1.2.1.9	phaseRedClear
1.3.6.1.4.1.1206.4.2.1.1.2.1.10	phaseRedRevert
1.3.6.1.4.1.1206.4.2.1.1.2.1.11	phaseAddedInitial
1.3.6.1.4.1.1206.4.2.1.1.2.1.12	phaseMaximumInitial
1.3.6.1.4.1.1206.4.2.1.1.2.1.13	phaseTimeBeforeReduction
1.3.6.1.4.1.1206.4.2.1.1.2.1.14	phaseCarsBeforeReduction
1.3.6.1.4.1.1206.4.2.1.1.2.1.15	phaseTimeToReduce
1.3.6.1.4.1.1206.4.2.1.1.2.1.16	phaseReduceBy
1.3.6.1.4.1.1206.4.2.1.1.2.1.17	phaseMinimumGap
1.3.6.1.4.1.1206.4.2.1.1.2.1.18	phaseDynamicMaxLimit
1.3.6.1.4.1.1206.4.2.1.1.2.1.19	phaseDynamicMaxStep
1.3.6.1.4.1.1206.4.2.1.1.2.1.20	phaseStartup
1.3.6.1.4.1.1206.4.2.1.1.2.1.21	phaseOptions
1.3.6.1.4.1.1206.4.2.1.1.2.1.22	phaseRing
1.3.6.1.4.1.1206.4.2.1.1.2.1.23	phaseConcurrency
1.3.6.1.4.1.1206.4.2.1.1.3	maxPhaseGroups
1.3.6.1.4.1.1206.4.2.1.1.4	phaseStatusGroupTable
1.3.6.1.4.1.1206.4.2.1.1.4.1	phaseStatusGroupEntry
1.3.6.1.4.1.1206.4.2.1.1.4.1.1	phaseStatusGroupNumber
1.3.6.1.4.1.1206.4.2.1.1.4.1.2	phaseStatusGroupReds
1.3.6.1.4.1.1206.4.2.1.1.4.1.3	phaseStatusGroupYellows
1.3.6.1.4.1.1206.4.2.1.1.4.1.4	phaseStatusGroupGreens
1.3.6.1.4.1.1206.4.2.1.1.4.1.5	phaseStatusGroupDontWalks
1.3.6.1.4.1.1206.4.2.1.1.4.1.6	phaseStatusGroupPedClears
1.3.6.1.4.1.1206.4.2.1.1.4.1.7	phaseStatusGroupWalks
1.3.6.1.4.1.1206.4.2.1.1.4.1.8	phaseStatusGroupVehCalls
1.3.6.1.4.1.1206.4.2.1.1.4.1.9	phaseStatusGroupPedCalls
1.3.6.1.4.1.1206.4.2.1.1.4.1.10	phaseStatusGroupPhaseOns

Table A2. List of ASC Object Identifiers (Continued).

NTCIP 1202 OID	Object Name
1.3.6.1.4.1.1206.4.2.1.1.4.1.11	phaseStatusGroupPhaseNexts
1.3.6.1.4.1.1206.4.2.1.1.5	phaseControlGroupTable
1.3.6.1.4.1.1206.4.2.1.1.5.1	phaseControlGroupEntry
1.3.6.1.4.1.1206.4.2.1.1.5.1.1	phaseControlGroupNumber
1.3.6.1.4.1.1206.4.2.1.1.5.1.2	phaseControlGroupPhaseOmit
1.3.6.1.4.1.1206.4.2.1.1.5.1.3	phaseControlGroupPedOmit
1.3.6.1.4.1.1206.4.2.1.1.5.1.4	phaseControlGroupHold
1.3.6.1.4.1.1206.4.2.1.1.5.1.5	phaseControlGroupForceOff
1.3.6.1.4.1.1206.4.2.1.1.5.1.6	phaseControlGroupVehCall
1.3.6.1.4.1.1206.4.2.1.1.5.1.7	phaseControlGroupPedCall
1.3.6.1.4.1.1206.4.2.1.2	detector
1.3.6.1.4.1.1206.4.2.1.2.1	maxVehicleDetectors
1.3.6.1.4.1.1206.4.2.1.2.2	vehicleDetectorTable
1.3.6.1.4.1.1206.4.2.1.2.2.1	vehicleDetectorEntry
1.3.6.1.4.1.1206.4.2.1.2.2.1.1	vehicleDetectorNumber
1.3.6.1.4.1.1206.4.2.1.2.2.1.2	vehicleDetectorOptions
1.3.6.1.4.1.1206.4.2.1.2.2.1.4	vehicleDetectorCallPhase
1.3.6.1.4.1.1206.4.2.1.2.2.1.5	vehicleDetectorSwitchPhase
1.3.6.1.4.1.1206.4.2.1.2.2.1.6	vehicleDetectorDelay
1.3.6.1.4.1.1206.4.2.1.2.2.1.7	vehicleDetectorExtend
1.3.6.1.4.1.1206.4.2.1.2.2.1.8	vehicleDetectorQueueLimit
1.3.6.1.4.1.1206.4.2.1.2.2.1.9	vehicleDetectorNoActivity
1.3.6.1.4.1.1206.4.2.1.2.2.1.10	vehicleDetectorMaxPresence
1.3.6.1.4.1.1206.4.2.1.2.2.1.11	vehicleDetectorErraticCounts
1.3.6.1.4.1.1206.4.2.1.2.2.1.12	vehicleDetectorFailTime
1.3.6.1.4.1.1206.4.2.1.2.2.1.13	vehicleDetectorAlarms
1.3.6.1.4.1.1206.4.2.1.2.2.1.14	vehicleDetectorReportedAlarms
1.3.6.1.4.1.1206.4.2.1.2.2.1.15	vehicleDetectorReset
1.3.6.1.4.1.1206.4.2.1.2.3	maxVehicleDetectorStatusGroups
1.3.6.1.4.1.1206.4.2.1.2.4	vehicleDetectorStatusGroupTable
1.3.6.1.4.1.1206.4.2.1.2.4.1	vehicleDetectorStatusGroupEntry
1.3.6.1.4.1.1206.4.2.1.2.4.1.1	vehicleDetectorStatusGroupNumber
1.3.6.1.4.1.1206.4.2.1.2.4.1.2	vehicleDetectorStatusGroupActive
1.3.6.1.4.1.1206.4.2.1.2.4.1.3	vehicleDetectorStatusGroupAlarms
1.3.6.1.4.1.1206.4.2.1.2.5	volumeOccupancyReport
1.3.6.1.4.1.1206.4.2.1.2.5.1	volumeOccupancySequence
1.3.6.1.4.1.1206.4.2.1.2.5.2	volumeOccupancyPeriod
1.3.6.1.4.1.1206.4.2.1.2.5.3	activeVolumeOccupancyDetectors
1.3.6.1.4.1.1206.4.2.1.2.5.4	volumeOccupancyTable
1.3.6.1.4.1.1206.4.2.1.2.5.4.1	volumeOccupancyEntry

Table A2. List of ASC Object Identifiers (Continued).

