Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-11/0-6177-1		

4. Title and Subtitle	5. Report Date
A PORTABLE TOOLBOX TO MONITOR AND EVALUATE SIGNAL OPERATIONS	November 2010 Published: October 2011
	6. Performing Organization Code
7. Author(s) Srinivasa R. Sunkari, Hassan A. Charara, and Praprut Songchitruksa	8. Performing Organization Report No. Report 0-6177-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-6177
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Technical Report: September 2008–August 2010 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Portable Traffic Signal Monitoring and Evaluation Toolbox to Improve Signal Operations and Safety

URL: http://tti.tamu.edu/documents/0-6177-1.pdf

16. Abstract

Researchers from the Texas Transportation Institute developed a portable tool consisting of a field-hardened computer interfacing with the traffic signal cabinet through special enhanced Bus Interface Units. The toolbox consisted of a monitoring tool and an analysis tool. The monitoring tool monitors and logs relevant events within the cabinet that provide input to analyze intersection operations. These inputs include signal status, detector status, preempt status, and coordination status. The user has to provide the basic signal timing data and coordination data as input data. The analysis tool then analyzes the log files for each day and produces easy to understand reports. The reports are available either in an hourly average format or individual cycle format for a selected time period. The measures of effectiveness (MOEs) presented include phase time, phase failures, queue clearance time, time to service; as well as counts on green, yellow, red, and split utilization during coordinated operations. 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.

The analysis tool analyzes the log files and generates user-specified MOEs in Microsoft Excel® format. This type of format provides the user with an opportunity to further analyze the data in a manner the user considers appropriate.

17. Key Words	18. Distribution Statement
Intersection Operations, Signal Operations, Signal Maintenance	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	80	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

A PORTABLE TOOLBOX TO MONITOR AND EVALUATE SIGNAL OPERATIONS

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Report 0-6177-1
Project 0-6177
Project Title: Portable Traffic Signal Monitoring and Evaluation Toolbox to Improve Signal Operations and Safety

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Federal Highway Administration

November 2010
Published: October 2011

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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 in charge of the project was Srinivasa Sunkari, P.E. (Texas) #87591.

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

ACKNOWLEDGMENTS

This research was conducted during a one-year study under a cooperative research program with TxDOT and FHWA. Henry Wickes of the Traffic Operations Division was the project director. Other TxDOT members of the project monitoring committee included Larry Colclasure, Don Baker, Gordon Harkey, Herbert Bickley, Adam Chodkiewicz, and Wade Odell. The project panel's input is greatly appreciated.

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INTRODUCTION

BACKGROUND

Traffic signal operators are faced with the challenge of determining performance measures of traffic signal operations. FHWA defines a performance measurement as the "use of statistical evidence to determine progress toward specific defined organizational objectives" (*1*). Performance measures provide a documentation of the appropriateness of the signal settings and detector operation and functionality. Typically, operators program the signal timings and do not have the resources to conduct long-term monitoring of the signal timing changes. For example, the maximum green settings are critical to minimize delay and improve safety; however, the operators cannot judge its appropriateness from the short time they spend at the site. If they can obtain a log of the signal controller response to traffic patterns over a long period of time, they can better judge the quality of the controller settings. Similarly, operators frequently get complaints from motorists about detection operations, especially video detection. However, the signal engineers and technicians are often unable to replicate the described problem and end up with a patchwork solution that may or may not address the complaint or the issue efficiently. Signal operators need a tool to document traffic signal controller and detection operations to diagnose problems reported and develop appropriate solutions. This tool can be used as a maintenance device due to the scarcity of manpower in most districts.

Improving operations at signalized intersections has been an important objective for TxDOT. TxDOT has proactively improved safety by sponsoring development of numerous alternative signal control strategies. Texas Transportation Institute (TTI), with support from TxDOT, has developed a number of these strategies. These include Detection-Control System (D-CS) (*2*), Platoon Identification Algorithm (PIA) (*3*), and Advance Warning of End-of-Green (AWEGS) (*4*). These advance strategies improve the safety at the intersections and enhance the signal operations. D-CS, PIA, and AWEGS systems require extensive monitoring of the signal controller and detector functionality in real time. This extensive monitoring of intersection operations is logged to a file for each day. These log files contain much data that can be used to determine some of the performance measures at an intersection and will serve as a prototype event logger to monitor intersection operations and evaluate performance measures.

Performance Measures for Coordinated System

The metrics for freeway performance are generally well understood, and the data are typically readily obtainable from sensors located within freeway infrastructure. Interrupted flow facilities, such as arterials, are more challenging as they represent a result of complex interactions among drivers, traffic control devices, and other road users such as pedestrians and bicyclists; lane changing and entry exit via driveways and side streets; and queuing due to periodic flow interruptions controlled by traffic signals (*5*). As such, traffic conditions can vary greatly from point-based sensors along arterials.

Table 1 summarizes some potentially useful measures of effectiveness (MOEs) for arterial traffic according to the survey Shaw (*6*) conducted. The most useful measure to report depends on the intended audience, the context, and the communications medium. Nee and Hallenbeck (*7*) found that tools for evaluating signal performance (such as computing delay, platoon ratio, or number of signal failures) are especially valuable to transportation agencies.

Table 1. Selected Arterial Performance Measures.

Metric	Measurement Interval	Location
Maximum speed		
Average speed		
Speed index (Ratio of average speed to posted speed limit)	Per vehicle	
Density	Per person	
Running time	Per distance	
Travel time	Per time (cycle, 15 min, hour, day)	Per lane
Travel time variance		Per lane group
Average delay		Per approach
Maximum delay		Per segment
Queue length		Per facility
Platoon ratio		Per area
Number of stops		
Signal failure		
Duration of congestion	Per day	
Number of incidents	Per day/peak period	
Duration of incidents	Per event	
Non-recurring delay		

Smaglik et al. (*8*) developed an integrated general-purpose data collection module that time stamps detector and phase state changes within a National Electrical and Mechanical Association (NEMA) actuated traffic signal controller and uses those data to provide quantitative graphs to assess arterial progression, phase capacity utilization, movement delay, and served volume on a cycle-by-cycle basis. The Econolite ASC/3 controller software was enhanced to include a data logger that features the ability to collect time-stamped state changes of phases in use (1 to 16) and detectors in use (1 to 64) and transmit the data via transmission control protocol/internet protocol network connection. The enhanced software was tested at an intersection in Noblesville, Indiana. The data that the controller software had logged were compared with the data collected separately by the data collection units. The following measures were calculated from cycle-by-cycle data:

- *Equivalent hourly volume*. This measure provides the volume on a movement at any point during the day. The 20-cycle moving average was used for the calculation.
- *Arrival type data*. The arrival type was determined using HCM platoon ratios calculated based on the percent of vehicles arriving on green, length of green indication, and cycle length. A vehicle arrival is defined as the time when the vehicle passes over the advanced detectors.
- *Delay data*. The average vehicular delay per cycle was calculated based on the arrival and departure profiles using the methodology developed by Sharma et al. (*9*). The queue profile was constructed from the arrival and departure profiles. The area under the queue profile is equivalent to the estimated vehicular delay.
- *Volume-to-capacity ratio*. The v/c ratio was estimated based on vehicle departures from stop bar count detectors binned on a cycle-by-cycle basis, phase indication length, and cycle length.

These calculated MOEs can be compared over time to determine the impact of operations such as the changes in timing plan and oversaturated conditions.

Figure 1 shows the example plot of arrival types over time. The shift in the arrival types noted in the figure was a result of a change in the starting time of coordinated timing plan from 1:00 p.m. to 2:30 p.m. a year later.

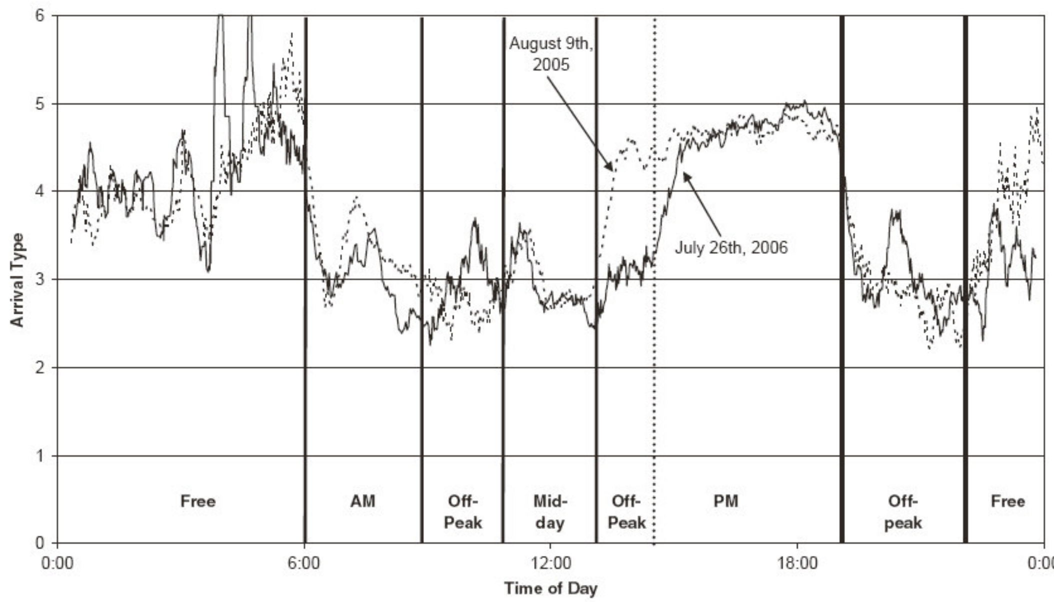


Figure 1. Example Plot of Arrival Type over Time (8).

Bullock et al. (*10*) described procedures and case studies that illustrate how the Highway Capacity Manual (HCM) concepts can be integrated with traffic signal system detection and controller status information to provide real-time performance measures characterizing the operation of a coordinated traffic signal system. The HCM equation for the delay is:

$$d = d_1(PF) + d_2 + d_3 \tag{1}$$

$$d_1 = \frac{0.5C\left(1 - \frac{g_i}{C}\right)^2}{1 - \min(1, X_i)\frac{g_i}{C}} \tag{2}$$

where

d = control delay to the lane group (sec/veh).

d_1 = uniform delay (sec/veh).

d_2 = incremental delay (sec/veh).

d_3 = initial queue delay (sec/veh).

PF = progression adjustment factor.

X_i = volume-to-capacity ratio for the lane group i.

C = cycle length (sec).

g_i = effective green time for the lane group i.

In addition, the overall intersection saturation can be evaluated by identifying the movements with critical volume-to-capacity ratios (X_c):

$$X_c = \sum \left(\frac{v}{s}\right)_{ci} \left(\frac{C}{C-L}\right) \quad (3)$$

where

X_c = critical volume-to-capacity ratio for intersection.

$\sum \left(\frac{v}{s}\right)_{ci}$ = summation of flow ratios for all critical lane groups.

L = lost time per cycle, computed as lost time for critical path of movements (sec).

Based on the HCM equations, the authors suggested that the following measures can be used to quantitatively characterize the operation of a coordinated signal system:

- Progression adjustment factor (*PF*). The *PF* is a function of the arrival type parameter that ranges from 1 (poor) to 6 (exceptional) and characterizes the proportion of the platoon that arrives on green versus that which arrives on red.
- Volume-to-capacity ratio (X_i). The v/c ratios have significant impact on both d_1 and d_2, and it also tells if the phase has extra green time that can be re-allocated to other competing phases.
- Overall intersection saturation (X_c). This measure helps identify which phases are critical by time of day and the overall slack in the cycle of a coordinated system.

Wolfe et al. (*11*) proposed methods for quantifying arterial performance using data from signal system loop detectors. The suggested performance metrics included traffic density, total delay, predicted travel time, and signal coordination effectiveness.

Liu et al. (*12*) developed a system named SMART-SIGNAL (Systematic Monitoring of Arterial Road Traffic Signals) that is capable of collecting and archiving event-based traffic signal data simultaneously at multiple intersections. This study proposed mathematical models to estimate time-dependent queue lengths and turning movement proportions. The queue lengths were estimated by examining the changes in detector occupancy profile within a cycle and then deriving the queue length by identifying traffic flow pattern changes during the queue discharging process. The authors used detector counts from nearby intersections to calculate right-turning traffic for the subject intersection. The authors also proposed an algorithm for arterial performance measurement by tracing virtual probe vehicles from origin to destination. In summary, the following measures were produced at an intersection level:

- Arrival type.
- Cyclic volume.
- Occupancy profile.
- Delay.
- Level of service.
- Queue size (number of vehicles in queue).
- Queue length (feet).

For arterial performance measurement, the following indicators were calculated and examined in the field study:

- Travel time.
- Delay.
- Number of stops.
- Stop time.
- Vehicle probe trajectory.

The SMART-SIGNAL has been deployed at an 11-intersection corridor along France Avenue in south Minneapolis. The field study showed that the proposed models can generate accurate time-dependent queue lengths, travel times, number of stops, and other performance measures under various traffic conditions.

Along with measures to evaluate signal controller performance, detector monitoring can be very useful to diagnose any problems with detectors. Detectors can malfunction for various reasons. Technicians are unable to detect these problems in many cases. Some of these malfunctions are detected by the diagnostics features within the signal controllers. However, the signal controller cannot store a history of detector behavior. To fix the problems, technicians change some parameters like delay, extension, sensitivity, detector size or shape (video). These fixes are more of bandages than solutions to the problems.

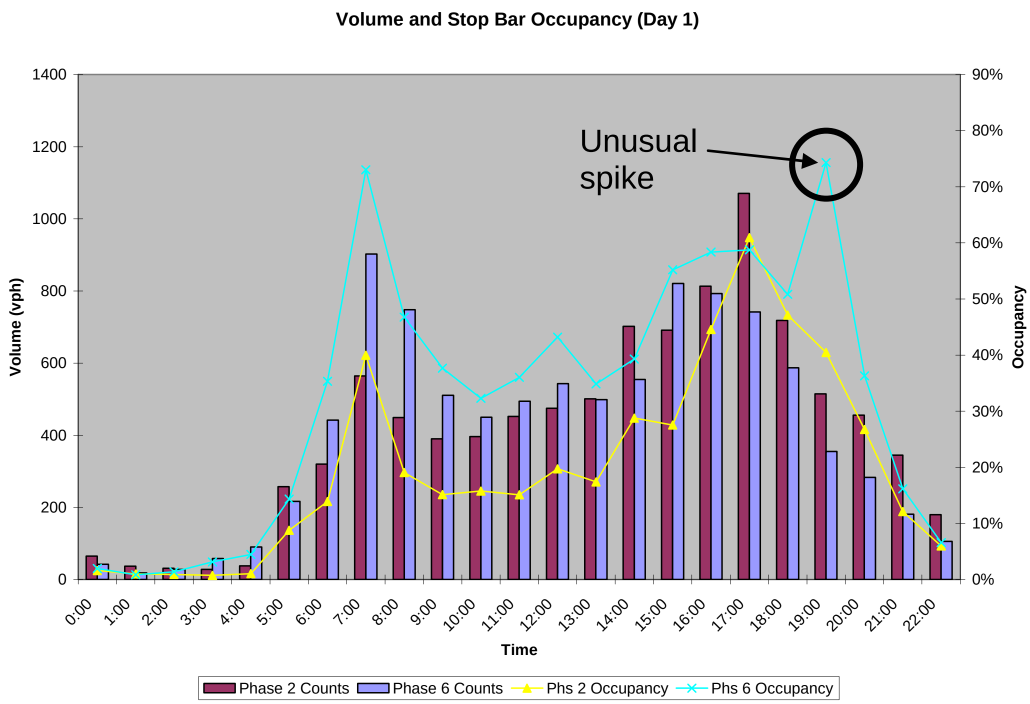
Figure 2 illustrates an example of a malfunction of a stop bar detector using video. An unusual spike in stop bar detection occupancy that was inconsistent with the trends in approach volumes was observed for several days. This observation was at an intersection where AWEGS was implemented.

Observations illustrated in Figure 2 are not usually available to engineers or technicians. However, such detector behavior will give rise to inefficient intersection operations, resulting in unsafe driver behavior and complaints. A technician will not be able to diagnose any malfunction when visiting the intersection. A system that can monitor the intersection behavior for a week or two and provide a quick summary of intersection and detector operations will be a very useful maintenance tool for engineers and technicians. Such a tool will be able to provide a summary based either in an interval-based format, i.e., 15 minutes, 1 hour, or 6 hours, or in an event-based format such as every cycle as per the user's preference.

CURRENT TECHNOLOGY

Signal Controller MOE Reports

A study conducted at TTI (*13*) identified the built-in capabilities of signal controllers to collect performance measures. Specifically, the study looked at the capabilities of the EPAC 300 Eagle traffic signal controller (*14*). The Eagle controller has the capability to estimate volumes, stops, delay, and green phase utilization. These parameters can be evaluated either for a specific time interval (only during coordinated operation) or on a cycle-by-cycle basis. The study found that these built-in capabilities need to be greatly expanded to provide accurate measures of signal performance. The effectiveness and accuracy of these systems are highly dependent on the design of the detection system and the placement of the detection zones. There are further limitations on the quantity of data that the controller can collect.



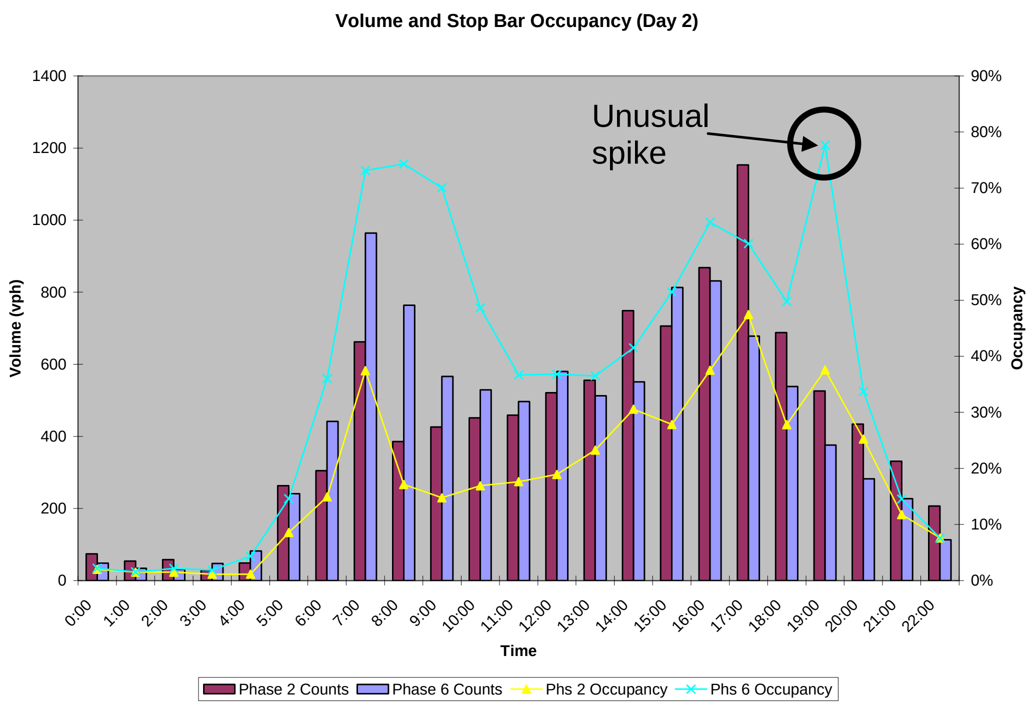


Figure 2. Volume and Stop Bar Occupancy at an Example Intersection.

Eagle's MOEs are accumulated and reported for the evaluation of coordination pattern parameters based on actual data collected during the periods the pattern is in control. MOE calculations are made once for each sequence cycle for volume, stops, delays, and utilization for each phase in the controller unit and then averaged over the duration of the pattern. Table 2 summarizes Eagle's MOEs.

Table 2. Eagle's MOE Report (*14*).

MOEs	Operational Definition	Calculation Procedure
Volume	The average number of actuations during the sequence cycle for the duration of the pattern.	Average number of actuations (0–999) received on each phase.
Stops	The average number of vehicles that must stop at an intersection during the cycle of the duration of the pattern.	Average number of actuations (0–999) received during the non-green time on each phase.
Delays	The average time in seconds that vehicles are stopped during the sequence cycle for the duration of the pattern.	The displayed data × 10 denote average time (0–999 seconds) of the delay on each phase per cycle. Delay accumulates based on cars waiting and elapsed time.
Utilization	The average seconds of green time used by each phase during the sequence cycle for the duration of the pattern.	The average green time (0–999 seconds) used on each phase per cycle.

