

Real-Time Signal Performance Measurement (RT-SPM)

FINAL REPORT

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Submitted by

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| 16. Abstract Transportation professionals measure traffic signal system to improve efficiency and reliability of roadway network. Traffic signal performance measurement and visualization provide insights as operational tools to help traffic management center get more benefits from infrastructure investment. The primary objective of the research is to identify and develop metrics, guidelines, and deployment strategies necessary to conduct real-time monitoring of traffic signal performance based on existing and planned infrastructure resources and the New Jersey Department of Transportation (NJDOT) needs. This research is especially important for New Jersey (NJ) with the deployment of Adaptive Traffic Signal Performance Measurement (ATSPM) and the establishment of the Arterial Management Center (AMC). This study's primary objective is twofold: 1) how to utilize existing field data and equipment to establish Signal Performance Measures (SPMs) for real-time monitoring, and 2) what additional data and equipment may be employed to generate additional SPMs while automating the real-time traffic signal monitoring process. The study included a review of the literature and best practices, several stakeholder meetings, recommendation and development of performance metrics, system architectures, data management, and strategies for deploying RT-SPM systems using existing and planned NJDOT arterial infrastructure and technologies. | | | | | |
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Executive Summary

Background

A performance measurement is defined by the Federal Highway Administration (FHWA) as “use of statistical evidence to determine progress toward specific defined organizational objectives.” The performance measures can also serve as an indicator of the customers’ levels of satisfaction with a service or facility. There are several performance measures being used to evaluate traffic signal controls currently made by rules of thumb, coupling indices based on ratios of volume to distance, and modeled traffic flows. Many tools (e.g., Highway Capacity Manual, computer simulation and optimization) are currently being employed to determine the offline effectiveness of a traffic signal system (e.g., delay, stops, and fuel consumption), relying on collected data in the field and further processing in the office. This data collection often incurs significant labor costs restricting field studies to specific time periods. Conversely, centrally managed automated SPMs provide the opportunity to present the real-time and historical functionality of signalized intersections 24-hours a day, 7-days a week. These 24-hour observations lead to proactively managed signalized corridors that can be quickly adjusted to minimize traffic delay, improve safety, improve travel time reliability and save fuel costs through better informed decision-making based on signal performance and timing. A reduction of even 1-minute of travel time over a 5-mile corridor can have a tremendous impact on the overall motoring public and the travel time reliability over a corridor, necessitating the development of an efficient tool to measure the online effectiveness of a traffic signal system.

This research is especially important for New Jersey (NJ) with the deployment of Controlled Traffic Signal Systems (CTSS) and the establishment of the Arterial Management Center (AMC). Agency wide, there are multiple types of signal configurations, equipment, and vehicle detection devices that contributed to traffic signal performance. However, antiquated equipment and inefficient detection technologies make it difficult, if not impossible, to perform real-time traffic monitoring. The advancement of centrally controlled traffic signal systems has made it possible to maintain constant communication with this antiquated equipment, but the hardware issue remains. As high-resolution traffic event data from signalized intersections becomes more readily available, it becomes possible to better characterize vehicle flows to analyze traffic signal performance. Based on this data, an analyst can make a more informed decision to determine when coordination is necessary, and how it may be achieved (adaptive, responsive, or well timed). Although models can tell part of the story, field evaluations that directly measure the effectiveness of a signal control strategy can be used to quantify user time and cost savings. This study’s primary perspective is twofold: 1) how to utilize existing field data and equipment to establish Signal Performance Measures (SPMs) for real-time monitoring, and 2) what additional data and equipment may be employed to generate additional SPMs while automating the real-time traffic signal monitoring process.

Research Objectives

The overall goal of this project is to recommend and develop performance metrics, system architectures, data management, and strategies for deploying RT-SPM systems using existing and planned NJDOT arterial infrastructure and technologies. In addition, recommendations and guidelines regarding obtaining

potential additional data and equipment to enhance/expand SPMs, their measurement methods, as well as the processes necessary to perform automated SPMs, are proposed. The research team recognizes that the deployment of various adaptive traffic control systems such as InSync and Sydney Coordinated Adaptive Traffic System (SCATS) systems on major NJ corridors and networks have extended the capability for building real-time performance measures. To implement a successful RT-SPM system in NJ, the following key research problems have been investigated.