NTCIP 1202 OID	Object Name
1.3.6.1.4.1.1206.4.2.1.2.5.4.1.1	detectorVolume
1.3.6.1.4.1.1206.4.2.1.2.5.4.1.2	detectorOccupancy
1.3.6.1.4.1.1206.4.2.1.2.6	maxPedestrianDetectors
1.3.6.1.4.1.1206.4.2.1.2.7	pedestrianDetectorTable
1.3.6.1.4.1.1206.4.2.1.2.7.1	pedestrianDetectorEntry
1.3.6.1.4.1.1206.4.2.1.2.7.1.1	pedestrianDetectorNumber
1.3.6.1.4.1.1206.4.2.1.2.7.1.2	pedestrianDetectorCallPhase
1.3.6.1.4.1.1206.4.2.1.2.7.1.3	pedestrianDetectorNoActivity
1.3.6.1.4.1.1206.4.2.1.2.7.1.4	pedestrianDetectorMaxPresence
1.3.6.1.4.1.1206.4.2.1.2.7.1.5	pedestrianDetectorErraticCounts
1.3.6.1.4.1.1206.4.2.1.2.7.1.6	pedestrianDetectorAlarms
1.3.6.1.4.1.1206.4.2.1.3	unit
1.3.6.1.4.1.1206.4.2.1.3.1	unitStartupFlash
1.3.6.1.4.1.1206.4.2.1.3.2	unitAutoPedestrianClear
1.3.6.1.4.1.1206.4.2.1.3.3	unitBackupTime
1.3.6.1.4.1.1206.4.2.1.3.4	unitRedRevert
1.3.6.1.4.1.1206.4.2.1.3.5	unitControlStatus
1.3.6.1.4.1.1206.4.2.1.3.6	unitFlashStatus
1.3.6.1.4.1.1206.4.2.1.3.7	unitAlarmStatus2
1.3.6.1.4.1.1206.4.2.1.3.8	unitAlarmStatus1
1.3.6.1.4.1.1206.4.2.1.3.9	shortAlarmStatus
1.3.6.1.4.1.1206.4.2.1.3.10	unitControl
1.3.6.1.4.1.1206.4.2.1.3.11	maxAlarmGroups
1.3.6.1.4.1.1206.4.2.1.3.12	alarmGroupTable
1.3.6.1.4.1.1206.4.2.1.3.12.1	alarmGroupEntry
1.3.6.1.4.1.1206.4.2.1.3.12.1.1	alarmGroupNumber
1.3.6.1.4.1.1206.4.2.1.3.12.1.2	alarmGroupState
1.3.6.1.4.1.1206.4.2.1.3.13	maxSpecialFunctionOutputs
1.3.6.1.4.1.1206.4.2.1.3.14	specialFunctionOutputTable
1.3.6.1.4.1.1206.4.2.1.3.14.1	specialFunctionOutputEntry
1.3.6.1.4.1.1206.4.2.1.3.14.1.1	specialFunctionOutputNumber
1.3.6.1.4.1.1206.4.2.1.3.14.1.3	specialFunctionOutputControl
1.3.6.1.4.1.1206.4.2.1.3.14.1.4	specialFunctionOutputStatus
1.3.6.1.4.1.1206.4.2.1.4	coord
1.3.6.1.4.1.1206.4.2.1.4.1	coordOperationalMode
1.3.6.1.4.1.1206.4.2.1.4.2	coordCorrectionMode

Table A2. List of ASC Object Identifiers (Continued).

NTCIP 1202 OID	Object Name
1.3.6.1.4.1.1206.4.2.1.4.3	coordMaximumMode
1.3.6.1.4.1.1206.4.2.1.4.4	coordForceMode
1.3.6.1.4.1.1206.4.2.1.4.5	maxPatterns
1.3.6.1.4.1.1206.4.2.1.4.6	patternTableType
1.3.6.1.4.1.1206.4.2.1.4.7	patternTable
1.3.6.1.4.1.1206.4.2.1.4.7.1	patternEntry
1.3.6.1.4.1.1206.4.2.1.4.7.1.1	patternNumber
1.3.6.1.4.1.1206.4.2.1.4.7.1.2	patternCycleTime
1.3.6.1.4.1.1206.4.2.1.4.7.1.3	patternOffsetTime
1.3.6.1.4.1.1206.4.2.1.4.7.1.4	patternSplitNumber
1.3.6.1.4.1.1206.4.2.1.4.7.1.5	patternSequenceNumber
1.3.6.1.4.1.1206.4.2.1.4.8	maxSplits
1.3.6.1.4.1.1206.4.2.1.4.9	splitTable
1.3.6.1.4.1.1206.4.2.1.4.9.1	splitEntry
1.3.6.1.4.1.1206.4.2.1.4.9.1.1	splitNumber
1.3.6.1.4.1.1206.4.2.1.4.9.1.2	splitPhase
1.3.6.1.4.1.1206.4.2.1.4.9.1.3	splitTime
1.3.6.1.4.1.1206.4.2.1.4.9.1.4	splitMode
1.3.6.1.4.1.1206.4.2.1.4.9.1.5	splitCoordPhase
1.3.6.1.4.1.1206.4.2.1.4.10	coordPatternStatus
1.3.6.1.4.1.1206.4.2.1.4.11	localFreeStatus
1.3.6.1.4.1.1206.4.2.1.4.12	coordCycleStatus
1.3.6.1.4.1.1206.4.2.1.4.13	coordSyncStatus
1.3.6.1.4.1.1206.4.2.1.4.14	systemPatternControl
1.3.6.1.4.1.1206.4.2.1.4.15	systemSyncControl
1.3.6.1.4.1.1206.4.2.1.5	timebaseAsc
1.3.6.1.4.1.1206.4.2.1.5.1	timeBaseAscPatternSync
1.3.6.1.4.1.1206.4.2.1.5.2	maxTimebaseAscActions
1.3.6.1.4.1.1206.4.2.1.5.3	timebaseActionTable
1.3.6.1.4.1.1206.4.2.1.5.3.1	timebaseActionEntry
1.3.6.1.4.1.1206.4.2.1.5.3.1.1	timebaseActionNumber
1.3.6.1.4.1.1206.4.2.1.5.3.1.2	timebaseAscPattern
1.3.6.1.4.1.1206.4.2.1.5.3.1.3	timebaseAscAuxillaryFunction
1.3.6.1.4.1.1206.4.2.1.5.3.1.4	timebaseAscSpecialFunction
1.3.6.1.4.1.1206.4.2.1.5.4	timebaseActionStatus
1.3.6.1.4.1.1206.4.2.1.6	preempt
1.3.6.1.4.1.1206.4.2.1.6.1	maxPreempts

Table A2. List of ASC Object Identifiers (Continued).