The Eagle's MOE report has two major limitations (*13*):

- The controller can generate the MOE report only when it is operating in a coordinated mode.
- The collected MOE report is limited to eight phases only.

Traffic Signal Performance Measurement System (TSPMS)

The study (*13*), developed a TSPMS to collect real-time performance measures from the controller using either TS-1 or TS-2 architecture. Table 3 summarizes the daily log data to produce the performance measures.

Table 3. Performance Measures Computed by TSPMS (*13*).

Performance Measure	Definition	Calculation Procedure
Cycle Time	The time that elapses between subsequent activations of a particular phase.	The time difference between the current start of green and the previous start of green of the same phase.
Time to Service	The time elapsed from when a call was first received for a phase to the start of green for that phase.	The time difference between the start of green for the phase and the first call received on the detector for that phase.
Queue Service Time	The time required to clear the queue on a particular phase.	The time difference between the start of green for a particular phase and the termination of a continuous call on the detector of that phase.
Duration of Green, Yellow, All-Red, and Red Intervals	The durations of the green, yellow, all-red, and red intervals for each phase.	The time elapsed between the beginning and the end of each interval in each respective phase.
Number of Vehicles Entering during Green, Yellow, All-Red, and Red Intervals	The number of vehicles that enter the intersection while each interval during a phase is active.	A number of actuations received at the stop-bar detectors of each phase during green, yellow, all-red, and red intervals.
Yellow and All-Red Violation Rates	The rate at which one or more actuations were recorded during the yellow and all-red intervals of that phase.	The ratio between the number of cycles in which one or more actuations were detected during the yellow and all-red intervals for each phase and the total number of cycles observed for that phase during the evaluation period.
Phase Failures	A scenario in which the queue fails to clear before the phase has ended.	The detector for the phase receives a constant call when the phase has ended.

This study conducted hardware-in-the-loop (HITL) simulation using VISSIM and Eagle® EPAC 300 signal controller to assess the quality of the performance measures automatically generated from the controller's automatic MOE report. The guidelines on how and when to use automatic MOE reports from the controller were also provided as part of this study (*13*). The system was deployed and tested at two locations in Texas: (1) US 70 and SH 36 in Milano and (2) FM 2871 and FM 247 in Huntsville. The evaluation results indicated that the effectiveness and the accuracy of these systems are highly dependent on the design of the detection system and the placement of the detection zones.

DESIGN OF ARCHITECTURE

This project developed a toolbox to monitor and evaluate traffic signal operations. This toolbox can monitor and log the signal phase status and detector status within the signal controller cabinet for a few days. These log files are then analyzed to evaluate detector and signal operations at the intersection. The toolbox is comprised of a monitoring component and an evaluation component. The following sections will describe these two components.

MONITORING ARCHITECTURE

The monitoring component of the toolbox will be the Traffic Signal Event Recorder. The monitoring component monitors the signal status, detector status, preemption status, and the coordination status. The architecture was designed for a simple and easy-to-install configuration. Due to the high prevalence of TS-2 cabinets in TxDOT's inventory, it was decided to develop architecture suitable for a TS-2 environment.

This monitoring component will be housed in an industrial PC. This PC will interface with the signal controller using simple to install procedures. TTI researchers decided to use a special type of Bus Interface Units (BIUs) to communicate with the cabinet. TS-2 cabinets use BIUs to transfer data between various components. Typical TS-2 cabinets operating an eight phase intersections require one signal BIU (BIU 1) and one detector BIU (BIU 9). Intersections or interchanges using more than eight phases require a second signal BIU (BIU 2). Each detector BIU can have up to 16 channels of detectors. Intersections or interchanges requiring either more than 16 channels or requiring channels with numbers greater than 16 warrant a second detector BIU (BIU 10).

The primary objective is to monitor all essential parameters to evaluate the signal and detector operations at the intersection. In the TS-2 environment, additional BIUs (BIU 3 and BIU 4) can also be installed. TTI researchers have used these BIUs in PIA and AWEGS deployments (3, 4) for monitoring additional parameters and facilitating additional commands. These additional BIUs are in a separate BIU rack that had to be installed. To facilitate use of the toolbox, TTI researchers decided to use architecture requiring no more than two signal BIUs and two detector BIUs. Figure 3 illustrates the architecture of the Monitoring Tool.

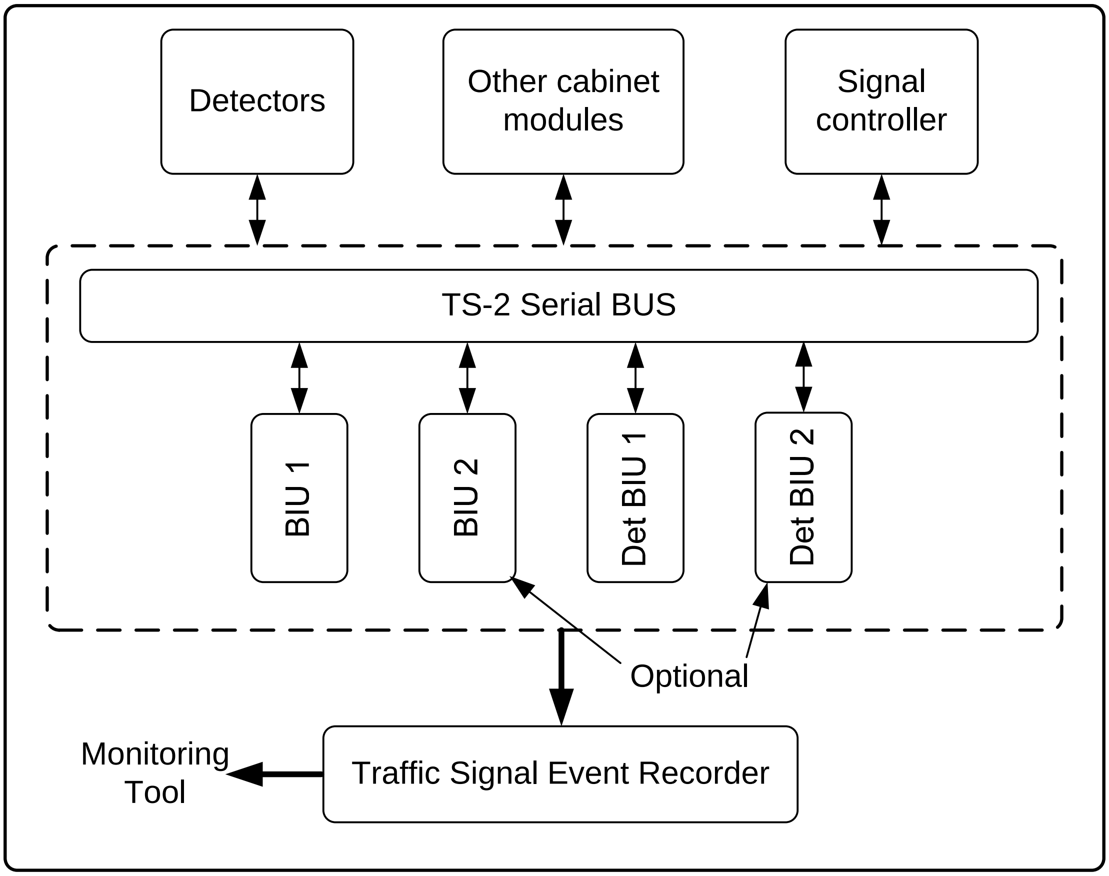


Figure 3. Monitoring Tool Architecture.

The monitoring tool consists of special BIU, a field-hardened computer, and interface cables. These components are described in this section.

Enhanced BIUs

A TS-2 cabinet has a small back panel having limited pin outs for monitoring the intersection operations. Deployments of D-CS, PIA, and AWEGS (2, 3, 4) have used enhanced BIUs to obtain all the functionality typically available from the back panel of a TS-1 cabinet. Enhanced BIUs are typical BIUs that also have a RS 232 port on the front. Connecting the PC to these BIUs is a quick and simple way to monitor the signal and detector operations in the cabinet.

Figure 4 illustrates two enhanced BIUs with an RS 232 port in a signal controller cabinet. One of the BIUs is attached to the field-hardened PC in the cabinet. These BIUs are produced by Naztec Inc. and are available for approximately $400.

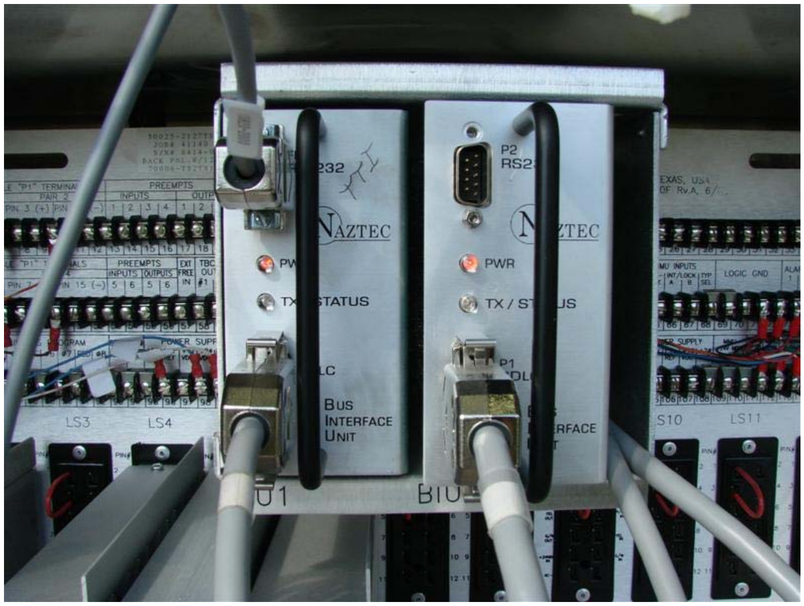


Figure 4. Enhanced BIU in a TS-2 Cabinet.

BIU Functionality

Each BIU has specific inputs/outputs that are monitored using the RS 232 port. Table 4 illustrates the signal assignment of BIU 1. As mentioned earlier, for a typical intersection with eight phases, only BIU 1 is used to monitor the phase status, preemption status, and pedestrian status. The shaded rows in Table 4 indicate the signals being monitored. These include the load switches drivers for the red, yellow, and green indications for phases 1 to 8, status of preempt 1 and 2, status of Force Off for Ring 1 and Ring 2, and status of four pedestrian detectors. For a typical intersection with eight phases, only BIU 1 is used. When more than eight phases are used, BIU 2 is used. Table 5 illustrates the signal assignment of BIU 2. The toolbox will monitor the load switch drivers for the red, yellow, and green indications for phases 9 to 16; preemption status and detectors for preempts 3, 4, 5, and 6; and pedestrian detectors 5, 6, 7, and 8. These signals are indicated as shaded in Table 5.

The toolbox will monitor the detector status using the detector BIUs. Table 6 illustrates the signal assignment for the various signals in the detector BIU (BIU 9). Signal assignment is common in all detector BIUs. Table 6 illustrates that each detector BIU can provide detector status information for 16 channels. Typical intersections do not use more than 16 channels, and hence, usually a single detector BIU is adequate. However in some cases, additional channels from a second detector rack are necessary. This is especially the case when video detection is used at diamond interchanges. In such cases, a second detector BIU (BIU 10) is installed in the second detector rack and is monitored by the toolbox.

Table 4. BIU 1 Signal Assignment.

Signal	Function	Signal	Function
Output 1	Load Switch 1 Red Driver	Input / Output 18	Automatic Flash [I]
Output 2	Load Switch 1 Yellow Driver	Input / Output 19	Dimming Enable [I]
Output 3	Load Switch 1 Green Driver	Input / Output 20	Manual Control Enable [I]
Output 4	Load Switch 2 Red Driver	Input / Output 21	Interval Advance [I]
Output 5	Load Switch 2 Yellow Driver	Input / Output 22	External Minimum Recall [I]
Output 6	Load Switch 2 Green Driver	Input / Output 23	External Start [I]
Output 7	Load Switch 3 Red Driver	Input / Output 24	TBC ON Line [I]
Output 8	Load Switch 3 Yellow Driver	Input 1	Stop Time Ring 1 (Stop Time)
Output 9	Load Switch 3 Green Driver	Input 2	Stop Time Ring 2
Output 10	Load Switch 4 Red Driver	Input 3	Max II Selection Ring 1
Output 11	Load Switch 4 Yellow Driver	Input 4	Max II Selection Ring 2
Output 12	Load Switch 4 Green Driver	Input 5	Force Off Ring 1 (Force Off)
Output 13	Load Switch 5 Red Driver	Input 6	Force Off Ring 2
Output 14	Load Switch 5 Yellow Driver	Input 7	Call To NA I
Output 15	Load Switch 5 Green Driver	Input 8	Walk Rest Modifier
Input / Output 1	Load Switch 6 Red Driver [O]	Opto Input 1	Pedestrian Detector 1
Input / Output 2	Load Switch 6 Yellow Driver [O]	Opto Input 2	Pedestrian Detector 2
Input / Output 3	Load Switch 6 Green Driver [O]	Opto Input 3	Pedestrian Detector 3
Input / Output 4	Load Switch 7 Red Driver [O]	Opto Input 4	Pedestrian Detector 4
Input / Output 5	Load Switch 7 Yellow Driver [O]	Opto Common	12 VAC
Input / Output 6	Load Switch 7 Green Driver [O]	Data Transmit	Reserved
Input / Output 7	Load Switch 8 Red Driver [O]	Data Receive	Reserved
Input / Output 8	Load Switch 8 Yellow Driver [O]	Address Bit 0	OFF
Input / Output 9	Load Switch 8 Green Driver [O]	Address Bit 1	OFF
Input / Output 10	TBC Auxiliary 1 [O]	Address Bit 2	OFF
Input / Output 11	TBC Auxiliary 2 [O]	Address Bit 3	OFF
Input / Output 12	Preempt 1 Status [O]	+24 VDC	Power Supply Interface
Input / Output 13	Preempt 2 Status [O]	Logic Ground	
Input / Output 14	Preempt 1 Detector [I]	Earth Ground	
Input / Output 15	Preempt 2 Detector [I]	Line Freq. Ref.	
Input / Output 16	Test A [I]		
Input / Output 17	Test B [I]		

Table 5. BIU 2 Signal Assignment.

Signal	Function	Signal	Function
Output 1	Load Switch 9 Red Driver	Input / Output 18	Preempt 5 Detector [I]
Output 2	Load Switch 9 Yellow Driver	Input / Output 19	Preempt 6 Detector [I]
Output 3	Load Switch 9 Green Driver	Input / Output 20	Call To NA II [I]
Output 4	Load Switch 10 Red Driver	Input / Output 21	Spare
Output 5	Load Switch 10 Yellow Driver	Input / Output 22	Spare
Output 6	Load Switch 10 Green Driver	Input / Output 23	Spare
Output 7	Load Switch 11 Red Driver	Input / Output 24	Spare
Output 8	Load Switch 11 Yellow Driver	Input 1	Inhibit Max Term Ring 1
Output 9	Load Switch 11 Green Driver	Input 2	Inhibit Max Term Ring 2
Output 10	Load Switch 12 Red Driver	Input 3	Local Flash Status
Output 11	Load Switch 12 Yellow Driver	Input 4	MMU Flash Status
Output 12	Load Switch 12 Green Driver	Input 5	Alarm 1
Output 13	Load Switch 13 Red Driver	Input 6	Alarm 2
Output 14	Load Switch 13 Yellow Driver	Input 7	Free (No Coord)
Output 15	Load Switch 13 Green Driver	Input 8	Test C
Input / Output 1	Load Switch 14 Red Driver [O]	Opto Input 1	Pedestrian Detector 5 (Signal Plan A)
Input / Output 2	Load Switch 14 Yellow Driver [O]	Opto Input 2	Pedestrian Detector 6 (Signal Plan B)
Input / Output 3	Load Switch 14 Green Driver [O]	Opto Input 3	Pedestrian Detector 7
Input / Output 4	Load Switch 15 Red Driver [O]	Opto Input 4	Pedestrian Detector 8
Input / Output 5	Load Switch 15 Yellow Driver [O]	Opto Common	12 VAC
Input / Output 6	Load Switch 15 Green Driver [O]	Data Transmit	Reserved
Input / Output 7	Load Switch 16 Red Driver [O]	Data Receive	Reserved
Input / Output 8	Load Switch 16 Yellow Driver [O]	Address Bit 0	ON
Input / Output 9	Load Switch 16 Green Driver [O]	Address Bit 1	OFF
Input / Output 10	TBC Auxiliary 3 [O]	Address Bit 2	OFF
Input / Output 11	Free/Coord Status [O]	Address Bit 3	OFF
Input / Output 12	Preempt 3 Status [O]	+24 VDC	Power Supply Interface
Input / Output 13	Preempt 4 Status [O]	Logic Ground	
Input / Output 14	Preempt 5 Status [O]	Earth Ground	
Input / Output 15	Preempt 6 Status [O]	Line Freq. Ref.	
Input / Output 16	Preempt 3 Detector [I]		
Input / Output 17	Preempt 4 Detector [I]		

Table 6. Detector BIU (BIU 9) Signal Assignment.

Signal	Function	Signal	Function
Output 1	Detector Reset Slot 1 & 2	Input / Output 18	Channel 2 Fault Status [I]
Output 2	Detector Reset Slot 3 & 4	Input / Output 19	Channel 3 Fault Status [I]
Output 3	Detector Reset Slot 5 & 6	Input / Output 20	Channel 4 Fault Status [I]
Output 4	Detector Reset Slot 7 & 8	Input / Output 21	Channel 5 Fault Status [I]
Output 5	Reserved	Input / Output 22	Channel 6 Fault Status [I]
Output 6	Reserved	Input / Output 23	Channel 7 Fault Status [I]
Output 7	Reserved	Input / Output 24	Channel 8 Fault Status [I]
Output 8	Reserved	Input 1	Channel 9 Fault Status
Output 9	Reserved	Input 2	Channel 10 Fault Status
Output 10	Reserved	Input 3	Channel 11 Fault Status
Output 11	Reserved	Input 4	Channel 12 Fault Status
Output 12	Reserved	Input 5	Channel 13 Fault Status
Output 13	Reserved	Input 6	Channel 14 Fault Status
Output 14	Reserved	Input 7	Channel 15 Fault Status
Output 15	Reserved	Input 8	Channel 16 Fault Status
Input / Output 1	Channel 1 Call [I]	Opto Input 1	Connected to Data Receive of each detector
Input / Output 2	Channel 2 Call [I]	Opto Input 2	Connected to Data Transmit of each detector
Input / Output 3	Channel 3 Call [I]	Opto Input 3	Reserved
Input / Output 4	Channel 4 Call [I]	Opto Input 4	Reserved
Input / Output 5	Channel 5 Call [I]	Opto Common	Reserved
Input / Output 6	Channel 6 Call [I]	Data Transmit	
Input / Output 7	Channel 7 Call [I]	Data Receive	
Input / Output 8	Channel 8 Call [I]	Address Bit 0	
Input / Output 9	Channel 9 Call [I]	Address Bit 1	
Input / Output 10	Channel 10 Call [I]	Address Bit 2	
Input / Output 11	Channel 11 Call [I]	Address Bit 3	Logic Ground
Input / Output 12	Channel 12 Call [I]	+24 VDC	Power Supply Interface
Input / Output 13	Channel 13 Call [I]	Logic Ground	
Input / Output 14	Channel 14 Call[I]	Earth Ground	
Input / Output 15	Channel 15 Call [I]	Line Freq. Ref.	
Input / Output 16	Channel 16 Call [I]		
Input / Output 17	Channel 1 Fault Status [I]		

Computer

TTI researchers initially developed a configuration using a field-hardened computer configuration. At the project director's suggestion, a laptop version of the toolbox was also developed. These desired specifications for the required computers are described below.

The computer had to be field-hardened; reasonably light and small so that it was portable; and have up to 2 GB of RAM, an 80 GB hard drive, expansion slots for added functionality, USB ports for data transfer, serial ports, and a DVD drive with read/write capability. Most importantly, the PC had to operate in a real-time data collection and data-analysis mode without any malfunctions. That laptop had to meet all the environmental requirements of the computer and also needed to have a battery that would operate the laptop for at least 60 minutes in case of a power failure.