- *State of Practice Review and Stakeholder Panel:* A scan of best practices helps the research team make informed recommendations to the NJDOT. The research team assembles a stakeholder panel to guide and review the proposed research. The proposed panel includes the NJDOT operational, maintenance, and information technology (IT) departments as well the system providers and developers in the academic and private sectors.
- *Comprehensive Component Inventory and System Design:* Different system components are provided by different vendors, such as CTSS vendors, traffic sensor providers, and Signal Performance Measurement system providers. Therefore, it is necessary to obtain comprehensive understanding of the needs, requirements, and limitations in different arterial signal components towards building the RT-SPM system.
- *Strategic Deployment:* Finally, it is important for the research team to identify strategies towards deploying and improving NJ's RT-SPM capabilities in the short term with existing systems and in the long term with the future capital investment that encourage emerging technologies such as RT-SPM-based signal time optimization, Connected Vehicles (CVs) and Data analytics.
- *Building RT-SPM System for Existing, Planned, and Future System:* The research team implements an integrated but open system approach that incorporate a) existing adaptive and coordinated traffic control systems in NJ, and b) planned and future systems and technologies.

Research Tasks

The research team achieves these goals mentioned above by considering the following essential items:

- Review the state-of-the-art and practice of real-time signal performance measurement (RT-SPM). Conduct a comprehensive nationwide review of existing national guidelines and recommendations on SPM systems and identify existing public and commercial SPM platforms.
- Review the existing NJDOT arterial management system. Identify and review existing traffic signal systems operated by NJDOT. Create an inventory of current detection, signaling, architecture, controller, video, and communication systems in arterial traffic signal management based on NJDOT input.
- Obtain feedback from NJDOT regarding needs and challenges in implementing SPM System. Organize stakeholder meetings to identify needs and challenges facing current arterial signal performance measurement practices. Prioritize critical arterial signal performance measurement indexes to be implemented in the SPM system.
- Review the existing RT-SPM Systems. As part of the literature search and stakeholder meeting, the team reviewed the current RT-SPM systems and learned their success stories and lessons.

- Recommend system design, architecture, and requirements of RT-SPM systems for NJDOT. Any recommended system will be based on the existing data, equipment, and management centers but can incorporate planned or future systems and technologies.
- Develop deployment plans for implementing the recommended system and strategies. The outcome of the project will be used to establish an actionable implementation plan for NJDOT to deploy the RT-SPM system.
- Develop prototype RT-SPM system based on existing arterial performance data available at NJDOT. Provide NJDOT with prototype RT-SPM toolboxes that can be implemented based on existing data sources available in the system and extendible with future and planned data sources.

Stakeholders of This Project

During the process of ATSPM system implementation, the transportation community will be affected and involved including users, operators and managers of road, devices and vehicles. The major users and stakeholders are:

- **Transportation Users:** People who are travelling on major arterial monitored by ATSPM will get the benefit of efficient and faster signal timing managements.
- **Transportation Planning Department:** The ATSPM system will impact recurrent and non-recurrent congestions along major corridors, which may change the travel time. Traffic planning department can utilize this system to predict and evaluate travel time status to make better transportation plan.
- **Traffic Management Centers (TMC):** TMC directly receive actionable information needed to reduce congestion due to obsolete signal timing. High-quality mobility and safety service can be delivered to customers without significant investment to existing infrastructure.
- **Signal Controller Vendors:** With this system, more advanced detector or adaptive system will be implemented. The reliability and capacity of vendor's products can be easily assessed by their users.