NTCIP 1202 OID	Object Name
1.3.6.1.4.1.1206.4.2.1.6.2	preemptTable
1.3.6.1.4.1.1206.4.2.1.6.2.1	preemptEntry
1.3.6.1.4.1.1206.4.2.1.6.2.1.1	preemptNumber
1.3.6.1.4.1.1206.4.2.1.6.2.1.2	preemptControl
1.3.6.1.4.1.1206.4.2.1.6.2.1.3	preemptLink
1.3.6.1.4.1.1206.4.2.1.6.2.1.4	preemptDelay
1.3.6.1.4.1.1206.4.2.1.6.2.1.5	preemptMinimumDuration
1.3.6.1.4.1.1206.4.2.1.6.2.1.6	preemptMinimumGreen
1.3.6.1.4.1.1206.4.2.1.6.2.1.7	preemptMinimumWalk
1.3.6.1.4.1.1206.4.2.1.6.2.1.8	preemptEnterPedClear
1.3.6.1.4.1.1206.4.2.1.6.2.1.9	preemptTrackGreen
1.3.6.1.4.1.1206.4.2.1.6.2.1.10	preemptDwellGreen
1.3.6.1.4.1.1206.4.2.1.6.2.1.11	preemptMaximumPresence
1.3.6.1.4.1.1206.4.2.1.6.2.1.12	preemptTrackPhase
1.3.6.1.4.1.1206.4.2.1.6.2.1.13	preemptDwellPhase
1.3.6.1.4.1.1206.4.2.1.6.2.1.14	preemptDwellPed
1.3.6.1.4.1.1206.4.2.1.6.2.1.15	preemptExitPhase
1.3.6.1.4.1.1206.4.2.1.6.2.1.16	preemptState
1.3.6.1.4.1.1206.4.2.1.6.2.1.17	preemptTrackOverlap
1.3.6.1.4.1.1206.4.2.1.6.2.1.18	preemptDwellOverlap
1.3.6.1.4.1.1206.4.2.1.6.2.1.19	preemptCyclingPhase
1.3.6.1.4.1.1206.4.2.1.6.2.1.20	preemptCyclingPed
1.3.6.1.4.1.1206.4.2.1.6.2.1.21	preemptCyclingOverlap
1.3.6.1.4.1.1206.4.2.1.7	ring
1.3.6.1.4.1.1206.4.2.1.7.1	maxRings
1.3.6.1.4.1.1206.4.2.1.7.2	maxSequences
1.3.6.1.4.1.1206.4.2.1.7.3	sequenceTable
1.3.6.1.4.1.1206.4.2.1.7.3.1	sequenceEntry
1.3.6.1.4.1.1206.4.2.1.7.3.1.1	sequenceNumber
1.3.6.1.4.1.1206.4.2.1.7.3.1.2	sequenceRingNumber
1.3.6.1.4.1.1206.4.2.1.7.3.1.3	sequenceData
1.3.6.1.4.1.1206.4.2.1.7.4	maxRingControlGroups
1.3.6.1.4.1.1206.4.2.1.7.5	ringControlGroupTable
1.3.6.1.4.1.1206.4.2.1.7.5.1	ringControlGroupEntry
1.3.6.1.4.1.1206.4.2.1.7.5.1.1	ringControlGroupNumber
1.3.6.1.4.1.1206.4.2.1.7.5.1.2	ringControlGroupStopTime
1.3.6.1.4.1.1206.4.2.1.7.5.1.3	ringControlGroupForceOff
1.3.6.1.4.1.1206.4.2.1.7.5.1.4	ringControlGroupMax2

Table A2. List of ASC Object Identifiers (Continued).

NTCIP 1202 OID	Object Name
1.3.6.1.4.1.1206.4.2.1.7.5.1.5	ringControlGroupMaxInhibit
1.3.6.1.4.1.1206.4.2.1.7.5.1.6	ringControlGroupPedRecycle
1.3.6.1.4.1.1206.4.2.1.7.5.1.7	ringControlGroupRedRest
1.3.6.1.4.1.1206.4.2.1.7.5.1.8	ringControlGroupOmitRedClear
1.3.6.1.4.1.1206.4.2.1.7.6	ringStatusTable
1.3.6.1.4.1.1206.4.2.1.7.6.1	ringStatusEntry
1.3.6.1.4.1.1206.4.2.1.7.6.1.1	ringStatus
1.3.6.1.4.1.1206.4.2.1.8	channel
1.3.6.1.4.1.1206.4.2.1.8.1	maxChannels
1.3.6.1.4.1.1206.4.2.1.8.2	channelTable
1.3.6.1.4.1.1206.4.2.1.8.2.1	channelEntry
1.3.6.1.4.1.1206.4.2.1.8.2.1.1	channelNumber
1.3.6.1.4.1.1206.4.2.1.8.2.1.2	channelControlSource
1.3.6.1.4.1.1206.4.2.1.8.2.1.3	channelControlType
1.3.6.1.4.1.1206.4.2.1.8.2.1.4	channelFlash
1.3.6.1.4.1.1206.4.2.1.8.2.1.5	channelDim
1.3.6.1.4.1.1206.4.2.1.8.3	maxChannelStatusGroups
1.3.6.1.4.1.1206.4.2.1.8.4	channelStatusGroupTable
1.3.6.1.4.1.1206.4.2.1.8.4.1	channelStatusGroupEntry
1.3.6.1.4.1.1206.4.2.1.8.4.1.1	channelStatusGroupNumber
1.3.6.1.4.1.1206.4.2.1.8.4.1.2	channelStatusGroupReds
1.3.6.1.4.1.1206.4.2.1.8.4.1.3	channelStatusGroupYellows
1.3.6.1.4.1.1206.4.2.1.8.4.1.4	channelStatusGroupGreens
1.3.6.1.4.1.1206.4.2.1.9	overlap
1.3.6.1.4.1.1206.4.2.1.9.1	maxOverlaps
1.3.6.1.4.1.1206.4.2.1.9.2	overlapTable
1.3.6.1.4.1.1206.4.2.1.9.2.1	overlapEntry
1.3.6.1.4.1.1206.4.2.1.9.2.1.1	overlapNumber
1.3.6.1.4.1.1206.4.2.1.9.2.1.2	overlapType
1.3.6.1.4.1.1206.4.2.1.9.2.1.3	overlapIncludedPhases
1.3.6.1.4.1.1206.4.2.1.9.2.1.4	overlapModifierPhases
1.3.6.1.4.1.1206.4.2.1.9.2.1.5	overlapTrailGreen
1.3.6.1.4.1.1206.4.2.1.9.2.1.6	overlapTrailYellow
1.3.6.1.4.1.1206.4.2.1.9.2.1.7	overlapTrailRed
1.3.6.1.4.1.1206.4.2.1.9.3	maxOverlapStatusGroups
1.3.6.1.4.1.1206.4.2.1.9.4	overlapStatusGroupTable
1.3.6.1.4.1.1206.4.2.1.9.4.1	overlapStatusGroupEntry
1.3.6.1.4.1.1206.4.2.1.9.4.1.1	overlapStatusGroupNumber
1.3.6.1.4.1.1206.4.2.1.9.4.1.2	overlapStatusGroupReds
1.3.6.1.4.1.1206.4.2.1.9.4.1.3	overlapStatusGroupYellows
1.3.6.1.4.1.1206.4.2.1.9.4.1.4	overlapStatusGroupGreens