EVALUATION ARCHITECTURE

Data Analysis

The objective of processing the data is to evaluate the signal and detector operations at the intersection. TTI researchers decided to process the data at the macro level and at the micro level. These two levels were also prepared in a Microsoft Excel® format, which is flexible enough to allow the user to analyze and present the data in a fashion that they choose. The macro-level analysis provides general trends of certain MOEs to the user. Based on certain criteria, the user will be able to view some trends over multiple days (up to a maximum of 7 days). These trends can also be viewed graphically. For example, Figure 5 illustrates the trend of Average Queue Service Time for Phase 4 over 6 days between 6 a.m. and 10 p.m.

Figure 5 clearly illustrates general trends in the queue service time (QST) for Phase 4. However, the individual data points are the average of the queue service time for the hour. The figure also shows that the QST is 3 seconds on May 17, 2010, from 7 a.m. until 10 a.m. Such numbers are not very realistic. Hence, there is a need to further analyze the QST parameter at a micro level. Once the user views the data at the macro level, some periods of interest can be identified and analyzed at a micro level.

Table 7 illustrates a micro-level analysis of the same data on May 17, 2010, starting from 7 a.m. The table illustrates the phase number, cycle number (from midnight) time of start of green for the respective phase, the duration of green, and the QST for that cycle. The micro-level analysis provides the actual reading of the MOE of interest (in this case, QST) on a cycle-by-cycle basis.

These two formats of the analysis of measures of effectiveness will allow the user to evaluate the intersection performance rapidly as well as thoroughly. The user will also have the flexibility to choose the time periods of interest, conduct a customized analysis using Excel, and present the analysis in a manner that the user chooses.

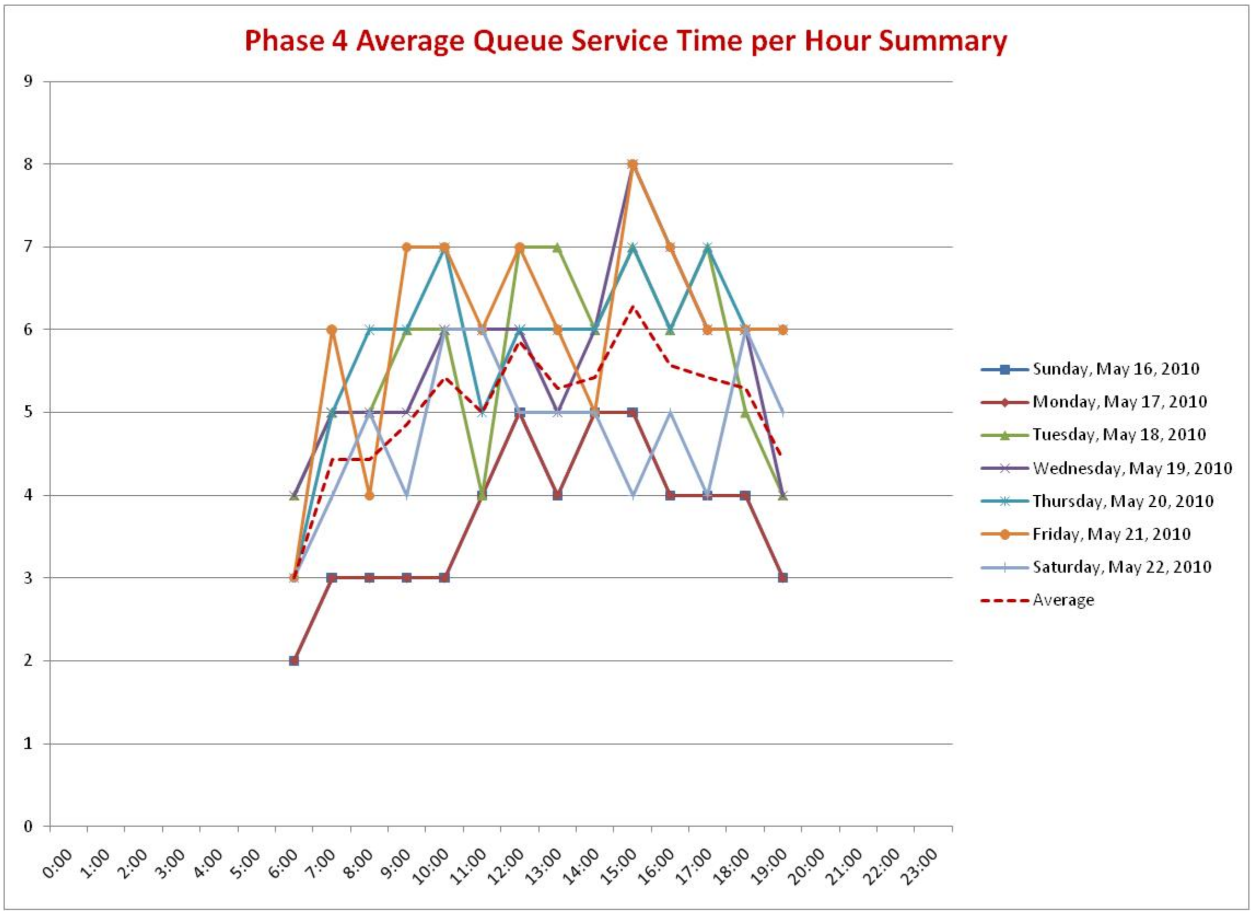


Figure 5. Illustration of a Macro-Level Analysis.

Table 7. Illustration of Micro-Level Analysis.

FRANKLIN				
US 79 AND	5/17/2010			
FM 46				
Phase	**CycleNo**	**GrnStart**	**Green**	**QueServiceTime**
4	169	07:01:05	00:07	
4	170	07:02:04	00:08	00:04
4	171	07:02:58	00:07	00:05
4	172	07:03:54	00:11	00:10
4	173	07:05:59	00:15	00:14
4	174	07:08:19	00:07	00:05
4	175	07:09:29	00:08	00:07
4	176	07:11:35	00:07	
4	177	07:14:22	00:15	
4	178	07:15:16	00:07	00:02
4	179	07:15:57	00:09	00:08
4	180	07:17:53	00:07	
4	181	07:18:53	00:09	00:08
4	182	07:19:37	00:15	00:09
4	183	07:22:10	00:07	00:05
4	184	07:23:06	00:07	00:03
4	185	07:24:42	00:07	00:05
4	186	07:25:24	00:07	
4	187	07:27:08	00:07	
4	188	07:28:01	00:07	00:06
4	189	07:29:02	00:07	
4	190	07:29:44	00:11	00:10
4	191	07:30:41	00:07	
4	192	07:31:27	00:07	
4	193	07:33:07	00:14	
4	194	07:35:43	00:09	
4	195	07:36:38	00:07	00:04
4	196	07:37:56	00:07	
4	197	07:39:39	00:07	00:05
4	198	07:40:20	00:07	00:02
4	199	07:41:13	00:09	00:08
4	200	07:46:18	00:07	00:01
4	201	07:47:50	00:07	00:06
4	202	07:48:32	00:14	00:04
4	203	07:49:32	00:08	00:08

Measures of Effectiveness

TTI researchers have estimated numerous MOEs to evaluate intersection operations. Most of these MOEs were identified during the development of the TSPMS (*13*) that monitored the signal status and detector status in the cabinet. The study project identified the following performance measures to be deduced from the parameters being monitored.

- Time to service.
- Queue service time.
- Duration of the green, yellow, all-red, and red interval for each phase.
- Phase failure rate.

Additional MOEs that were generated from the data analysis included:

- Number of minimum greens.
- Occupancy in red and green.
- Number of preempts.
- Counts on green, yellow, and red.
- Detector failures.

Time to Service

Time to service illustrated in Figure 6 is a measure of snappiness of the controller settings at an intersection. A long time to service can mean that a motorist has to wait for a long time for the green phase. This can be either due to high demands on other phases or large minimum greens and/or passage times.

Queue Service Time

Queue service time illustrated in Figure 7 is another measure to determine the demand and type of demand on a phase. If the queue service time is high and phase time is low, then the phase is operating in an efficient manner. However, a small queue service time with a large phase time indicates that a majority of the traffic being serviced is arriving randomly. Such a signal setting can potentially be improved by reducing the passage time.

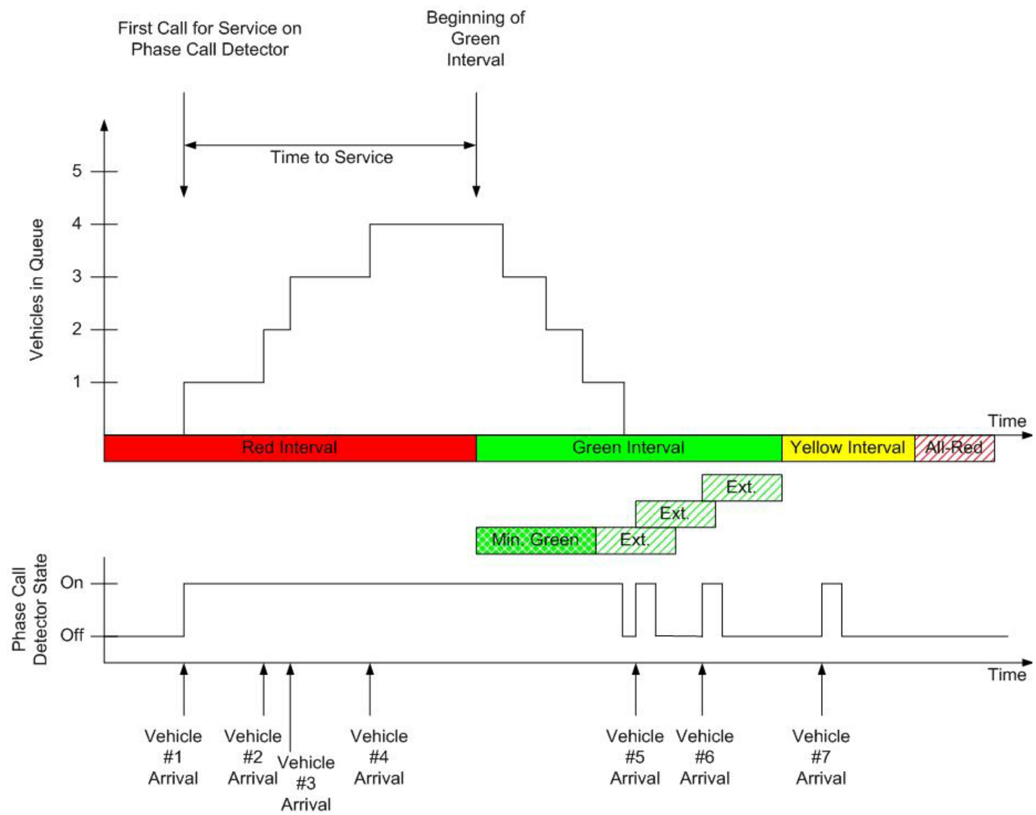


Figure 6. Illustration of Time to Service Performance Measure (*13*).

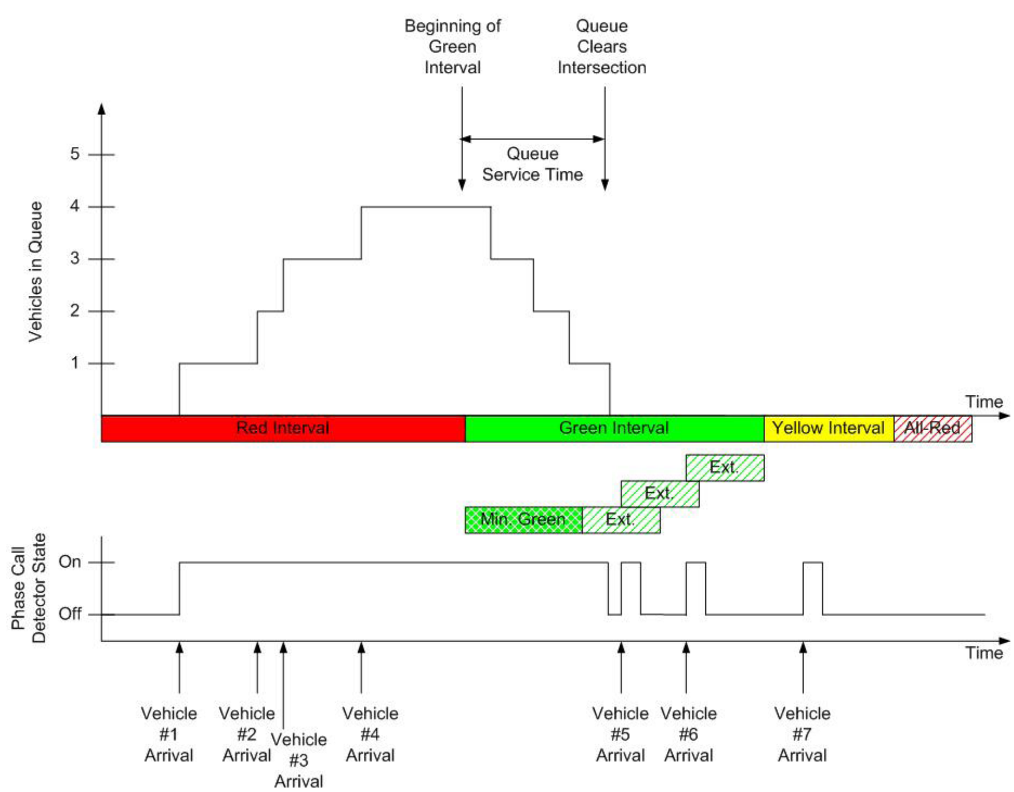


Figure 7. Illustration of Queue Service Time Performance Measure (*13*).

Phase Failure

A phase failure is another MOE, which provides an indication of the level of congestion on a particular phase. A high phase failure rate only on one phase may either indicate a need to reallocate the maximum times or an unexpected spike in traffic arrival patterns. However, a high failure rate on more than one phase (especially conflicting phases) may indicate a need to increase the cycle length or the physical capacity at the intersection. During the development of TSPMS (*13*), phase failure was defined as the detector being in a state of On from the start of the phase until the end of the phase as illustrated in Figure 8. This definition was primarily designed for a phase having a long stop bar detector.

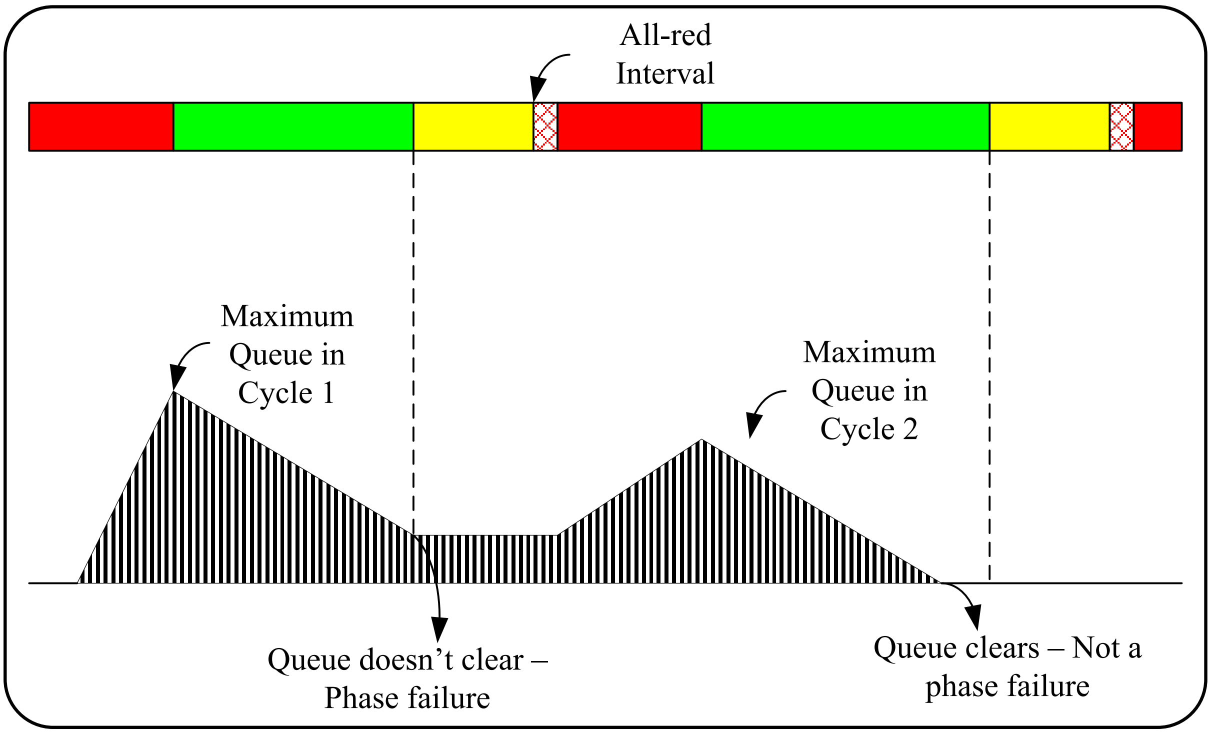


Figure 8. Typical Illustration of Phase Failure.

However, such a definition does not include phase failures occurring on high speed approaches where a detector may be occupied but another vehicle arrives before the phase gaps out. This definition also does not cover the scenario where two compatible phases (for example, Phase 2 and Phase 6 or Phase 4 and Phase 8) are on and while one phase may have gapped out, the other phase does not and the phases may max-out. Thus, TTI researchers used the functionality built into the traffic signal controller to define a max-out as illustrated in Figure 9.

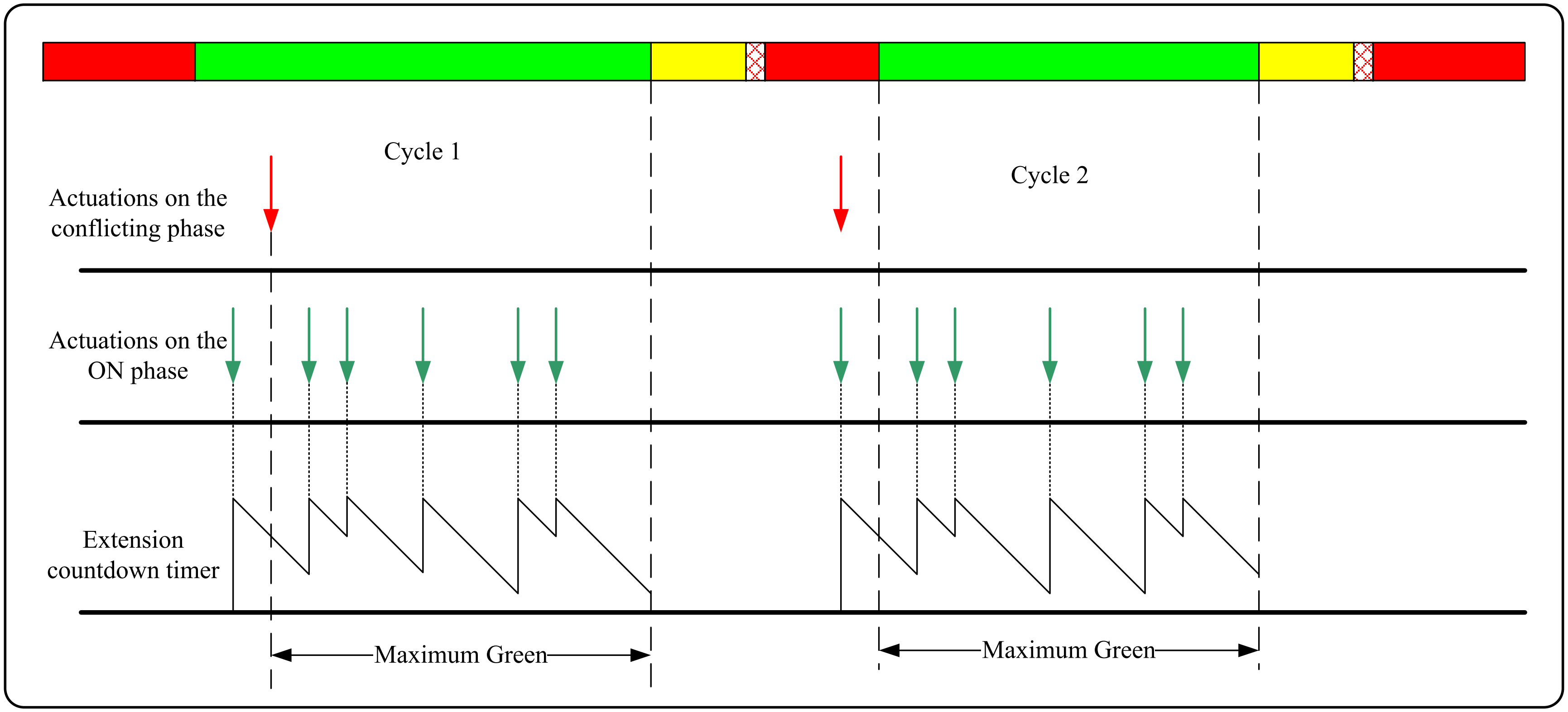


Figure 9. Illustration of Maximum Green and Phase Failure.