Acronyms and Abbreviations

| MOE | Measures of Effectiveness |
|---------------|---|
| SPM | Signal Performance Measurement |
| RT-SPM | Real-time Signal Performance Measurement |
| ATSPM | Automated Traffic Signal Performance Measures |
| ATCS | Adaptive Traffic Control System |
| NJDOT | New Jersey Department of Transportation |
| FHWA | Federal Highway Administration |
| ITS | Intelligent Transportation Systems |
| AMC | Arterial Management Center |
| RTMS | Remote Traffic Microwave Sensor |
| MSE | Mobility and Systems Engineering |
| PCD | Purdue Phase Diagram |
| ATMS | Arterial Traffic Management System |
| PPT | Purdue Phase Termination |

| | |
|-------------|---------------------------|
| TMC | Traffic Management Center |
| TMCs | Traffic Message Channels |

Literature Review

Introduction

Traffic administrators, engineers, and researchers often face the problem of how to better monitor and evaluate traffic signal performance. Performance measurements of traffic signal systems are used to provide feedback on the operational effectiveness of highway segments, corridors, or intersections. Our transportation professionals measure the traffic signal system to improve the efficiency and reliability of the roadway network. Traffic signal performance measurement and visualization provide insights as operational tools to help traffic management center get more benefits from infrastructure investment. However, evaluating and monitoring signal performance are challenging in real time, which requires immediate data collection and analysis capability. Some general standards for adopting performance measures have been summarized by Pickrell and Neumann (2000) in a presentation at the Transportation Research Board (TRB) 79th Annual Meeting as follows: 1) Accountability, which means performance measurement system can determine resource allocation based on priority needs that have been identified; 2) Efficiency, performance measurements become an internal management process that focuses on actions and resources on organizational outputs and the process delivery; 3) Communication, performance measurement provides understandable information to customers and stakeholders; and 4) Improvement, performance measurement allows periodic refinement of programs and service delivery given more intermediate results of system monitoring. Traffic management center generates performance measurements to various audiences, including the governor's office, legislature, municipalities, and public. These signal timing performance measurements also include different users, such as transit, bicycles, pedestrians, etc. This literature review session will focus on relevant issues of real-time signal performance measurements, specifically, emphasizes on

- Signal Performance Metrics
- Data needs and measurement methods for SPM
- Existing SPM Systems
- Major research literature and documents and on-going works.

The State of Practice on Real-Time Signal Performance Measurement

The traditional signal timing practices that employ modeling software are time-consuming and labor-intensive because they require a variety input parameter such as volumes, speeds, roadway characteristic, etc. These signal timing plans do not incorporate unpredicted traffic events and are usually retimed at an interval of 30 to 36 months, resulting in aged timing plans that can increase road user complaints while potentially decreasing roadway safety. In 2005, the Indiana Department of Transportation (INDOT) conducted research to develop new traffic signal system performance measurements using logged time-stamped vehicle detectors and traffic signal controller events otherwise known as high-resolution data. The new SPMs obtained from these data provide policymakers an effective tool to proactively manage traffic signals and corridors with a higher degree of accuracy. Representative real-time signal performance metrics are as follows (Day et al., 2014):

- Capacity Performance Measures: The capacity performance measures are used to monitor the capacity utilization at signalized intersections. These performance measures include cycle length, volume and capacity utilization, green time and capacity allocation, green occupancy ratio, red occupancy ratio,

phase termination, and degree of intersection saturation. Note that either advance detectors or stop bar detectors are sufficient to evaluate the local controller for capacity performance measures.

- **Progression Performance Measures:** The progression performance measures describe the quality of progression at a signalized intersection with respect to delay and queue length. Delay estimates from measured arrival profiles, Purdue Coordination Diagram (PCD), flow profiles, and maximum queue length from shockwave estimation are examples of these performance measures.
- **Multimodal Performance Measures:** Non-vehicle modes have their own detection capabilities and performance considerations under traffic signal system. Multimodal performance measures are developed to evaluate the performances of three most common non-vehicle modes (i.e., pedestrians, transit, and railroad), which are incorporated in traffic signal through pedestrian phasing, transit priority, and railroad preemption.
- **Maintenance Performance Measures:** One of the most important considerations for performance measurement is the functionality of traffic control equipment. Specifically, it is essential to maintain the detection devices and communication equipment to support the signal performance system. Communication quality and detector failures are relevant performance measures for maintenance.
- **Advanced Performance Measures:** Advanced performance measures include those SPMs which do not fall within any of the above groups. For instance, a safety performance measure can be developed to describe the safety performance of an intersection with respect to intersection-related crashes and conflict points.