APPENDIX B: UTDF DATA EXCHANGE FORMAT

A desired feature of the toolbox is to automate, to the extent possible within the scope of this project, the steps needed to optimize signal timings using software available to TxDOT staff. To this end, it was necessary to use a standard format for data exchange between the toolbox and the selected optimization software. As stated previously, the research team selected UTDF to provide standardization because several traffic engineering programs have adopted this format either partially or fully. In UTDF, data names followed by data values are written to a file using comma separated value (CSV) format.

FORMAT OF VOLUME DATA

Common signal timing analysis and optimization programs require that volume data be provided by movement and approach designations. However, this information is not available in a controller's database; the user must enter it manually. Researchers determined that keeping this process external to NPTSES was the best way to keep its use simple. This section provides information about the UTDF movement numbering scheme and input data format to allow a user interested in making NPTSES-generated volume data ready for use with a signal timing optimization program.

The left side of Figure B1 shows the UTDF movement labeling scheme for all possible approaches at an intersection with two-way roads. The right side of this figure illustrates all possible turning movements at a northbound (NB) approach. Other approaches will have a similar movement labeling scheme.

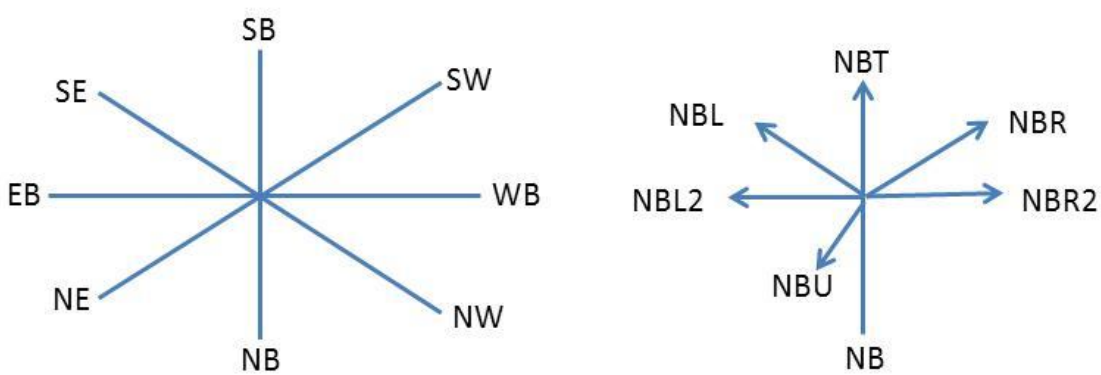


Figure B1. UTDF Movement Numbering Scheme.

In the UTDF volume data file, the order of approach data is in the following order:

1. North-bound (NB).
2. South-bound (SB).
3. East-bound (EB).
4. West-bound (WB).
5. Northeast-bound (NE).

6. Northwest-bound (NW).
7. Southeast-bound (SE).
8. Southwest-bound (SW).

For each of these approaches, the order of movements is:

1. U-turn (U).
2. Left turn 2 (L2).
3. Left-turn (L).
4. Through (T).
5. Right-turn (R).
6. Right-turn 2 (R2).

Thus, for instance, the order of data for northbound movements for the case of Figure B1 will be NBU, NBL2, NBL, NBT, NBR, and NBR2. Figure B2 illustrates a 15-minute UTDF volume data file that contains volume counts for two four-legged intersections with intersection identification (INTID) numbers of 3 and 6.

```
15-Minute Counts
DATE,TIME,INTID,NBL,NBT,NBR,SBL,SBT,SBR,EBL,EBT,EBR,WBL,WBT,WBR
8/20/2013,1700,3,,,,300,200,50,,400,100,200,500,
8/20/2013,1700,6,100,200,100,,,,200,500,,,600,100
```

Figure B2. Format of UTDF Turning Moving Count Data File.

This CSV file has the following data entries:

- The first required line identifies the data aggregation level. The UTDF file must contain either 15-minute (as in Figure B2) or 60-minute volume data.
- The second required line provides tags (names) of data fields in the following lines. These tags include:
  - Date.
  - Time data collection interval began.
  - Identification number of intersection to which this line applies.
  - One or more lines containing successive 15-minute count data. In this example, there is one line of data for intersection 3 and one line of data for intersection 6. Both lines contain counts collected on August 20, 2013, for period starting at 5:00 p.m. (17:00 hours).

READING TIMING DATA FROM A UTDF FILE

Depending on software version, UTDF files that optimization and analysis software had produced may contain all or a subset of data for a coded network. For instance, the standard UTDF file that Synchro 7 and later versions had generated contains all data, while earlier versions of this software created different files for network geometry, timing plans, phase information, and volumes. This project assumes that all output of interest will be contained in a single data file. Two sections of this file, illustrated in Figures B3 and B4, contain all timing data that the user of this toolbox will be interested in downloading to a controller running under free and coordinated modes. As illustrated here, these sections are identified by [TimePlans] and [Phase] tags. At the beginning of each of these sections is a record (a line) that identifies the data contained in the remainder of this section. As illustrated in Figure B3, the *TimePlans* section identifies control type, cycle length, reference phases, and offsets for all intersections in the network. The timing data are organized by record name, intersection number, and value of data for the item identified by the record name. For instance, Figure B3 illustration indicates that the control type and cycle length for intersection 3 are 0 (see below for explanation of control types) and 40 seconds, respectively.

```
[Timeplans]
Timing Plan Settings
RECORDNAME,INTID,DATA
Control Type,3,0
Cycle Length,3,40.0
Lock Timings,3,0
Referenced To,3,0
Reference Phase,3,206
Offset,3,0.0
Master,3,0
Yield,3,0
Node 0,3,3
Node 1,3,0
```