According to TS-2 specifications (*15*), Maximum Green is defined as "the maximum green time with a serviceable opposing actuation, which may start during the initial portion." This term can refer to the maximum time a phase can be extended in the presence of an actuation on a serviceable conflicting phase and is applicable for all actuated phases. The toolbox monitors the signal status and detector status. It also identifies the compatible phases, conflicting phases, major street phases, major street left-turn phases, and minor street phases. The toolbox can track the onset of a green indication on a phase and the onset of an actuation on a conflicting phase for the phase that is On. The user also provides the maximum green values programmed in the controller. Thus, the toolbox will initiate the max-out counter and identify a max-out when it occurs. When an intersection is operating in a fully actuated mode, all phases can be monitored for max-outs. However, when the intersection is operating in a coordinated mode, only the non-coordinated (fully actuated) phases are monitored for max-outs. By identifying the phases that max-out and documenting the number of times the phases max-out, we identify phase failures.

Phase Durations

Averages of phase durations, which include the green indications and red indications, will be provided in the macro analysis. The micro analysis will include the phase durations for each phase to provide additional clarity of phase utilizations for shorter periods of time.

Other MOEs

Other MOEs to be extracted from the data files include the occupancy during green indications and red indications and vehicle counts during the green indications and red indications. Occupancy along with vehicle counts can provide an idea of vehicle arrival patterns that can be used to determine the status of coordination for intersections operating in a coordinated mode. Other MOEs include tabulating the number of minimum green durations, documenting the onset and removal of preempts, logging the number of pedestrian calls each hour of the day, and identifying detector failures in the cabinet.

Table 8 summarizes the performance measures the toolbox produced along with the definitions and reporting format. Based on the definitions, Table 9 provides the interpretation of the performance measures collected in the system. A utility program was developed using Visual Basic for off-line evaluation of the daily data logs.

Table 8. 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.
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.
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.
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.
Time to Service	The time period 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.
Phase Time	The observed green duration of a phase.	Average phase time observed per hour or per cycle.
Phase Utilization	The observed phase green duration divided by phase max time.	Average phase utilization observed per hour or per cycle.

Table 9. Interpretation of Performance Measures.

Measure	Interpretation
Number of Minimum Green	The phase is being serviced with the shortest service time possible. High number of minimum greens may indicate that the phase is being serviced more than the need for that phase.
Occupancy on Green	This measure indicates how much the green time is being utilized by the traffic in that phase.
Queue Service Time	This measure indicates the time it takes to clear the queue for each cycle.
Max-out	The phase maxes out when the demand exceeds the maximum green time allocated for the phase. The vehicles may be trapped in the dilemma zone when the phase maxes out. Hence, the more frequent max-out is likely to increase the opportunity for dilemma zone, which may, in turn, lead to a crash risk from red-light running vehicles.
Occupancy on Red	For stop bar detectors, this measure is a proxy of vehicle presence on red. For upstream detectors, the high occupancy on red may serve as an indicator of demand on red and/or queue length.
Time to Service	This measure indicates the maximum amount of time the vehicles have waited for the onset of a green signal. It can serve as a measure of the snappiness of the signal operation as well as a measure of drivers' frustration, particularly when there is little to no demand on the conflicting phases.
Phase Time	This measure provides the average green time for each phase. The patterns of green time generally follow the traffic patterns by time of day and day of week. The departure of phase time from historical trend may indicate either unusual traffic activities or abnormal signal operation that warrants further examination.
Phase Utilization	This measure indicates the percentage of green time taken by the observed phase relative to the cycle length. This measure can provide a quick summary of how the phases are allocated in each cycle for a specific time of day.

Diagnostics

This section describes how to diagnose the indicators generated from the toolbox to analyze the performance of a signal system. The signal technicians may use the guidelines provided here in conjunction with their experience to analyze and fine-tune the signal operation as needed. Table 10 through Table 16 describe how the users can use the data logged from the system to perform a series of diagnostics, determine possible causes of observed activities, and identify any potential actions that could be taken based on the monitored results.

Table 10. Diagnostics of Number of Minimum Green.

Indicators	Possible Causes	Potential Actions
• High number of minimum greens. • Relative low occupancy on green at the same time.	• The phase may be on minimum recall. • The demand on the phase is light but fairly uniform.	• Check if the minimum green is too long. • Check if the right-turn-on-red vehicles can be sufficiently serviced with detector delay.
• Low number of minimum greens.	• Moderate to heavy traffic demand on that phase. • The arrival pattern is consistent.	• No action required.

Table 11. Diagnostics of Occupancy on Green.

Indicators	Possible Causes	Potential Actions
• High occupancy on green (near 100%) only at a certain time of day.	• Heavy traffic demand on that phase.	• If the occupancy on green on the conflict phase is below 100%, max time for this phase may be increased.
• High occupancy on green (near 100%) constantly throughout the day.	• Malfunctioned detector is placing a constant call.	• Check the phase detector.

Table 12. Diagnostics of Queue Service Time.

Indicators	Possible Causes	Potential Actions
• Queue service time is relatively close to the phase time.	• Most of phase time is used for queue discharge.	• No action required.
• Queue service time is relatively short compared to the phase time.	• Short queue coupled with random vehicle arrivals.	• Passage time may be reduced to increase the snappiness of the phase.

Table 13. Diagnostics of Number of Max-Out.

Indicators	Possible Causes	Potential Actions
• High number of max-out. • Phase failure rate > 0.2 if calculated based on the number of cycles observed.	• Heavy traffic demand on the phase. • Inappropriate passage time setting.	• If occupancy on green from the conflicting phase is below 100%, consider increasing the phase max time. • Revisit the passage time setting.

Table 14. Diagnostics of Occupancy on Red.

Indicators	Possible Causes	Potential Actions
• High occupancy on red.	• Heavy traffic demand for the phase may lead to residual queues at the beginning of green for several successive cycles.	• If the intersection is not oversaturated, consider adjusting the max times of conflicting phases to increase the snappiness of the phase with high occupancy on red.

Table 15. Diagnostics of Time to Service.

Indicators	Possible Causes	Potential Actions
• Long time to service and high occupancy on red.	• Heavy traffic demand on red.	• If appropriate, max time and/or passage time of the conflicting phases may be reduced to decrease the time to service.
• Long time to service and low occupancy on red.	• Right-turn-on-red vehicles arrive early on red.	• Use appropriate detector delay setting to minimize the calls from RTOR vehicles.
• Long time to service for left-turn phases.	• Heavy left-turn demand.	• Consider protected-permissive left turn. • Consider lagging versus leading left turn sequence.
• Short time to service.	• Light demand and vehicles tend to arrive at the end of red duration.	• No action required.

Table 16. Diagnostics of Phase Time and Phase Utilization.

Indicators	Possible Causes	Potential Actions
• Average phase time is at least 20% greater than the phase max time. • Phase utilization > 120%.	• Heavy phase demand. • Insufficient max time.	• Increase max time.
• The phase utilizations are significantly beyond the 80%–120% range.	• Traffic demand patterns may have changed significantly from when the signal was last timed.	• Signal retiming may be needed.

PROTOTYPE TOOLBOX

LABORATORY IMPLEMENTATION

The various components of the toolbox were acquired, and the monitoring and evaluation software was developed. The hardware components and the software were then integrated and tested. The following section describes the equipment procured for this project.

Computer

Hardened Computer

TTI researchers investigated numerous field-hardened computers for use as a portable toolbox. To meet the required specifications, they checked three hardened computers that other TTI researchers had purchased for other projects and finally selected the 1546 Heavy-Duty Industrial PC from Pro-face (*16*). Figure 10 illustrates the computer selected to house the toolbox. The computer is rated to operate between 0°C (32°F) and 50°C (122°F) and is small enough to be installed in a signal controller cabinet. It was tested out on the laboratory and in the field and could satisfactorily recover after a power failure. TTI researchers use this PC for numerous real-time applications in Texas.

Figure 10. The Industrial PC Selected for Housing the Toolbox (*16*).

The computer has two serial ports. TTI researchers purchased a Digi Neo Universal 4 port and a Digi Network Splitter cable (*17*) as illustrated in Figure 11 to connect the four BIUs to the computer. A rugged suitcase with wheels was purchased to contain all the equipment was purchased.

Figure 11. DIGI Neo Universal PCI and Digi Neo Splitter Cable (*17*).

Hardened Laptops

TTI researchers conducted a review of all available hardened, rugged laptops from Dell, Panasonic, and Lenovo. TTI researchers also tested the Portable Traffic Signal Maintenance and Evaluation System (PTSMES) on a rugged laptop with a Digi Edgeport/4 USB Expansion Module that provides four serial ports over a USB connection. The tests were conducted at the TransLink® laboratory in College Station by connecting the PTSMES to a cabinet and interfacing with multiple BIUs (BIU 1, BIU 2, and a detector BIU). A number of scenarios were tested to simulate field conditions, such as a sudden power interruption where everything in the cabinet gets rebooted or a failure in the laptop where it reboots while the cabinet stays operational. All the tests were conducted successfully without causing the cabinet to go into flash, and the PTSMES recovered after each interruption and resumed operations successfully.

Based on these tests, TTI researchers selected the Dell Latitude E6400 XFR (*18*) (illustrated in Figure 12) as the most suitable laptop for this project. The laptop requires less space than a hardened computer. The Dell Latitude E6400 XFR is rated to operate between −20°F and 145°F. It thus exceeds the specification of the Pro-face hardened PC. A Digi Edgeport/4 USB expansion module was used to obtain four additional RS 232 ports. These ports functioned satisfactorily when PTSMES was implemented in a rugged Dell laptop and tested in the laboratory. The Digi Edgeport module costs approximately $200. Its functionality in a hot cabinet has not been evaluated.

Figure 12. Dell Latitude E6400 XFR Laptop (*18*).

Enhanced BIU Interface with AWEGS Computer

Enhanced BIUs have an extra RS-232 serial port (illustrated in Figure 4) on the front casing that the computer can use to monitor the necessary controller inputs. These enhanced BIUs send a status message via the serial port every 100 milliseconds. The toolbox computer requires a serial port expander to increase the number of available serial ports to at least four. Typically, a computer has one or two serial ports. The computer needs to have at least as many serial ports as the BIUs being used. In TS-2 cabinets, enhanced BIUs will replace all BIUs being used (e.g., BIU1, BIU2 if being used, Detector BIU1, and Detector BIU2). Using enhanced BIUs has simplified the installation of the toolbox in a TS-2 cabinet. These BIUs are available from Naztec Inc.

Laboratory Implementation

The toolbox was integrated and tested in an actual signal controller cabinet in TTI's TransLink laboratory. The toolbox was tested for various configurations ranging from two BIUs to four BIUs. Various forms of intersection control were simulated ranging from isolated intersection to an isolated diamond interchange to a coordinated intersection. Power failures were simulated to review and evaluate the recovery capabilities of the toolbox. Figure 13 illustrates the testing done in the TransLink laboratory. The figure illustrates the hardened computer version of the toolbox being tested and also shows the computer hooked up to the enhanced BIUs using a serial expansion card.

Figure 13. Illustration of the Toolbox Being Tested in the TransLink Laboratory.

FIELD IMPLEMENTATION

Based on the testing in the laboratory, the toolbox was deployed at three field locations to test the system in a real-world environment. These three sites were selected in the Bryan District for their proximity to TTI researchers. The first location was at a diamond interchange in College Station at SH 6 and FM 40. The cabinet at this interchange is using all four BIUs, which included two signal BIUs and two detector BIUs. This deployment gave us an opportunity to test the toolbox with all four BIUs to monitor more than eight phases and 16 detector channels. Figure 14 and Figure 15 illustrate the layout of the intersection and the implementation of the toolbox at this location.

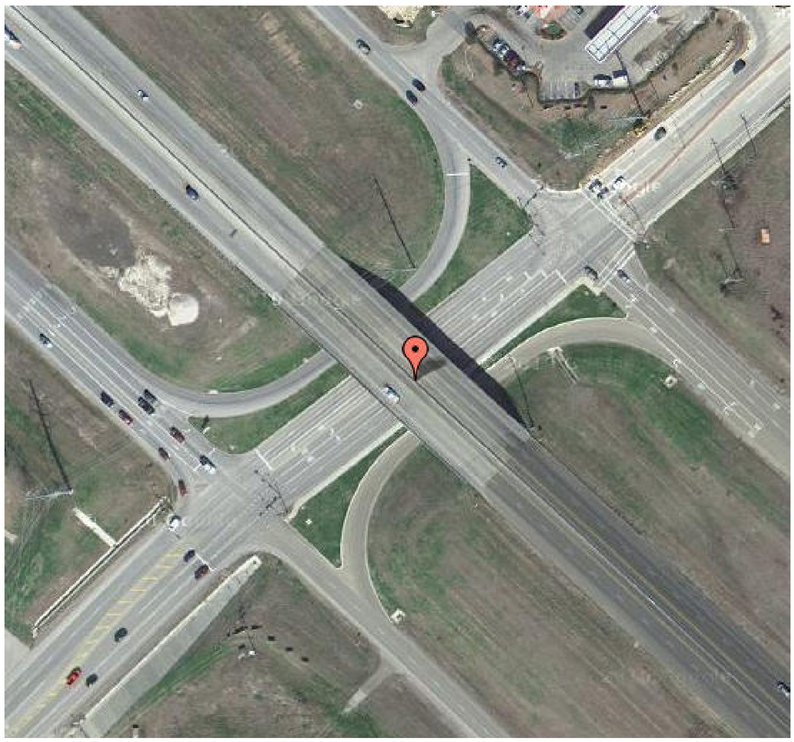


Figure 14. Intersection Layout at SH 6 and SH 40 Project Site (Courtesy Google Maps).

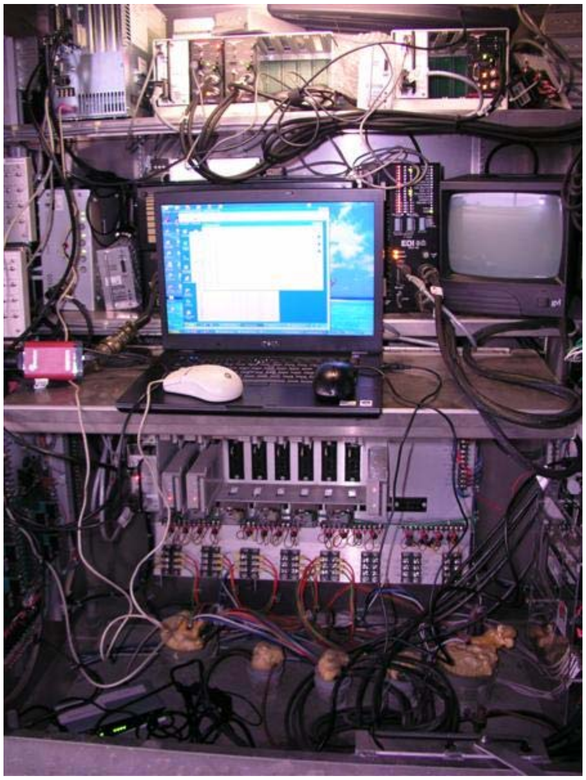


Figure 15. Toolbox Implementation at SH 6 and SH 40 Site.

The second location was at the intersection of US 79 and FM 46 in Franklin to evaluate the preemption monitoring capabilities. This intersection is adjacent to a railroad track. Figure 16 illustrates the proximity of the railroad tracks to the intersection in Franklin.

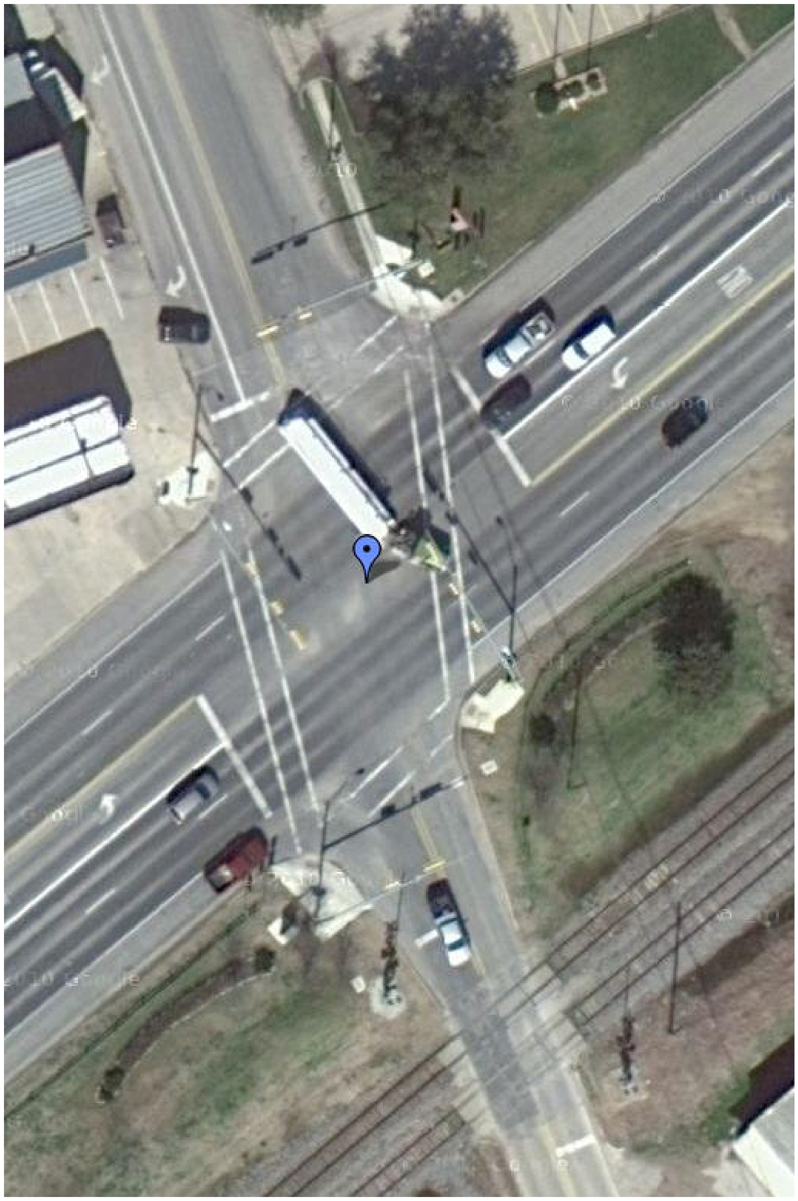


Figure 16. Intersection and Railroad Layout at US 79 and FM 46 in Franklin (Courtesy Google Maps).

The final implementation of the toolbox was done at the interchange of SH 6 and FM 60 in College Station to evaluate the coordination and pedestrian monitoring capabilities of the toolbox. Figure 17 and Figure 18 illustrate the layout and toolbox deployed at the interchange of SH 6 and FM 60 in College Station.

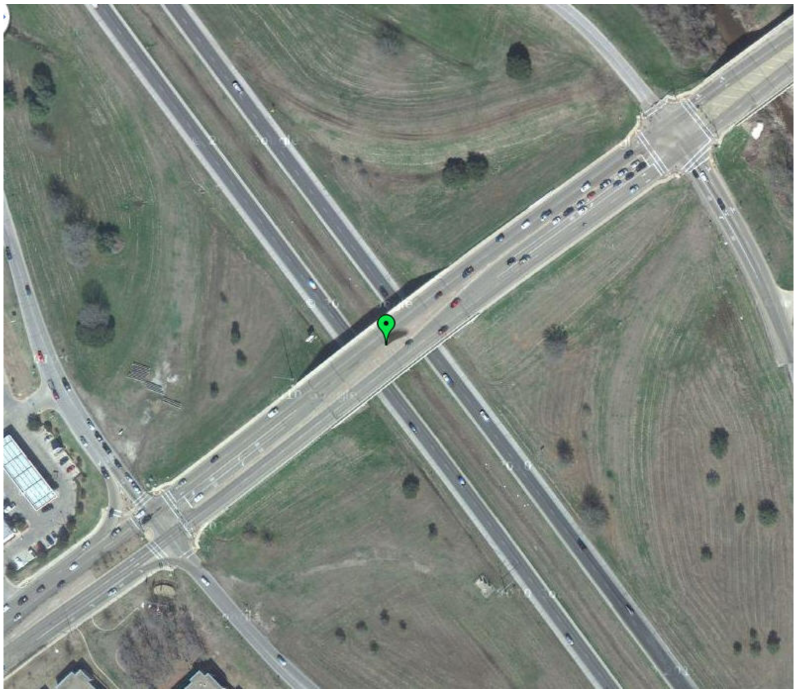


Figure 17. Intersection Layout at SH 6 and FM 60 Project Site (Courtesy Google Maps).