Figure B3. Timing Plan Section of UTDF File.

```
[Phases]
Phasing Data
RECORDNAME,INTID,D1,D2,D3,D4,D5,D6,D7,D8
BRP,3,111,112,211,212,121,122,221,222
MinGreen,3,,4,,4,,4,,4
MaxGreen,3,,16,,16,,16,,16
VehExt,3,,3,,3,,3,,3
TimeBeforeReduce,3,,0,,0,,0,,0
TimeToReduce,3,,0,,0,,0,,0
MinGap,3,,3,,3,,3,,3
Yellow,3,,3.5,,3.5,,3.5,,3.5
AllRed,3,,0.5,,0.5,,0.5,,0.5
Recall,3,,3,,3,,3,,3
Walk,3,,5,,5,,5,,5
DontWalk,3,,11,,11,,11,,11
PedCalls,3,,0,,0,,0,,0
MinSplit,3,,20,,20,,20,,20
DualEntry,3,,1,,1,,1,,1
InhibitMax,3,,1,,1,,1,,1
Start,3,,0,,20,,0,,20
End,3,,20,,0,,20,,0
Yield,3,,16,,36,,16,,36
Yield170,3,,5,,25,,5,,25
LocalStart,3,,0,,20,,0,,20
LocalYield,3,,16,,36,,16,,36
LocalYield170,3,,5,,25,,5,,25
ActGreen,3,,16,,16,,16,,16
```

Figure B4. Phase Data Section of UTDF File.

The following text provides additional information/notes regarding key data items in this section:

- Control Type:
  - 0–pretimed.
  - 1–actuated uncoordinated.
  - 2–semi-actuated uncoordinated.
  - 3–actuated coordinated.
- Referenced to:
  - 0–last of the phases to turn green.
  - 1–the first phase to turn yellow.
  - 2–the first phase to turn red.

- 3–the first referenced phase to turn green.
- 4–the beginning of flashing Don't Walk.

- Reference phase provides a single number identifying one or more coordinated phases.
  - First phase times 100 + the second phase.
  - In the above sample, 206 means coordinated phases are 2 and 6.
- Offset values are in seconds.
  - Node data for each intersection specifies if a single controller also controls additional intersections. When multiple nodes are controlled using a single controller, output section for the first node contains phase data for that controller. In the output provided in Figure B3, the line "Node 0, 3, 3" states that controller 3 controls intersection 3, and the following line (Node 1, 3, 0), indicates that there are no other nodes controlled by controller 3. If a controller controls more than one intersections (i.e., a diamond interchange), the output will contain more than two lines with the tag Node. In such a case, all phase data will be listed under the first node. The following show an example of a case where one controller controls two intersections (3 and 4), and where all phase data will be listed under intersection (node) 3.
  - Node 0, 3, 3.
  - Node 1, 3, 4.
  - Node 2, 3, 0.

The *Phases* section provides timing data for each intersection. These data include:

- Sequence of phases (rather a ring-barrier mapping).
- Maximum green times.
- Minimum green times.
- Lengths of clearance intervals.
- Other parameters.

Each of these sets of output for an intersection is contained in a single line. In each line, two back-to-back commas indicate that there is no data for the corresponding field. Note that the output in Figure B4 contains data for only phases 2, 4, 6, and 8. Except record named BRP, which is described below, most of these data items are self-explanatory.

The BRP (Barrier-Ring-Position) line specifies sequences of phases by identifying the locations of phases in a ring-barrier structure. Table B1 interprets the sequence data contained in Figure B4.

Table B1. Interpretation of BRP Data in Figure B4.

	Barrier 1		Barrier 2	
Position	1	2	1	2
Ring 1	1	2	3	4
Ring 2	5	6	7	8

Thus, the sequence of phases in the two rings is:

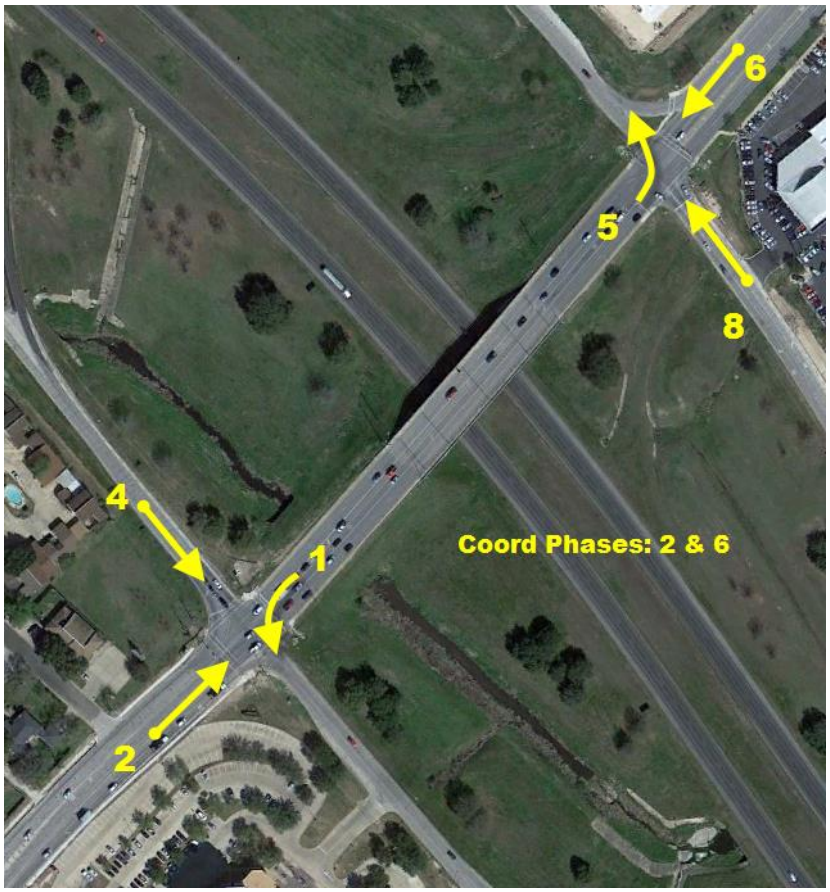
- Ring 1: 1-2-3-4.
- Ring 2: 5-6-7-8.

The research team adopted a four-barrier, four-ring, and eight-position-per-barrier data structure to provide for a wide range or ring-barrier configurations that the toolbox users might encounter during its use.

As illustrated above, once BRP information is translated into such a structure, non-zero entries in each ring provides the sequence of phases. However, this information needs to be further translated into a sequence number corresponding to programmed phase sequences in the controller. The toolbox has been designed to read phase sequence data programmed in the controller and match it with sequence read from the UTDF file to identify the sequence number for programming the pattern data.

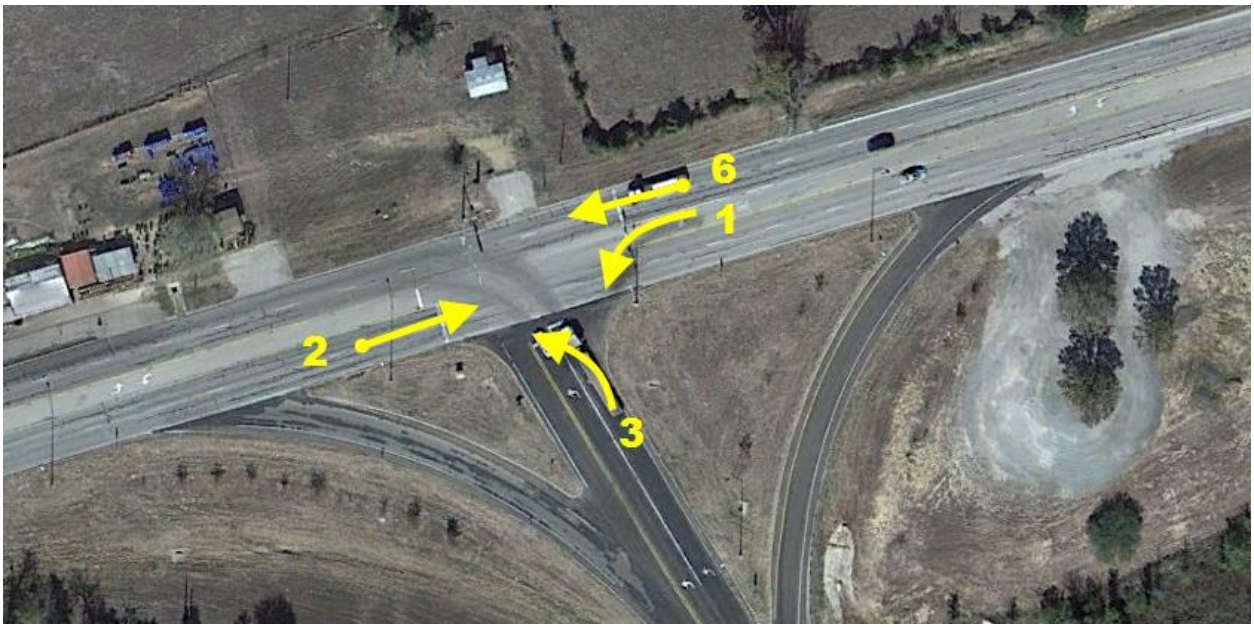
Lastly, it should be noted that the *Phases* section does not contain split times for phases. Calculation of phase splits is trivial because the split for a phase is equal to the sum of corresponding max time, yellow interval, and all red clearance time. When appropriate, the toolbox will add these times to obtain splits for downloading to the split table in the controller. However, the user will be responsible for identifying a pattern number and split table number for downloading optimized timings for coordinated operations.

APPENDIX C: MAPS AND TIMING DATA FOR TEST SITES



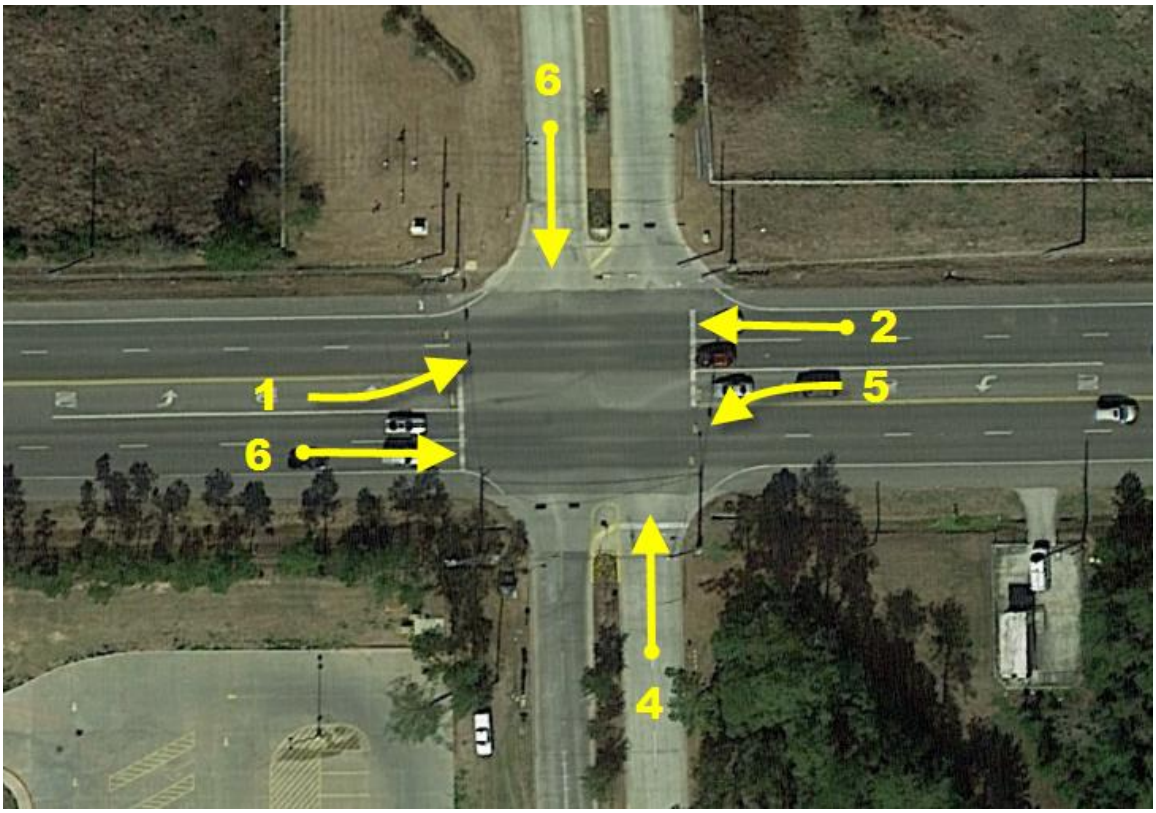
Diamond Interchange at SH 6 and Briarcrest Drive in Bryan, Texas.