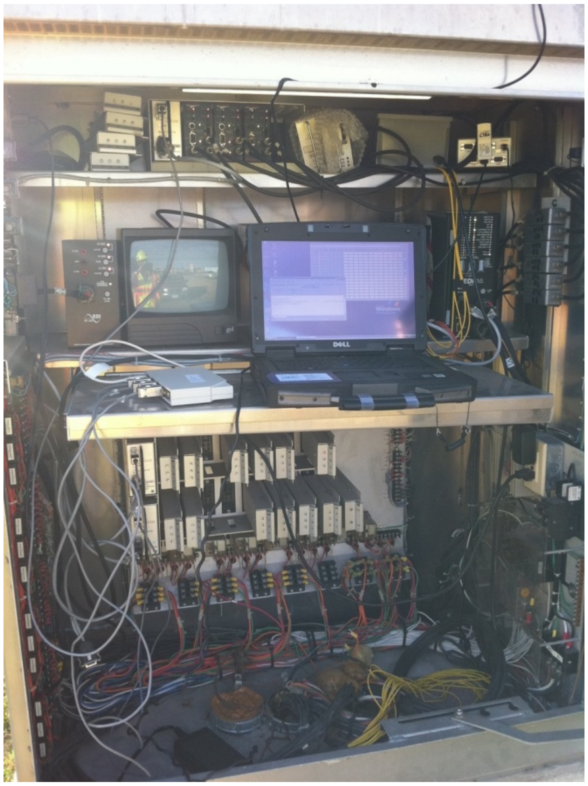


Figure 18. Toolbox Implementation at SH 6 and FM 60 Site.

CONCLUSION AND RECOMMENDATIONS

The objective of the project was to develop a toolbox to evaluate intersection operations. This toolbox is primarily a maintenance tool to assist engineers and technicians to quickly troubleshoot any operational problems at the intersection. TTI researchers initially developed a hardened computer version of the toolbox. Upon the panel's suggestion, a laptop version of the toolbox was also developed. Field testing of the toolboxes has shown that the device is very stable in monitoring intersection operations. The toolbox collected data at the intersections of FM 79 and FM 46 as well as at SH 6 and FM 60 for over a month. Data collected were of a high quality and provided not only information about the intersection performance, but also identified times when the intersection lost power. The toolbox was very easy to install in the cabinet and very simple to configure.

Data collected in Franklin and College Station were analyzed to address various MOEs. The data analysis module was designed to be fairly straightforward, and results were presented in a manner so that they were easy to understand. The user has a choice to analyze the data either in an average per-hour format or in a cycle-by-cycle format. Once the data files are loaded, the user has a choice of the MOE to analyze, the day(s) to analyze, phase(s) to analyze, and time period of analysis. The results of the analysis are presented in a graphical format for the Hourly MOE Report or in a tabular format for the Time-Period Report. The toolboxes have been delivered to TxDOT's TRF division for internal testing, and TTI researchers will provide technical support in the use of these toolboxes.

TTI researchers recommend that the TRF division should facilitate training to engineers and technicians in some districts so they can use the toolbox to monitor signal and detector operations at intersections in their respective districts. TRF can contact TTI personnel to assist in this training to district personnel. TRF and the districts can identify further improvements to the toolboxes to increase their utility value. These improvements can include not only software, but also hardware improvements. Currently the toolbox can be used in a TS-2 cabinet for ease of installation. Improvements in hardened computers and digital I/O cards have made it possible to develop a toolbox for a TS-1 environment, too. This improvement will enable deployment of the toolbox in more types of cabinets and environments.

REFERENCES

1. Federal Highway Administration Website on Transportation Performance Measures. Available at http://ops.fhwa.dot.gov/perf_measurement/index.htm. Accessed on May 13, 2008.
2. Bonneson J.A., D.R. Middleton, K.H. Zimmerman, H.A. Charara, and M.M. Abbas. *New Detection System for Rural Signalized Intersections.* Report No. TX-00/0-4022-S. Texas Department of Transportation, Austin, Texas, August 2000.
3. Nadeem. C.A., M.M. Abbas, H.A. Charara, and R.T. Parker. *An Intelligent Control System for Detecting and Progressing Platoons at Isolated Traffic Signals.* Report No. TX-03/0-4304-S. Texas Department of Transportation, Austin, Texas, September 2003.
4. Messer, C.J., S.R. Sunkari, H.A. Charara, and R.T. Parker. *Advance Warning for End-of-Green to Reduce Red-Light-Running.* Report No.Tx-03/0-4260-S, Texas Department of Transportation, Austin, Texas, September 2003.
5. Hicks, B. and M. Carter. What Have We Learned About Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.
6. Shaw, T. Performance Measures of Operational Effectiveness for Highway Segments and Systems. *NCHRP Synthesis 311*, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2003.
7. Nee, J. and M. Hallenbeck. Surveillance Options for Monitoring Arterial Traffic Conditions. *Report WA-RD 510.1*, Washington State Transportation Center (TRAC), Seattle, Washington, June 2001.
8. Smaglik, E. J., A. Sharma, D. M. Bullock, J. R. Sturdevant and G. Duncan. Event-Based Data Collection for Generating Actuated Controller Performance Measures. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2035, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 97–106.
9. Sharma, A., D. M. Bullock and J. A. Bonneson. Input-Output and Hybrid Techniques for Real-Time Prediction of Delay and Maximum Queue Length at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2035, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 69–80.
10. Bullock, D. M., J. R. Sturdevant and C. M. Day. Signalized Intersection Performance Measures for Operations Decision-Making. *ITE Journal*, Vol. 78, No. 8, 2008, pp. 20–23.
11. Wolfe, M., C. Monsere, P. Koonce and R. L. Bertini. Improving Arterial Performance Measurement Using Traffic Signal System Data. *Proceedings of the 2007 Intelligent Transportation Systems Conference*, Seattle, Washington, 2007.
12. Liu, H. X., W. Ma, X. Wu and H. Hu. Development of a Real-Time Arterial Performance Monitoring System Using Traffic Data Available from Existing Signal Systems. *Report MN/RC 2009-01*, Department of Civil Engineering, University of Minnesota, Minneapolis, MN, December 2008.
13. Balke, K.N., H. A. Charara, and R. T. Parker. Development of a Traffic Signal Performance Measurement System (TSPMS). *Report No.Tx-05/0-4422-2*, Texas Department of Transportation, Austin, Texas, May 2005.
14. EPAC 300 Actuated Controller Unit. Product Manual PIM-177 Rev. C.10. Eagle Signal, Austin, Texas.

15. NEMA Standards Publications TS-2 2003 Version 02.06, *Traffic Controller Assemblies With NTCIP Requirements*, National Electrical Manufacturers Association, Rosslyn, Virginia, 2003.
16. http://www.profaceamerica.com/cms/site/841df35d572b686e/index.html. Accessed on October 29, 2010.
17. http://www.cdw.com/. Accessed on October 29, 2010.
18. http://www.dell.com/. Accessed on October 29, 2010.

APPENDIX A – SPECIFICATIONS FOR THE TOOLBOX

INDUSTRIAL PC

Specifications

An industrial PC or a field-hardened laptop running the Windows XP operating system is currently used to operate the PTSMES field data collection module. The industrial PC used is manufactured by Pro-face and the specifications include:

- Pentium® M 2.0 GHz, with 2 GB memory.
- 80 GB Serial ATA hard drive.
- DVD-R/W.
- Ethernet and USB ports.
- Four available expansion slots.
- ThreeRS-232 serial ports.

The field-hardened laptop used is the Dell Latitude E6400 XFR and the specifications include:

- Intel® CoreTM 2 Duo Processor, with 2 GB of memory.
- 80 GB hard drive.
- DVR-R/W.
- Ethernet and USB 2.0 ports.

Procurement

Vendor
Pro-face America
1546 Heavy-Duty Industrial PC
http://www.profaceamerica.com/cms/resource_library/datasheets/f95da99f64744ec0/ds_154600_d__1_10_08.pdf
750 North Maple Rd
Saline, MI 48176
Phone: 734-429-4971
Fax: 734-429-1010
Email: customercare@profaceamerica.com
Website: http://www.profaceAmerica.com
Number required: 1

Vendor
Dell, Inc.
Dell Latitude E6400 XFR
http://www.dell.com/downloads/global/products/latit/en/laptop-latitude-e6400-xfr-specsheet.pdf
Phone: 1 800-WWW-Dell
Website: http://www.dell.com

ADDITIONAL SERIAL PORTS EXPANSION DEVICES

Specifications

The PTMSES field data collection module requires a maximum of 4 RS-232 serial ports to interface with the enhanced Bus Interface Units (BIUs) in a TS-2 cabinet. Both hardware systems, the industrial PC and the Dell laptop, do not have enough serial ports to interface with the TS-2 cabinet. In case of the industrial PC, additional RS 232 ports were available by installing a Digi Neo Universal PCI 4 port card in one of the available expansion slots and a Digi Network Splitter Cable to connect to the BIUs. On the other hand, since the laptop came with no serial ports, a Digi Edgeport/4 USB to 4 Port DB-9 Serial Converter was used with the Dell laptop to interface with the enhanced BIUs. The Digi Edgeport device connects to one of the USB ports on the laptop and it provides 4 RS-232 ports.

Procurement

Vendor
Digi International
Telephone: (952) 912-3444, 877-912-3444
Website: http://www.digi.com or through local distributor

Digi 4 RS-232 Serial Port Expansion Card for Industrial PC
http://www.digi.com/pdf/prd_msc_digineo.pdf
http://www.cdw.com/shop/products/default.aspx?EDC=534357
Manufacturer Part No: 77000857
Number required: 1

Digi Network Splitter Cable for Serial Expansion Card for Industrial PC
http://www.cdw.com/shop/products/default.aspx?EDC=255964
Manufacturer Part No: 76000528
Number required: 1

Digi Edgeport/4 USB to 4 port DB-9 Serial Converter for Dell Laptop
http://www.digi.com/products/usb/edgeport.jsp#overview
http://www.cdw.com/shop/products/default.aspx?EDC=259264
Manufacturer Part No.: 301-1000-04
Number required: 1

ENHANCED BIUS

Specifications

The enhanced BIUs are used in the TS-2 cabinet to replace the existing standard BIUs. The enhanced BIU has an extra RS-232 serial port on the front that the PTSMES system uses to monitor the controller inputs such as phase and detector status. The enhanced BIU sends a status message via the serial port every 100 milliseconds. In most TS-2 cabinet standard installations, the PTSMES would require the replacement of BIU 1 and the detector BIU with enhanced BIUs. However, in some cases where more than eight phases are configured at the intersection and more than one detector BIU is used, the PTMSES will require the replacement of BIU 2 and the second detector BIU with enhanced BIUs to be able to monitor all the configured phases and detectors at the intersection.

Procurement

Vendor
Naztec, Inc.
820 Park Two Dr.
Sugar Land, Texas 77478
Telephone: (281) 240-7233
Website: http://www.naztec.com
Number required: Maximum 4 enhanced BIUs with serial cables.

APPENDIX B–PORTABLE TRAFFIC SIGNAL MONITORING AND EVALUATION SYSTEM USER GUIDE

USER GUIDE

Portable Traffic Signal Monitoring and Evaluation System consists of two components: a monitoring system (Portable Traffic Signal Monitoring System [PTSMS]) and an evaluation system (Portable Traffic Signal Evaluation System [PTSES]). Detailed instructions to use both these systems are given in this section. The instructions to set up a monitoring system will assist the engineers/technicians to install the system in a TS-2 cabinet to monitor and log the signal operations within the cabinet. These include the selection of the parameters to be monitored and logged within the cabinet. Instructions to use the evaluation system will assist engineers/technicians to read the log files and generate a report of various measures of effectiveness to evaluate intersection operations.

PORTABLE TRAFFIC SIGNAL MONITORING SYSTEM

PTSMS consists of the computer interfacing with the cabinet through enhanced BIUs. Figure B-1 illustrates architecture of the monitoring tool. Two types of computers were used in this project: a field-hardened PC and a field-hardened laptop. Instructions will be provided to install either of these PCs in a cabinet.

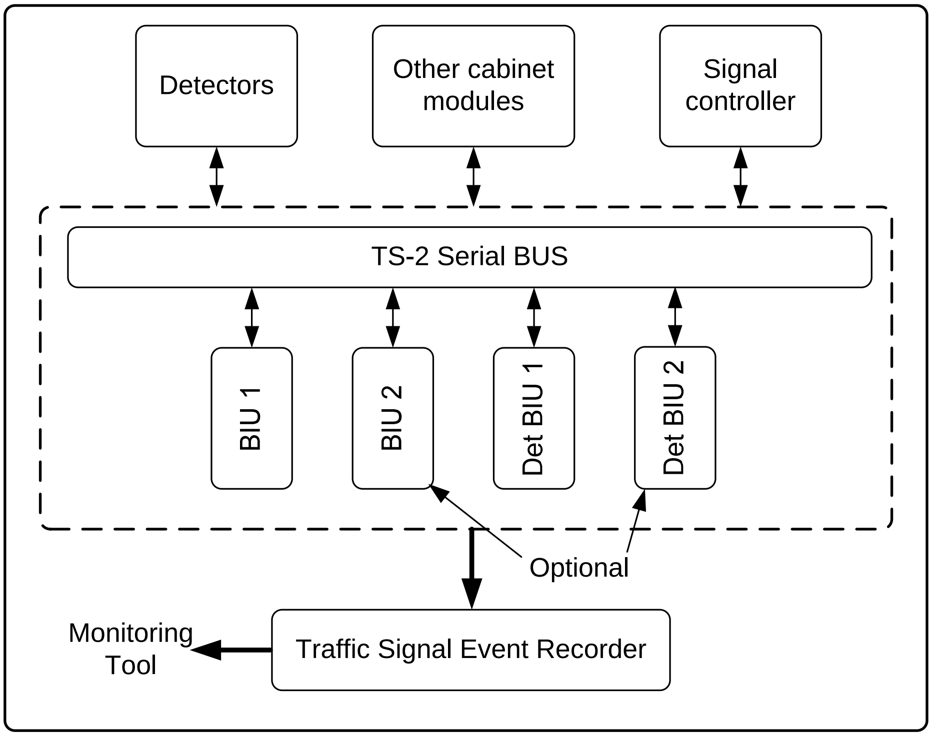


Figure B-1. Monitoring Tool Architecture.

Step 1–Replace the BIUs in the Cabinet with Enhanced BIUs.

These enhanced BIUs are provided as part of the toolbox. Replace the BIUs in the cabinet with the enhanced BIUs *only* after connecting the serial cables to the enhanced BIUs. Connect a BIU serial cable to each enhanced BIU that will be used to replace a standard BIU in the cabinet. Tighten the screws on the serial port connector connected to each enhanced BIU.

Figure B-2 illustrates the BIUs with a serial port in a TS-2 Cabinet.

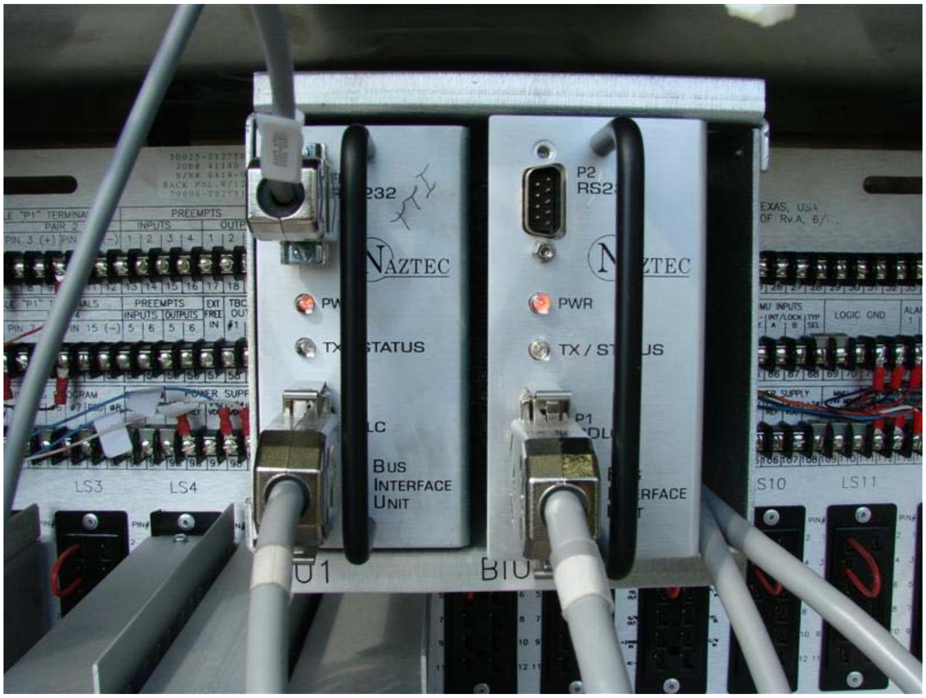


Figure B-2. Enhanced BIU in a TS-2 Cabinet.

Step 2–Connect the Serial Cables to the PC

If using the field-hardened PC, connect a monitor to the PC before connecting power to the PC. Do not connect the power cable to the PC yet. Connect the other end of the serial cable connected to the enhanced BIUs to available serial ports at the back of the PC. If the laptop is being used, connect the serial cables to the USB-to-serial box. A recommended mapping of the enhanced BIUs to available ports on the PC or Laptop is illustrated in Table B-1.

Table B-1. Recommended Mapping of the Ports for the PC and the Laptop.

BIU #	Port Assignment on PC	Port Assignment on Laptop
BIU 1	Port # 1 on the PC	Port # 1 on the USB to serial expansion Box (currently Port # 4)
BIU 2	Port # 2 on the PC	Port # 2 on the USB to serial expansion Box (currently Port # 5)
Detector BIU 1	Port # 1 on the serial expansion cable (currently Port # 4)	Port # 3 on the USB to serial expansion Box (currently Port # 6)
Detector BIU 2	Port # 2 on the serial expansion cable (currently Port # 5)	Port # 4 on the USB to serial expansion Box (currently Port # 7)

Step 3–Start the PC or Laptop

Connect the power cable to the PC. The PC will start in few seconds. If using the laptop, power up the laptop. It is, however, recommended to verify the ports assigned to each of the ports on the USB to serial expansion Box after the laptop is started. This is accomplished by opening Control Panel, Selecting System, Selecting Hardware Tab, Selecting Device Manager, and Expanding the Ports. The port numbers assigned to each Port of the USB to Serial Expansion Box will be visible.

The PTSMS system will start automatically once the laptop or the PC boots up. If it did not start automatically, start the PTSMS system by double-clicking the PTSMS shortcut on the desktop or by clicking Start, All Programs, TTI, and PTSMS on your machine. The PTSMS system might give the error message illustrated in Figure B-3 if the BIUs are not configured properly for the site..

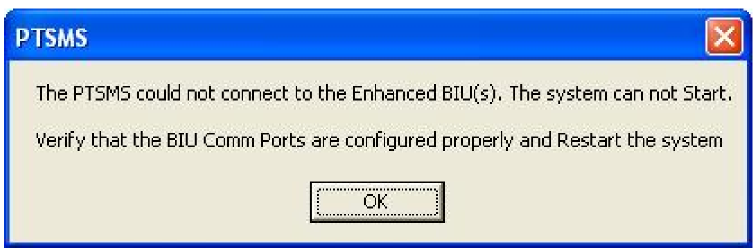


Figure B-3. Error Message Indicating BIUs Are Not Connected.

The error message indicates that the PTSMS is still running but is not connected to the BIUs and no data is being collected yet. The BIUs need to be configured before the system can proceed with data collection. Click on the OK button to close the error message.

Step 4–Configure the PTSMS System

Click on Configuration Tab (Figure B-4) of the program to start the configuring PTSMS.