Phase #	Min Green	Max1	Yellow	All-Red	Detectors
1	5	30	40	10	1
2	17	45	40	10	2, 11
4	12	40	40	10	4, 12, 21
5	5	35	40	10	5
6	17	45	40	10	6,15
8	12	40	40	10	8, 16, 22
10	5	25	40	10	
11	2	2	40	10	
12	2	2	40	10	
14	5	25	40	10	
15	2	2	40	10	
16	2	2	40	10	



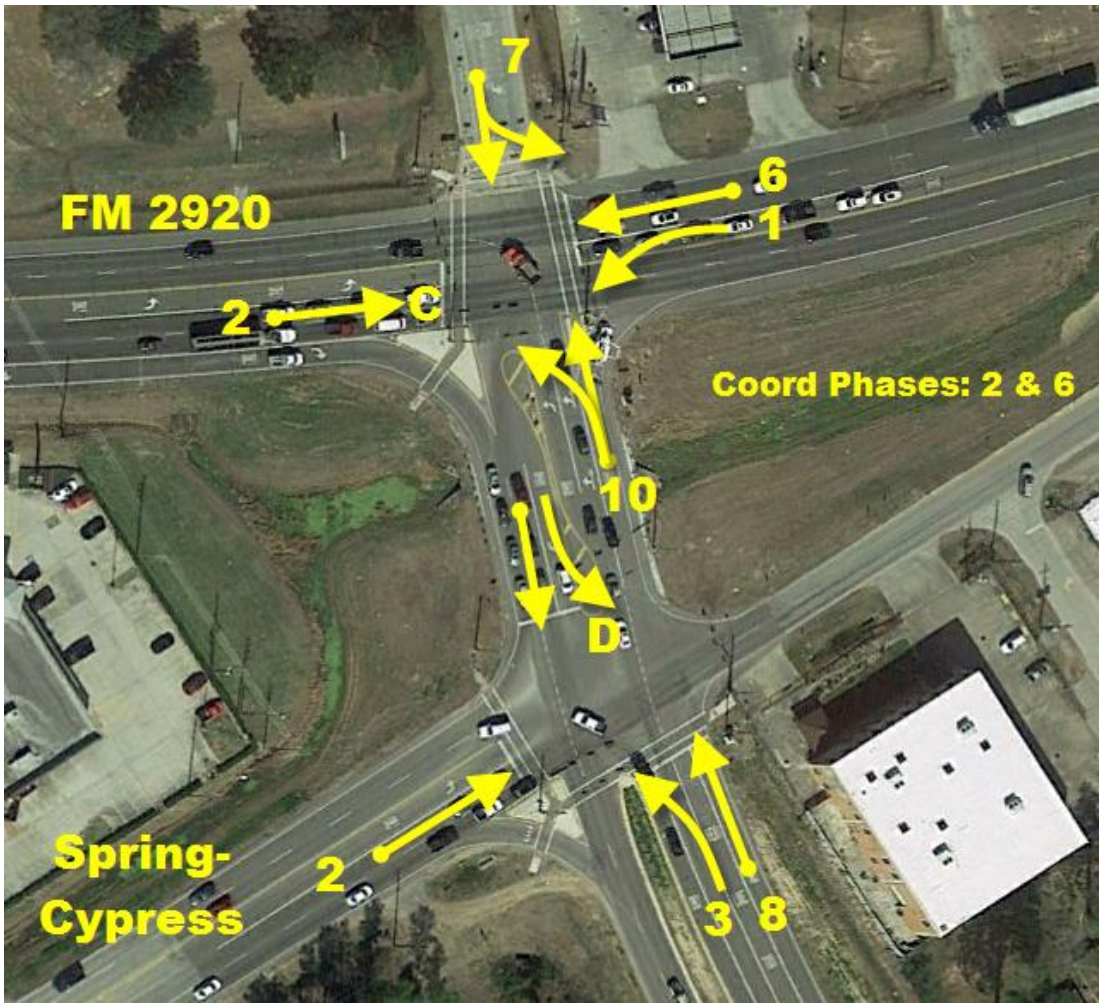
US 79/190 and SH 36 in Milano, Texas.

Phase #	Min Green	Max1	Yellow	All-Red	Detectors
1	5	15	40	0	5
2	10	35	40	20	1, 10
3	5	35	40	0	7
6	10	25	40	20	3, 6



FM 2920 and Alvin A. Klein in Spring, Texas.

Phase #	Min Green	Max1	Yellow	All-Red	Detectors
1	5	15	50	15	1
2	15	35	50	10	12, 16
4	7	20	35	25	3, 4
5	5	15	50	10	5
6	15	35	50	15	10, 14
8	7	20	35	25	7, 8

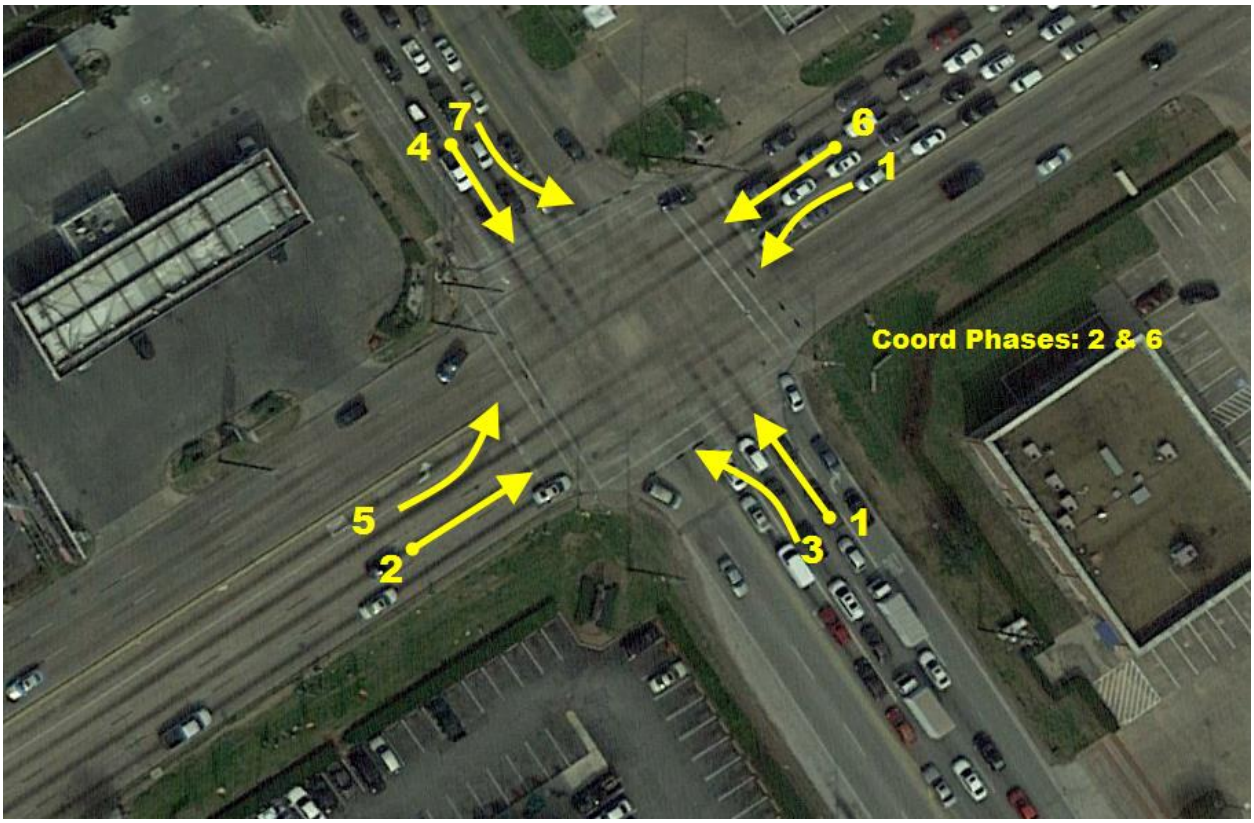


FM 2920 and Holzwarth in Spring, Texas.