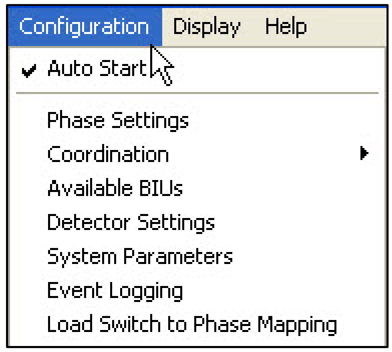


Figure B-4. Configuration Tab.

Select the Phase Settings option under the Configuration menu and enter the Min Grn, Max1, Passage Time, and other values for the available phases at the intersection as illustrated in Figure B-5. Click Update Phase Settings when you finish entering the values to save the phase settings data.

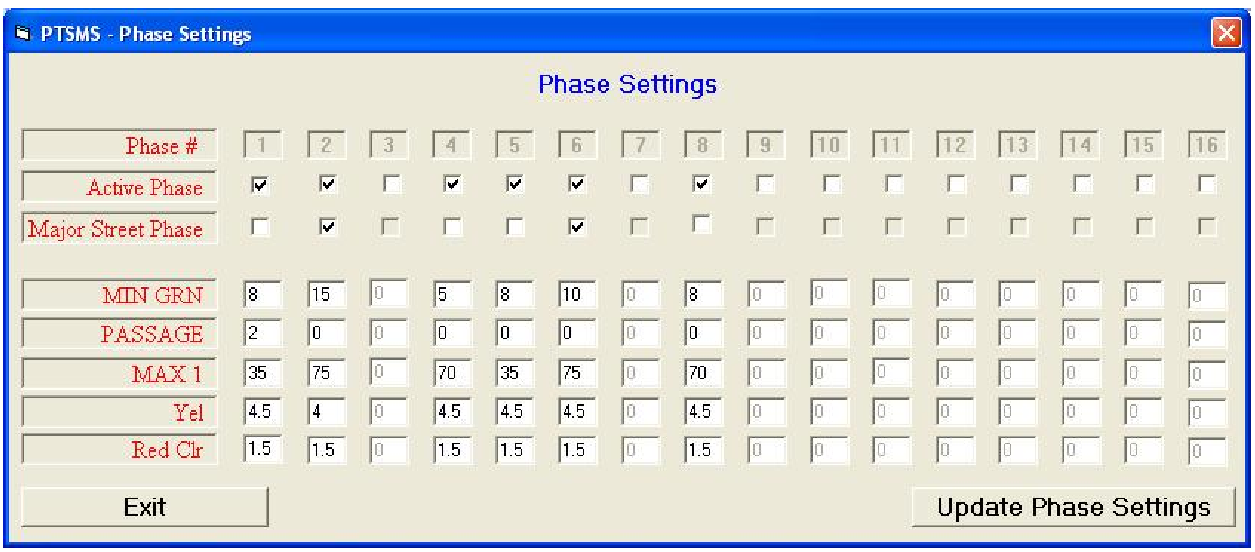


Figure B-5. Phase Settings Window.

Select Coordination under the Configuration menu to enter the information regarding coordination. Coordination Menu has two settings: Time-Based Data and Dial Split Data. The user will enter the time at which each timing plan starts in the Time-Based Data Menu as illustrated in Figure B-6. The user then enters the dial split data for each plan in Dial-Split Menu as illustrated in Figure B-7.

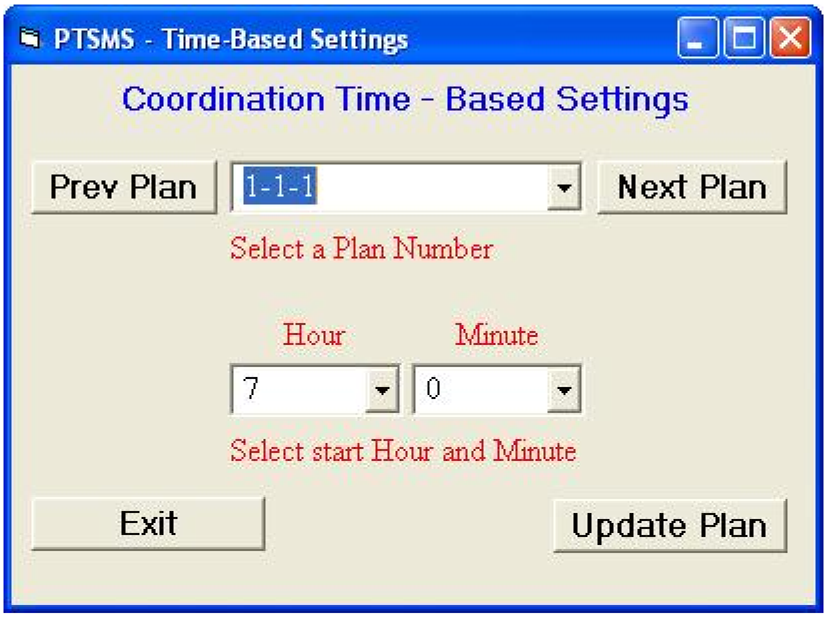


Figure B-6. CoordinationTime-Based Data.

Select the Available BIUs option under the Configuration menu to configure the available BIUs and the serial ports they are connected to on the PC or laptop. For each available BIU, check the box next to it in the Select BIU window, and then select the corresponding serial port it is connected to on the back of the PC or the USB-to-serial box used with the laptop using the drop down menu as shown in Figure B-8. Repeat the process until all the BIUs you are using in the cabinet are configured. For normal operations, a signal controller will not have more than two signal BIUs and two detector BIUs. Click the Update BIU Settings to save your selections and press the Exit button to exit.

Figure B-7. CoordinationDial-Split Data.

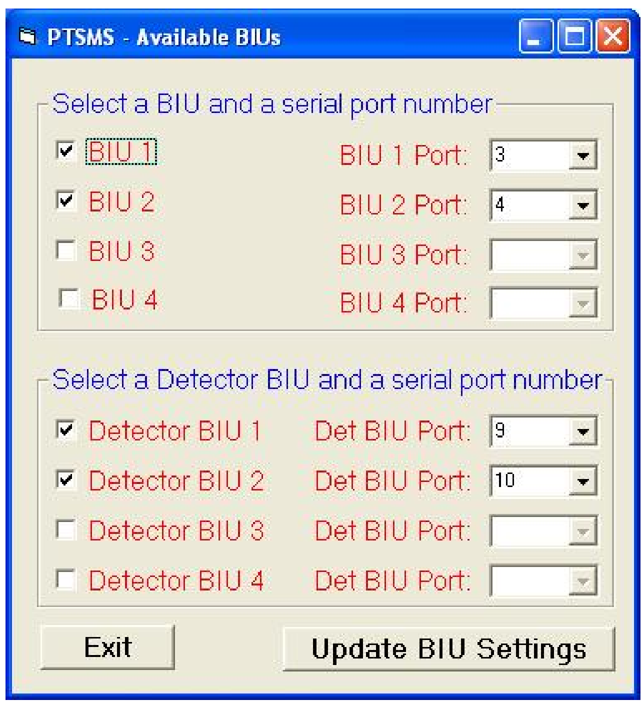


Figure B-8. BIU Configuration Screen.

Select the Detector Settings option under the Configuration menu to configure all the available detectors at the intersection as illustrated in Figure B-9. The same window can be used to configure the detector failure module. The controller uses three means to determine if a detector is malfunctioning. These three means are No Activity, Max Presence, and Erratic counts. The user needs to configure the PTSMS with the same settings that are programmed in the signal controller. Click the Update Detector Settings button once finished to save the detector settings information that you entered.

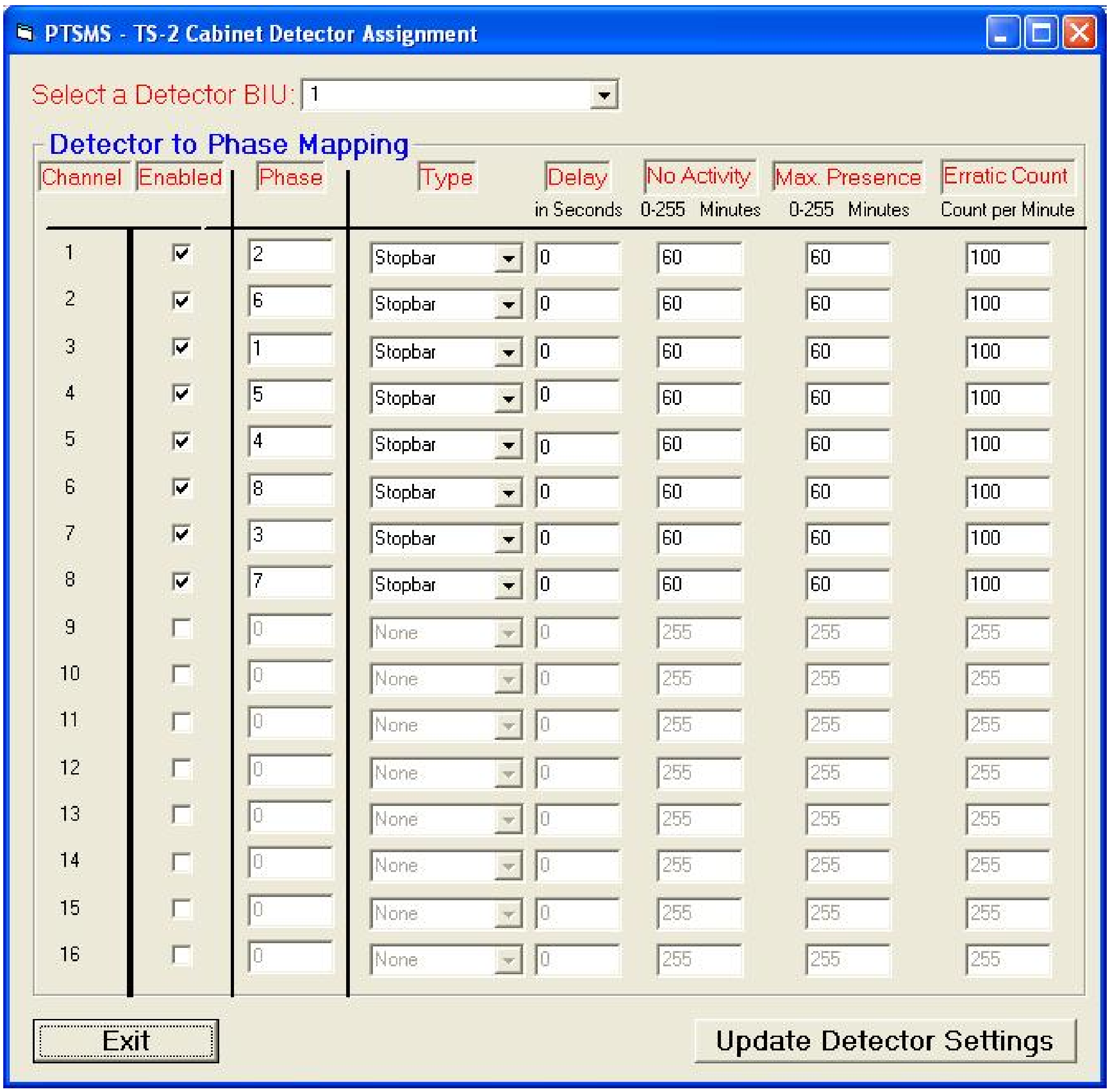


Figure B-9. Detector Configuration Screen.

Repeat the same process for the last three options under the Configuration menu, i.e., the System Parameters, Event Logging, and the Load Switch to Phase Mapping options. The logging options to be selected can be based on the objectives of the monitoring process. The BIU events need to be selected if any troubleshooting needs to be done; it is usually not selected. The load switch mapping is then done based on how they are mapped in the cabinet. These two windows are illustrated in Figure B-10.

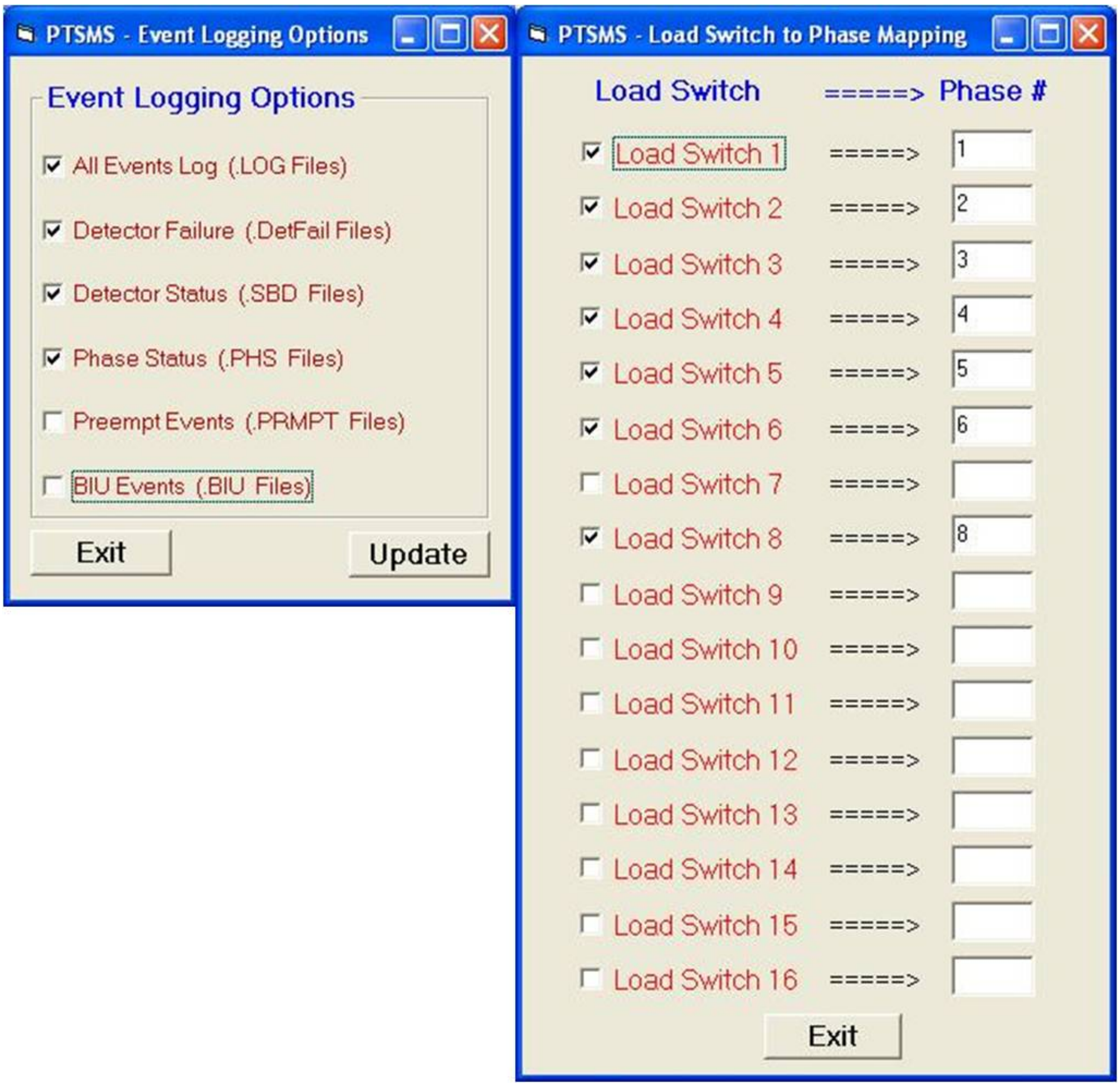


Figure B-10. Event Logging and Load Switch Mapping Windows.

Step 5–Save Configuration File and Start Monitoring

Once the configuration process is complete, select the Save XML Configuration File option under the PTSMS menu to save the data you entered into an XML file used by the PTSMS system when it starts. However, it is a good habit to choose the Save XML Configuration File after configuring each one of the options under the Configuration menu. Reboot the system, and the PTSMS system should start normally.

Step 6–Verify Monitoring Process

To allow the PTSMS to monitor the controller, the computer has to communicate with all the BIUs properly. The connection with the BIUs is verified by viewing the Display BIU Window, which is under the Display menu. A window will pop up to show the last time the PC was able to communicate with the connected BIUs as illustrated in Figure B-11. If the value in the textbox next to each connected BIU is showing a number other than −1, this means that the PC is communicating properly with the corresponding BIU. Otherwise, if the value in the text box is −1, then this means that the PC or laptop cannot connect to the corresponding BIU. The user then has to verify the serial port configuration of the BIUs in the Available BIUs option under the Configuration menu. Figure B-11 illustrates that BIU1, BIU2, and detector BIU1 are connected to the monitoring system.

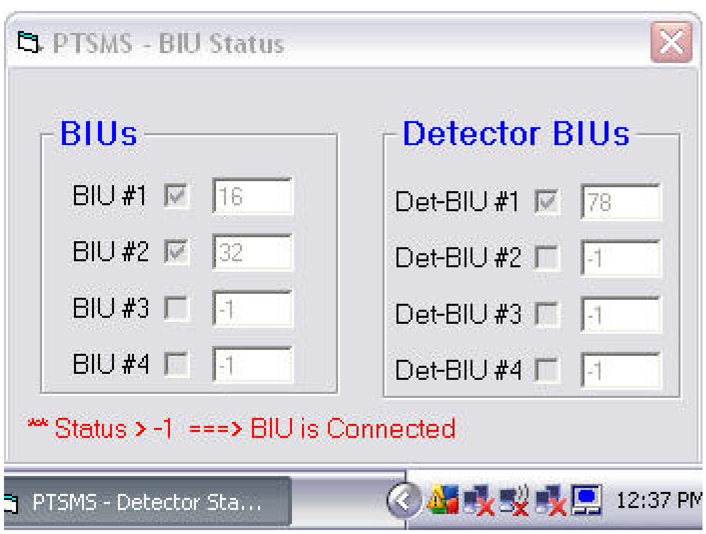


Figure B-11. BIU Status Window.

While the monitoring process is under way, the user can view additional processes like the Phase Status Window, Detector Status Window, and Pedestrian Detector Status Window. Phase Detector Status Window illustrates the duration of the phase the last time the phase was on and shows a running counter of the phase currently running (Figure B-12).