Phase #	Min Green	Max1	Yellow	All-Red	Detectors
1	10	60	35	15	3
2	15	45	45	15	1, 9, 10
3	5	35	40	10	13
4	1	20	40	20	
5	5	15	35	15	4
6	15	65	45	15	2
7	7	20	40	20	8
8	7	20	40	0	14
9	1	1	40	20	11, 12
10	1	3	40	20	5, 15, 16

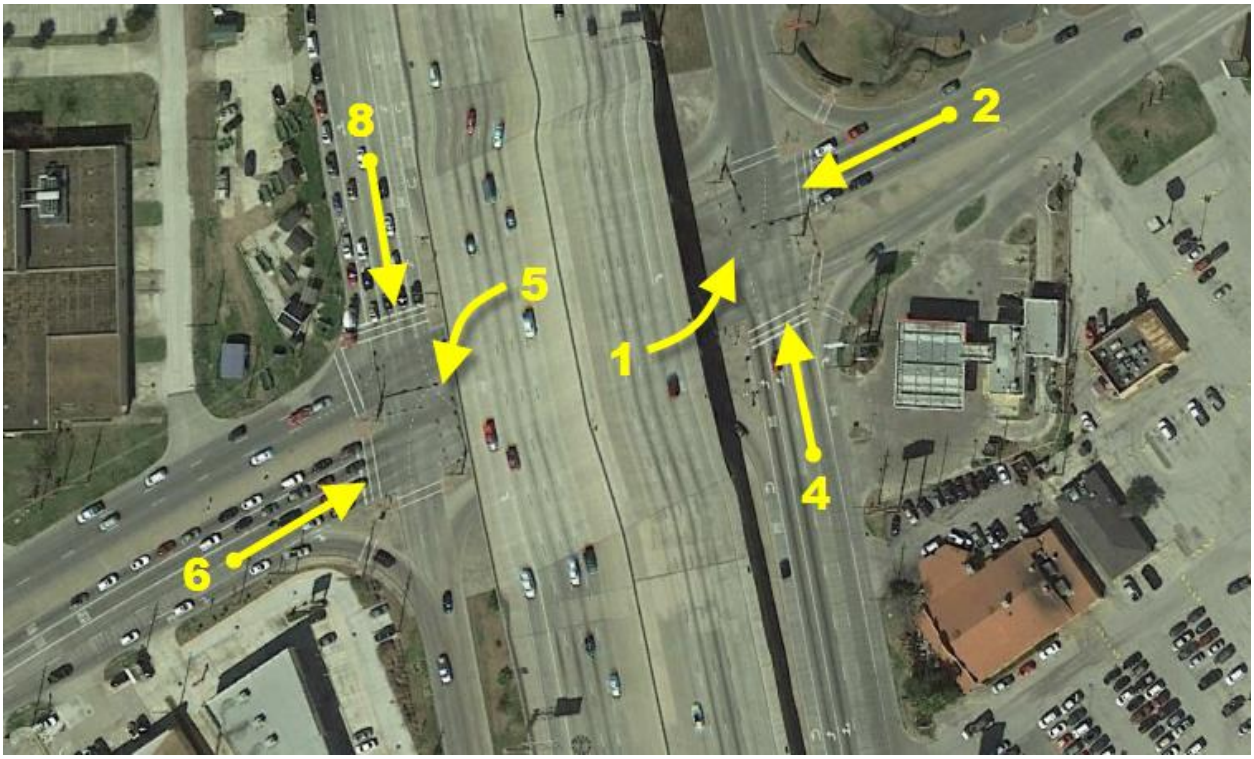
FM 2920 and Dowdell Road, Tomball, Texas.

Note: Toolbox was not able to communicate with the Siemens M50 Controller at this location. The controller is configured to provide IP-based center-to-field communications to the toolbox from a server at the district office. However, it appears that the controller firmware does not allow more than one IP-based connection at a time.



FM 1960 and Stuebner Airline Drive, Houston, Texas.

Phase #	Min Green	Max1	Yellow	All-Red	Detectors
1	6	20	40	20	1
2	10	45	40	20	2, 41
3	6	20	40	20	4, 5
4	9	25	40	20	6, 7, 8, 42
5	6	35	40	20	9
6	10	45	40	20	10, 11, 43
7	6	20	40	20	12, 13
8	9	25	40	20	14, 15, 16, 44,



FM 2920 and I-45 in Houston, Texas.

Phase #	Min Green	Max1	Yellow	All-Red	Detectors
1	5	30	40	15	1
2	15	45	40	15	2, 11
4	7	45	45	25	4, 12
5	5	30	40	15	5
6	15	60	40	15	6, 15
8	7	45	45	25	8, 16, 21

APPENDIX D: CONTROLLER TIMING FROM FM 1960 AND STUEBNER AIRLINE INTERSECTION

Weekday Time Base Day Plan/Schedule.

Start Time	Action Plan	Pattern	Timing Plan	Detector Plan	Sequence	Cycle Length	Start Time
12:00 AM	7	7	0	1	7	90	12:00 AM
6:30 AM	3	3	0	1	13	120	6:30 AM
9:00 AM	7	7	0	1	7	90	9:00 AM
11:30 AM	1	1	1	1	1	105	11:30 AM
4:00 PM	5	5	0	1	7	135	4:00 PM
7:00 PM	1	1	1	1	1	105	7:00 PM
8:30 PM	7	7	0	1	7	90	8:30 PM

Pattern–1

Cycle	105s
Offset Value	45s
Sequence	1

Splits (Seconds)								
Phase	1	2	3	4	5	6	7	8
Splits (Split Pat 1)	20	41	24	20	24	37	24	20

Pattern–3

Cycle	120
Offset Value	40s
Sequence	13

Splits (Seconds)								
Phase	1	2	3	4	5	6	7	8
Splits (Split Pat 1)	18	48	20	34	18	48	24	30

Pattern–5

Cycle	135s
Offset Value	45s
Sequence	7

Splits (Seconds)								
Phase	1	2	3	4	5	6	7	8
Splits (Split Pat 1)	22	59	28	26	28	53	22	32

Pattern–7

Cycle	90s
Offset Value	40s
Sequence	7

Splits (Seconds)								
Phase	1	2	3	4	5	6	7	8
Splits (Split Pat 1)	18	32	20	20	18	32	20	20