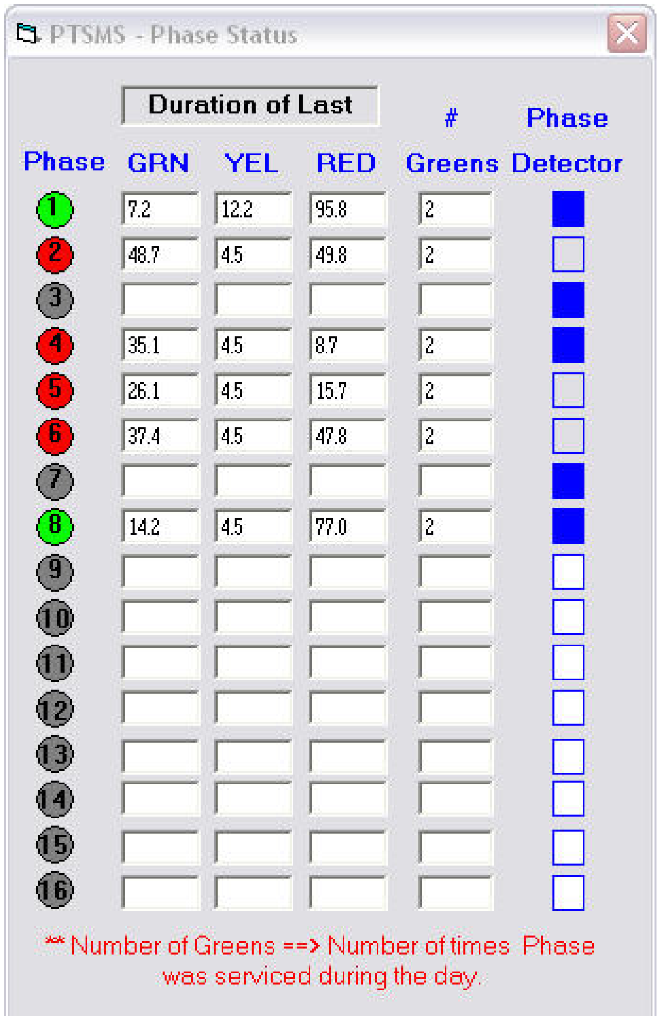
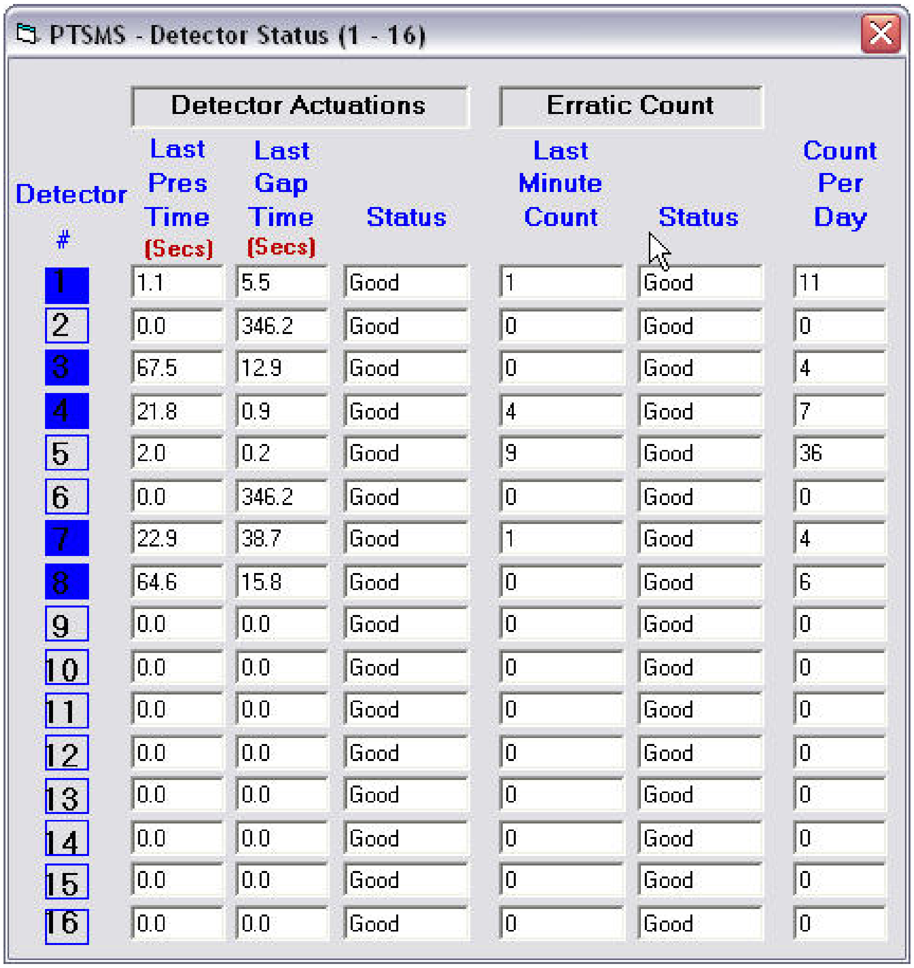


Figure B-12. Phase Status Window.

The Detector Status Window (Figure B-13) illustrates the activities on all the detectors that were mapped in the configuration process. Pedestrian Detector Status Window illustrates the onset of pedestrian calls and the onset of pedestrian phases (Figure B-14). The user needs to realize that these windows only provide a visual confirmation of the processes underway currently in the PTSMS. The system is logging these processes in a log file, and these log files are available for further analysis.



PTSMS - Detector Status (1 - 16)

Detector #	Detector Actuations: Last Pres Time (Secs)	Detector Actuations: Last Gap Time (Secs)	Detector Actuations: Status	Erratic Count: Last Minute Count	Erratic Count: Status	Count Per Day
1	1.1	5.5	Good	1	Good	11
2	0.0	346.2	Good	0	Good	0
3	67.5	12.9	Good	0	Good	4
4	21.8	0.9	Good	4	Good	7
5	2.0	0.2	Good	9	Good	36
6	0.0	346.2	Good	0	Good	0
7	22.9	38.7	Good	1	Good	4
8	64.6	15.8	Good	0	Good	6
9	0.0	0.0	Good	0	Good	0
10	0.0	0.0	Good	0	Good	0
11	0.0	0.0	Good	0	Good	0
12	0.0	0.0	Good	0	Good	0
13	0.0	0.0	Good	0	Good	0
14	0.0	0.0	Good	0	Good	0
15	0.0	0.0	Good	0	Good	0
16	0.0	0.0	Good	0	Good	0

Figure B-13. Detector Status Window.

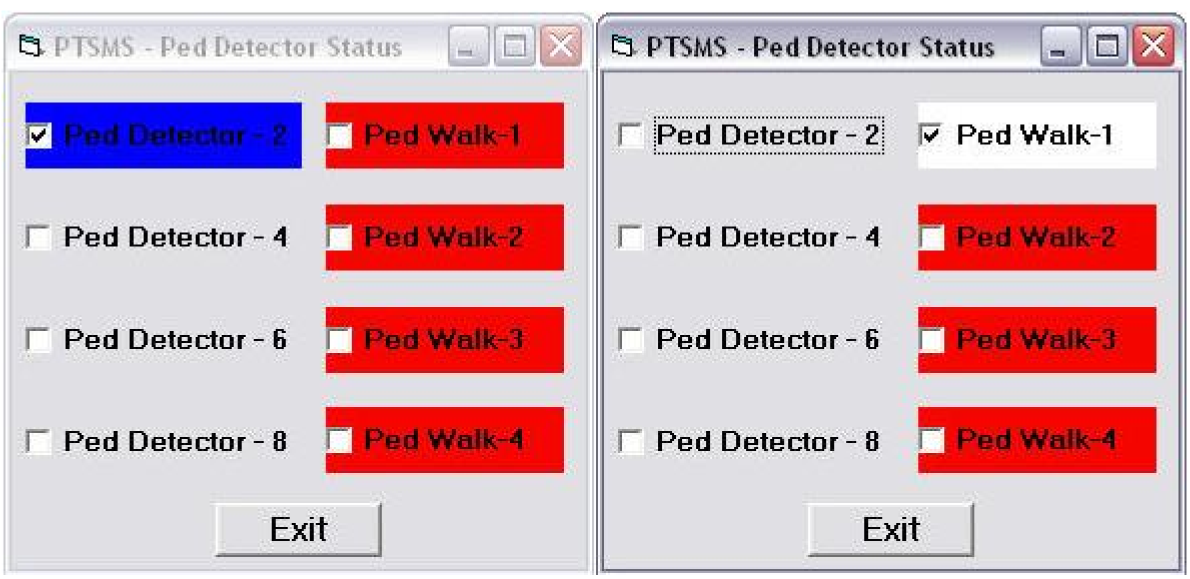


Figure B-14. Pedestrian Detector Window.

PORTABLE TRAFFIC SIGNAL EVALUATION SYSTEM (PTSES)

Proper configuration of the monitoring system described in the previous section will result in log files for various purposes being created for each day. A typical log file will consist of all the events logged for a period of 24 hours, starting at midnight. This section will give detailed steps to analyze these log files and evaluate intersection operations.

1. Install the PTSES software, and copy the data files collected from the field onto your PC.
2. Start the PTSES program. Select either Hourly MOE Report, Time Period MOE Report, Preempt Report, or Detector Failure Report (Figure B-15).
   - The hourly MOE report provides an hourly average of the selected MOE for the hours selected.
   - Time period MOE report provides cycle-by-cycle statics of the MOE within the time period selected.
   - Preempt report provides the number and duration of all preempts occurring at the intersection during the day selected.
   - Finally, the Detector Failure Report will generate the detector failures as configured by the user when the intersection was monitored.
3. Click on the arrow button at the bottom of the window to advance to the next TAB.

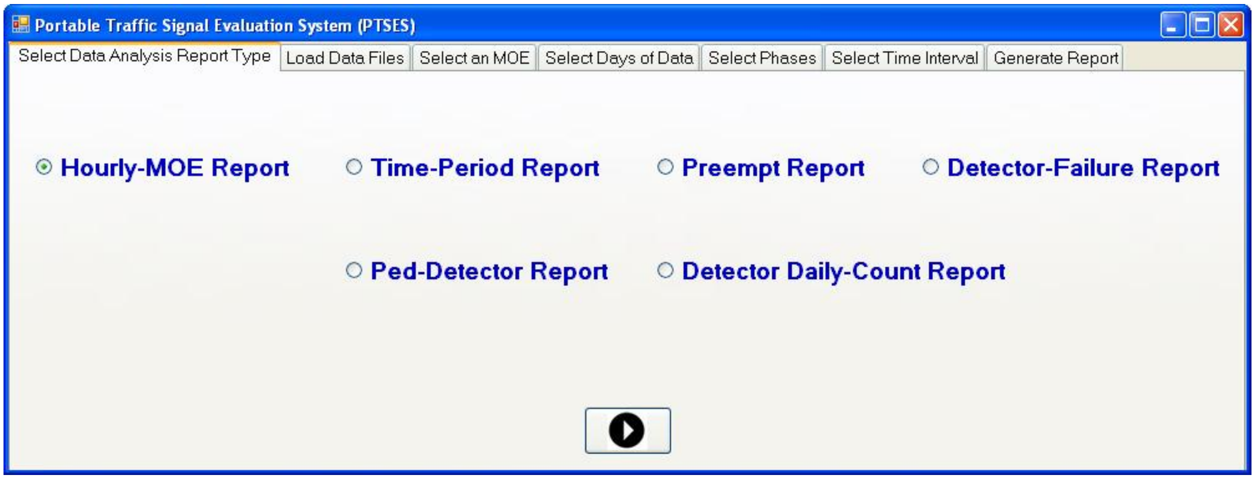


Figure B-15. PTSES Analysis Start-Up Screen.

4. When the Hourly MOE Report or Time Period MOE reports are selected, the user will have the option of selecting two types of files: the Phase Info File and the Data File (Figure B-16). Click on Load Phase Info File First and select one file that has an extension "PHS" (any date) from the folder on your PC where all the data files are located (Figure B-17). This provides critical information about phase times required for the data analysis.

Figure B-16. Load Data Screen.

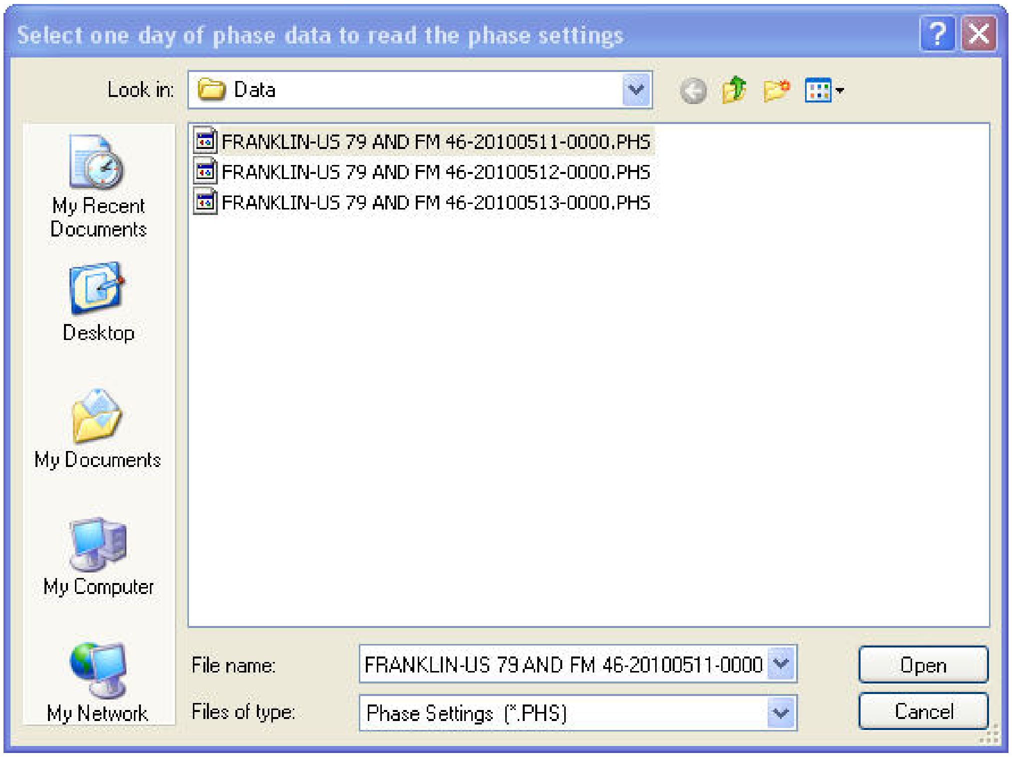


Figure B-17. Loading Phase Info Files.

5. Click on Load Data Files to select data files (no more than seven days) for analysis (Figure B-18). Here, four days were selected. Click on the arrow button in the right bottom corner to move to the next TAB. Select any of the MOEs indicated on the screen, or click on the Show Additional MOEs (Figure B-19). Note only one MOE can be selected. In this case, Number of Max-outs was selected. Click on the arrow button in the right bottom corner to move to the next TAB.

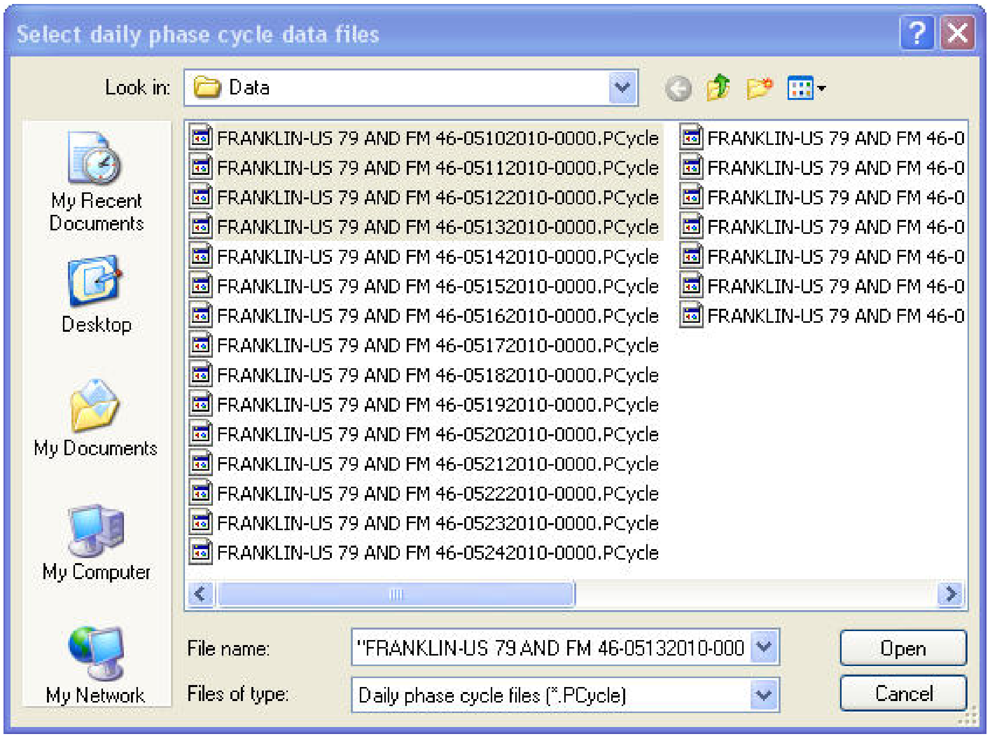


Figure B-18. Loading Phase Data Files.

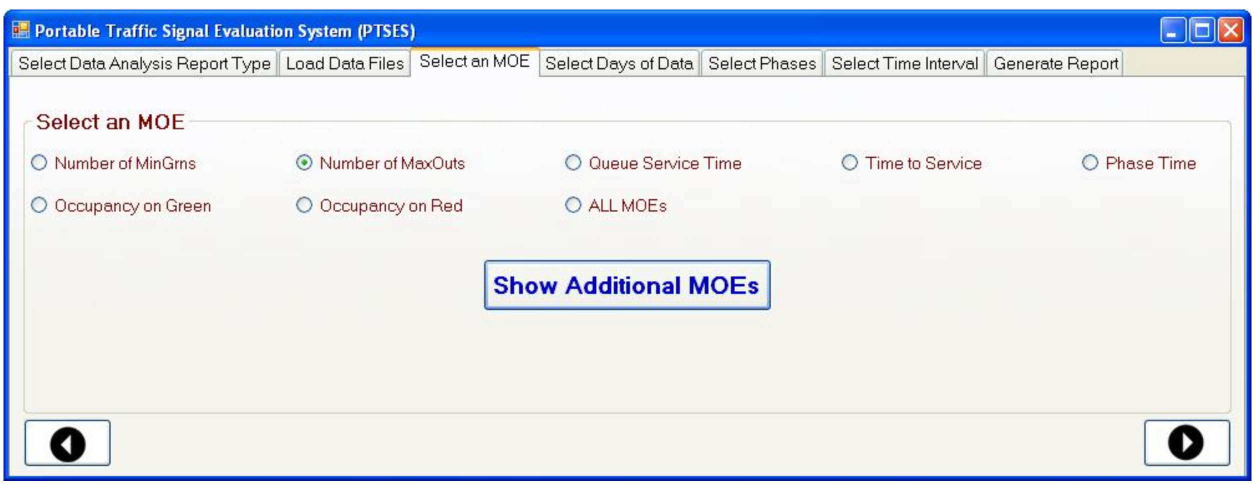


Figure B-19. Select MOE Screen.

6. Select the day(s) from the list of data files that were loaded to be analyzed (Figure B-20). In this case, four days were selected. Click on the arrow button in the right bottom corner to move to the next TAB.

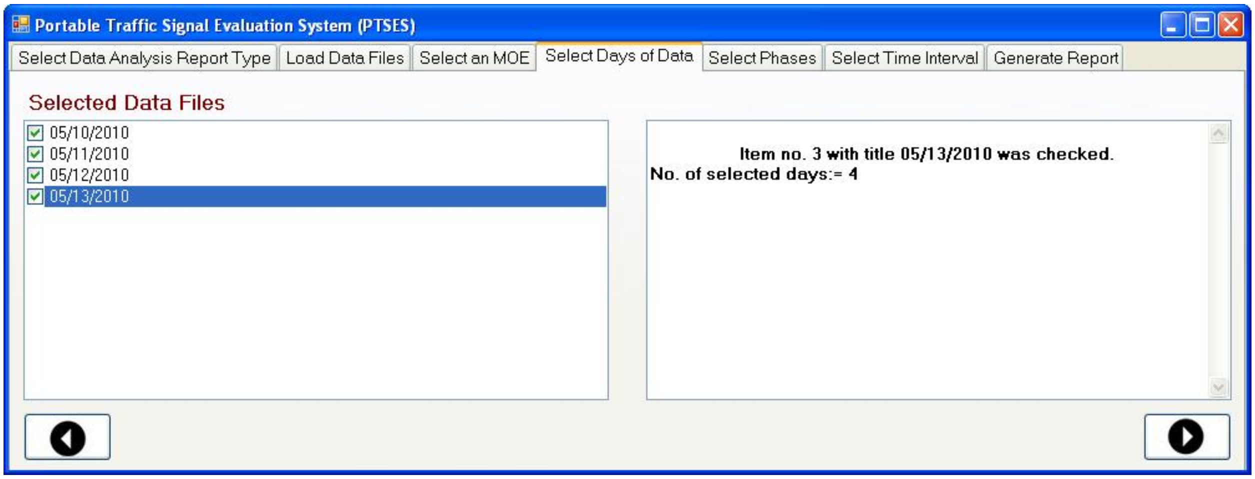


Figure B-20. Number of Days to be Selected Screen.

7. Select the Phase(s) to be analyzed (Figure B-21). If multiple days are selected, only a single phase can be analyzed. However, if only a single day was selected, multiple phases can be selected. A message to this effect pops up in the window. Click on the arrow button in the right bottom corner to move to the next TAB.

Figure B-21. Select Phases Screen.

8. If Hourly MOE Report was selected, the user will be prompted to select the beginning and ending hour. Select the time period to be analyzed (Figure B-22). If, however, Time Period MOE Report is selected, the user will be prompted to select the hour and minute for the start and end time (Figure B-23). Once the time Interval is selected, click on the arrow button in the right bottom corner to move to the next TAB.

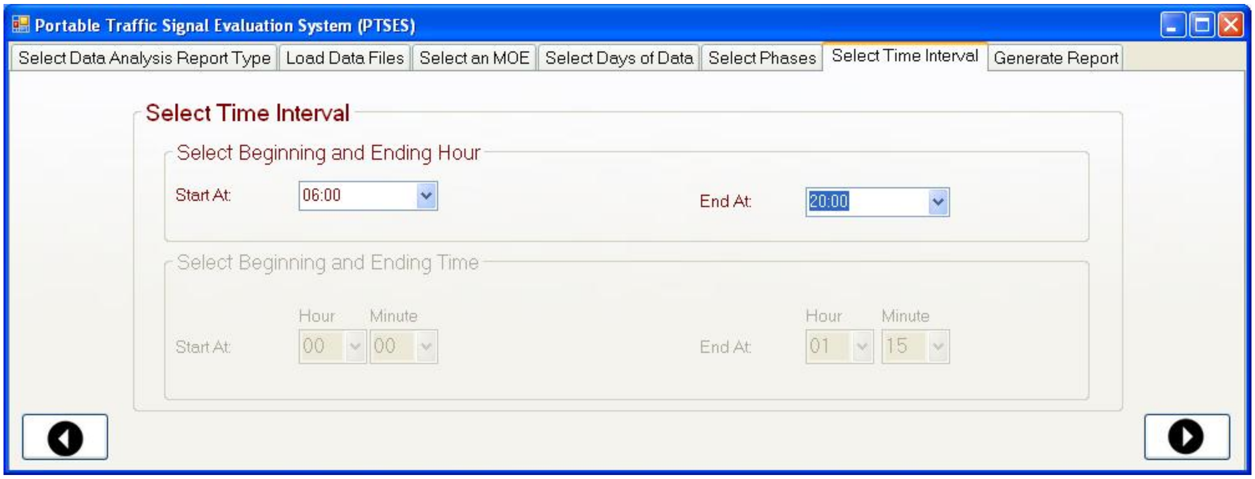


Figure B-22. Selection of Time Interval for Hourly MOE Report.

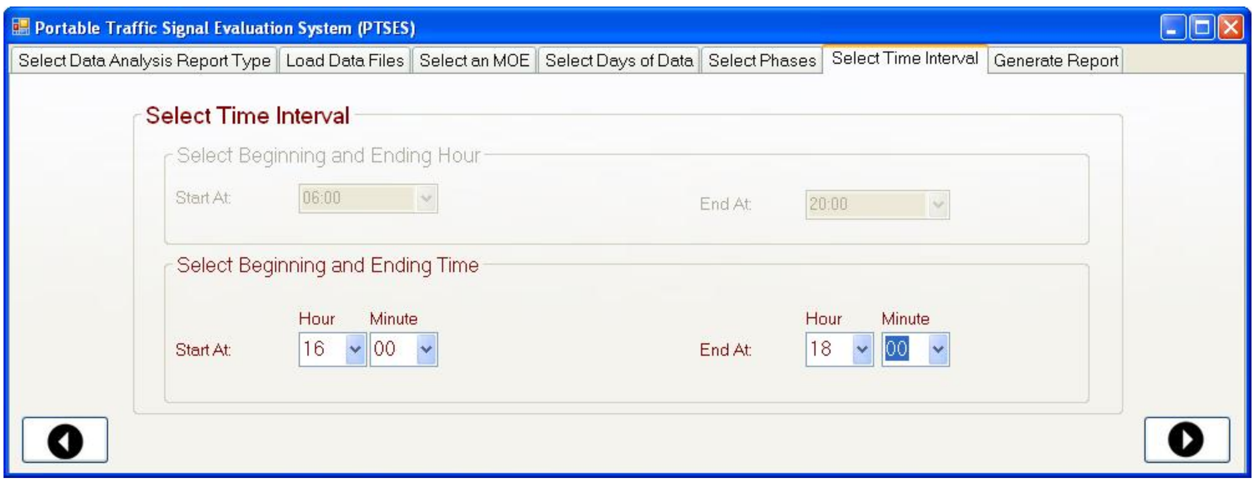


Figure B-23. Selection of Time Interval for Time Period MOE Report.

9. Click on the Generate MOE Report button in the right bottom corner to generate a report in a Microsoft® Excel document. The Hourly MOE report will consist of a graph illustrating the MOE analyzed along with a sheet of MOE data analyzed (Figure B-24). The Time Period MOE Report will generate a sheet of all MOEs analyzed for each day and a single phase (Figure B-25). The user can then study the analysis generated or generate any additional summaries and graphs. Figure B-24 illustrates that Phase 4 has nine max-outs between 4 p.m. and 5 p.m. on May 12, 2010. Figure B-25 illustrates for cycles when Phase 4 was maxed out on May 12, 2010, between 4 p.m. and 5 p.m.

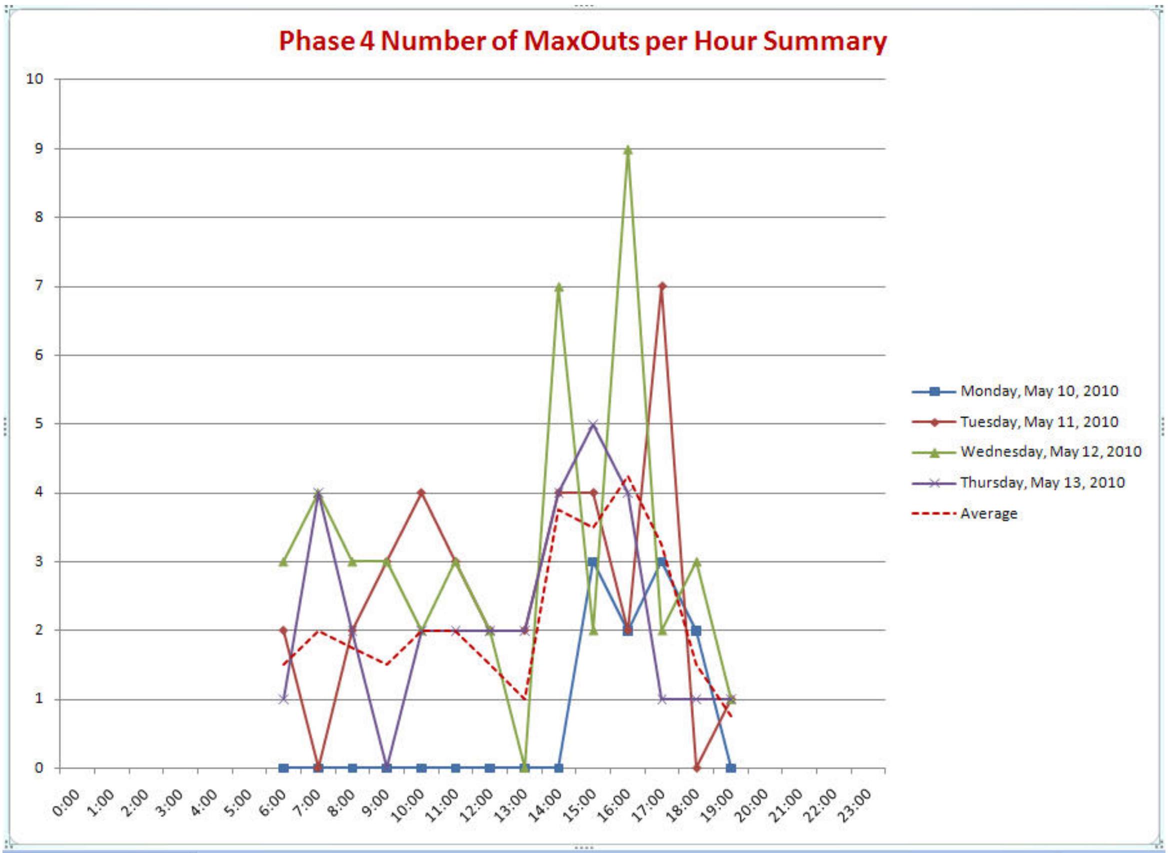


Figure B-24. Hourly MOE Report.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	FRANKLIN																		
2	US 79 AND I	5/12/2010																	
3																Detector Status at the Onset of			
4	Phase	CycleNo	GrnStart	Green	MinGrn	Max1	QueServiceTime	OccOnGrn	Red	OccOnRed	TimetoService	CountOnGrn	CountOnYel	CountOnRed	SBD Count	Green	Yelllow	Red	PhaseFailure
5	4	547	16:00:50	00:07	00:07	00:20	00:06	00:06	01:00	00:47	00:47	0	0	2	2	ON	OFF	ON	
6	4	548	16:02:02	00:07	00:07	00:20	00:05	00:05	00:47	00:42	00:40	1	0	2	3	ON	OFF	ON	
7	4	549	16:03:00	00:13	00:07	00:20	00:12	00:12	00:35	00:44	00:41	0	0	3	3	ON	OFF	ON	
8	4	550	16:03:52	00:20	00:07	00:20		00:24	00:44	00:13	00:01	0	0	0	0	ON	ON	ON	Phase Maxed Out
9	4	551	16:05:00	00:20	00:07	00:20	00:12	00:21	00:44	00:44	00:44	1	0	2	3	ON	ON	ON	Phase Maxed Out
10	4	552	16:06:08	00:07	00:07	00:20	00:05	00:06	00:55	00:25	00:23	0	1	0	1	ON	OFF	ON	
11	4	553	16:07:14	00:10	00:07	00:20	00:05	00:05	00:52	00:55	00:55	0	0	1	1	ON	OFF	ON	
12	4	554	16:08:20	00:12	00:07	00:20	00:11	00:11	00:32	00:35	00:35	0	0	4	4	ON	OFF	ON	
13	4	555	16:09:07	00:08	00:07	00:20	00:07	00:07	01:37	00:13	00:05	0	0	5	5	ON	OFF	ON	
14	4	556	16:10:56	00:07	00:07	00:20	00:05	00:05	01:05	00:45	00:36	0	0	1	1	ON	OFF	ON	
15	4	557	16:12:12	00:20	00:07	00:20		00:24	00:45	00:57	00:57	0	0	0	0	ON	ON	ON	Phase Maxed Out
16	4	558	16:13:21	00:20	00:07	00:20		00:24	00:42	00:45	00:45	0	0	2	2	ON	ON	ON	Phase Maxed Out
17	4	559	16:14:27	00:16	00:07	00:20	00:14	00:16	00:50	00:34	00:29	1	1	1	3	ON	OFF	ON	
18	4	560	16:15:37	00:10	00:07	00:20	00:09	00:09	00:31	00:40	00:35	0	0	4	4	ON	OFF	ON	
19	4	561	16:16:22	00:14	00:07	00:20	00:07	00:07	01:36	00:05	00:02	0	0	3	3	ON	OFF	ON	
20	4	562	16:18:16	00:07	00:07	00:20	00:04	00:04	00:40	00:57	00:44	0	0	2	2	ON	OFF	ON	
21	4	563	16:19:07	00:20	00:07	00:20		00:24	00:44	00:24	00:20	0	0	0	0	ON	ON	ON	Phase Maxed Out
22	4	564	16:20:15	00:07	00:07	00:20	00:06	00:09	00:47	00:44	00:44	0	1	0	1	ON	OFF	ON	
23	4	565	16:21:13	00:14	00:07	00:20	00:13	00:13	01:02	00:47	00:47	0	0	2	2	ON	OFF	ON	
24	4	566	16:22:33	00:23	00:07	00:20	00:04	00:17	01:31	00:55	00:53	1	0	1	2	ON	ON	ON	Phase Maxed Out
25	4	567	16:24:31	00:07	00:07	00:20	00:04	00:04	00:45	00:42	00:42	0	0	6	6	ON	OFF	ON	
26	4	568	16:25:26	00:20	00:07	00:20	00:06	00:18	00:49	00:08	00:01	2	0	4	6	ON	OFF	ON	
27	4	569	16:26:39	00:10	00:07	00:20	00:04	00:08	00:52	00:17	00:11	1	1	3	5	ON	OFF	ON	
28	4	570	16:27:44	00:09	00:07	00:20	00:08	00:08	01:08	00:33	00:21	0	0	1	1	ON	OFF	ON	
29	4	571	16:29:05	00:13	00:07	00:20	00:12	00:12	00:42	00:55	00:55	0	0	4	4	ON	OFF	ON	
30	4	572	16:30:05	00:10	00:07	00:20	00:09	00:09	02:10	00:26	00:19	0	0	2	2	ON	OFF	ON	
31	4	573	16:32:29	00:08	00:07	00:20	00:07	00:09	01:07	00:52	00:49	0	1	0	1	ON	OFF	ON	
32	4	574	16:33:48	00:07	00:07	00:20	00:06	00:06	00:40	01:07	01:07	0	0	1	1	ON	OFF	ON	

Sheet1 Sheet2 Sheet3

Figure B-25. Time Period MOE Report.

When the procedure is repeated for the Hourly MOE report and Generate All MOE is selected (Figure B-19), numerous MOEs are illustrated in a snap shot as illustrated in Figure B-26. The MOEs include number of max-outs, number of minimum greens, percentage phase utilization, percentage green for queue clearance, average time to serve, and average red time.

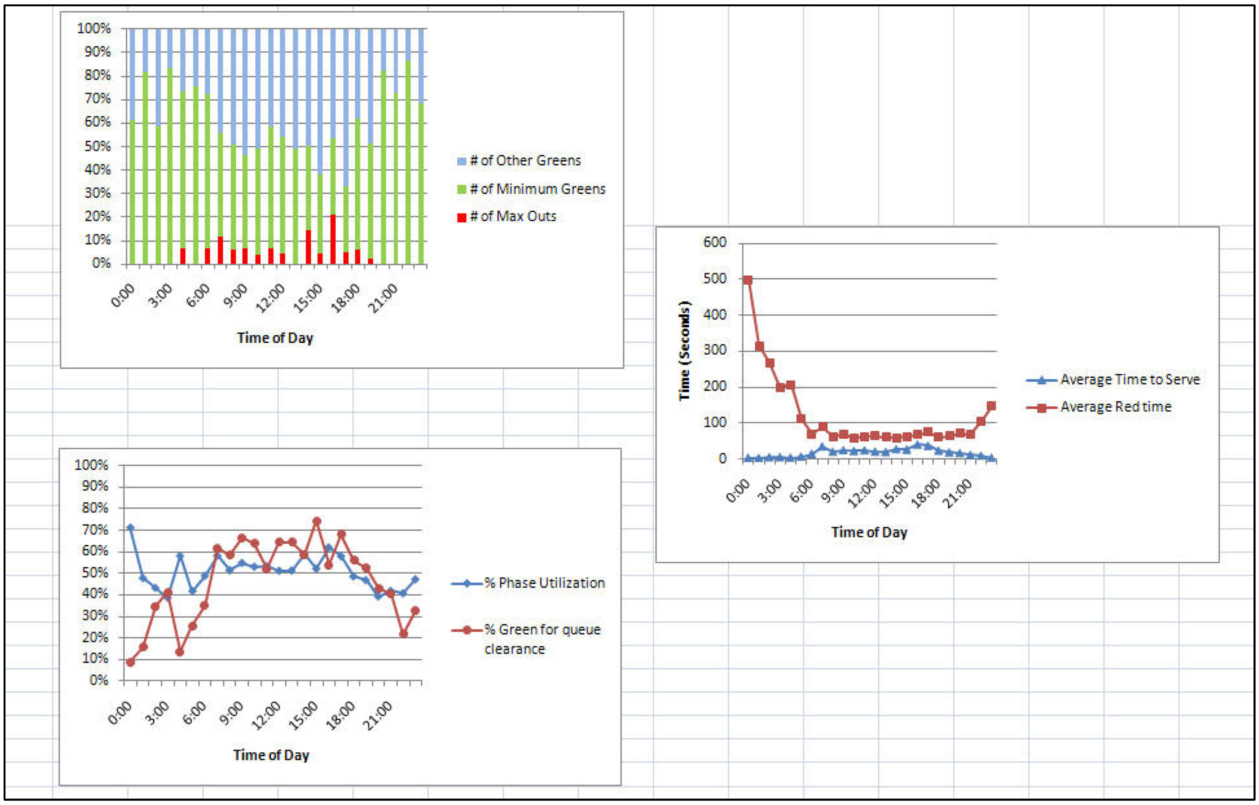


Figure B-26. Results of All MOEs Selected Option.

10. The procedure is similar for analyzing the Preempt Report and Detector Failure Report. The system will prompt the user to select the appropriate data files and days of data to analyze and then generate an analysis report. Figure B-27 and Figure B-28 illustrate the Preempt Report and Detector Failure Report for May 11, 2010, to May 13, 2010. The Preempt Report illustrates all the preempts that occurred each day, the timing that the preempts occurred, and the duration of each preempt. The Detector Failure Report illustrates a summary of the detector failures that met the threshold set by the user for each day.

FRANKLIN			
US 79 AND FM 46	5/11/2010		
PreemptNo	**Start Time**	**End Time**	**Duration**
1	2:33:39	2:35:44	2:05
1	3:14:08	3:16:27	2:19
1	4:53:48	4:55:59	2:11
1	9:53:47	9:57:19	4:31
1	16:55:37	16:58:06	2:29
1	18:58:55	19:02:17	3:22
1	21:31:02	21:33:38	3:36
7	Preempts	Avg Duration	3:39
FRANKLIN			
US 79 AND FM 46	5/12/2010		
PreemptNo	**Start Time**	**End Time**	**Duration**
1	10:19:17	10:22:01	3:44
1	14:07:29	14:09:37	2:09
1	19:38:51	19:41:39	3:48
1	20:59:35	21:02:05	2:29
1	23:47:33	23:51:00	3:27
5	Preempts	Avg Duration	3:43
FRANKLIN			
US 79 AND FM 46	5/13/2010		
PreemptNo	**Start Time**	**End Time**	**Duration**
1	0:16:44	0:20:01	3:17
1	1:50:40	1:54:13	4:34
1	4:28:39	4:31:51	3:12
1	4:50:56	4:54:38	4:43
1	6:41:19	6:44:04	3:45
1	10:00:29	10:03:00	3:31
1	11:01:00	11:03:57	3:56
1	16:36:44	16:40:08	3:24
1	17:15:26	17:23:59	9:34
1	22:27:43	22:31:56	4:13
1	23:54:40	23:57:39	3:59
11	Preempts	Avg Duration	4:44

Figure B-27. Preempt Analysis Report.

FRANKLIN					
US 79 AND FM 46	5/11/2010				
DetectorNo	**Phase**	**Start Time**	**End Time**	**Duration**	**Reason**
3	1	1:47:51	1:58:07	10:16	Exceeded Maximum Presence Limit
4	5	2:18:29	3:00:31	42:02:00	Exceeded Maximum Presence Limit
FRANKLIN					
US 79 AND FM 46	5/12/2010				
DetectorNo	**Phase**	**Start Time**	**End Time**	**Duration**	**Reason**
4	5	23:55:43	0:00:03	4:20	Exceeded Maximum Presence Limit
4	5	2:08:38	2:21:17	13:39	Exceeded Maximum Presence Limit
FRANKLIN					
US 79 AND FM 46	5/13/2010				
NO DETEECTOR FAILURE RECORDS FOR THIS DAY.					

Figure B-28. Detector Failure Report.

11. The procedure is similar for analyzing the detector count report and pedestrian status report. The detector count report provides a summary of all actuations on each detector that is assigned in the controller at the end of each day. This feature is useful as a data collection or a detector evaluation tool. The user can connect different detectors located at the same location on different channels and compare the counts to evaluate the detectors. A sample of the detector count report is illustrated in Figure B-29. Similarly the pedestrian status report provides a summary of the pedestrian service for each pedestrian phase for each hour for the entire day. This report is illustrated in Figure B-30 and provides the level of pedestrian activity at the intersection for a 24 hour period at a glance.
12. The user can then save the analysis reports for each report as Excel files for further analysis.

FRANKLIN				
US 79 AND FM 46			5/11/2010	
DETECTOR DAILY COUNT REPORT				
DetectorNo	**Daily Count**	**Daily Count On Green**	**Daily Count On Yellow**	**Daily Count On Red**
1	18494	3245	477	14772
2	26495	9275	760	16460
3	2	0	0	2
4	68	6	2	60
5	0	0	0	0
6	0	0	0	0
7	271	17	12	242
8	13166	3581	355	9230

Figure B-29. Detector Count Report.

FRANKLIN				
US 79 AND FM 46	5/11/2010			
PEDESTRIAN ACTIVITY REPORT				
Hour	**PedWalk # 2**	**PedWalk # 4**	**PedWalk # 6**	**PedWalk # 8**
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	1	0	0
6	0	0	0	0
7	1	0	0	0
8	0	0	0	0
9	0	0	1	0
10	0	0	0	0
11	1	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	2	0	0	0
17	0	0	0	0
18	0	0	0	0
19	2	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0

Figure B-30. Pedestrian Activity Report.