Table 1 presents commonly used performance measurements for signal traffic control. Table 2 shows some criteria to select specific performance measurements for a particular task.

Table 1. Commonly Used Performance Measurements for Signal Traffic Control

| Performance Measure | Description |
|------------------------------------|---|
| Travel Speed | Travel speed is an important index for progression analysis to measure the coordinated signal timing effectiveness along a corridor. |
| Travel Time | Travel time is a key measure of effectiveness that has been widely used. The Travel Time Index is defined as the ratio of the peak-period travel time to the free-flow travel time. |
| Delay | The control delay is defined as the duration of time between when the vehicle first started to decelerate and when it later finished accelerating, minus the travel time between the two positions. |
| Number of Stops | Total number of vehicle stops is of particular interest as performance measures, as it is not only a measure of the level of service but also of the fuel consumption and air pollution. |
| Bandwidth | Bandwidth is defined as the period of time available for vehicles to travel through a coordinated signal system at a constant progression speed. |
| Queue Length | Through queue length, other arterial performance measures, such as intersection delay, travel time, and level of service can be estimated quite readily. |
| Green time per cycle length | The effective green time indicates the total number of seconds per cycle that the green indication is actually displayed. |
| Cycles of delay | The number of cycles a vehicle must wait prior to being given green time |

| | |
|--------------------|---|
| per vehicle | |
| Throughput | Throughput is defined as the VMT (Vehicle Miles Traveled) carried by a segment for a specified period of time. It is described as measuring flow rates for each section of highway between points of entry or egress. It is often used to characterize the efficiency of a highway facility and to evaluate the "before-and-after" effects of operational improvements. |

Table 2 Criteria for selection of performance measurements (NCHRP Synthesis 311, 2003)

| General Criteria | Specific Criteria |
|---|--|
| Clarity and simplicity | <ul style="list-style-type: none"> The measure is simple to present, analyze, and interpret The measure is unambiguous The measure's units are well defined and quantifiable The measure has professional credibility Clarity and simplicity Technical and nontechnical audiences understand the measure |
| Descriptive and predictive ability | <ul style="list-style-type: none"> The measure describes existing conditions The measure can be used to identify problems The measure can be used to predict change and forecast condition The measure reflects changes in traffic flow conditions only |
| Analysis capability | <ul style="list-style-type: none"> The measure can be calculated easily The measure can be calculated with existing field data There are techniques available to estimate the measure The results are easy to analyze The measure achieves consistent results |
| Accuracy and precision | <ul style="list-style-type: none"> The accuracy level of the estimation techniques is acceptable The measure is sensitive to significant changes in assumptions The precision of the measure is consistent with planning applications The precision of the measure is consistent with an operation analysis |
| Flexibility | <ul style="list-style-type: none"> The measure applies to multiple modes The measure is meaningful at varying scales and settings |

Data Needs and Measurement Methods for SPM Systems

Table 3 summarizes potential detection technologies for SPMs. Point detectors such as presence/count detectors deployed at different locations relative to intersections can provide a wide variety of data elements. Paired detectors can provide a reliable estimation of travel time, delay, and origin-destination (OD) but not too much information on the vehicle movement and flow at intersections. Trajectory detectors include both low-sampling-rate GPS probe vehicles and high-sampling-rate method such as advanced vehicle sensors, Doppler radar sensors, and Connected Vehicle messaging, that provides, e.g., second-by-second full vehicle trajectories at and near intersections.

Table 3 Sensor Technologies for Arterial Signal Performance Measurements

| Classification | Technologies | Direct Measurement |
|------------------------|-----------------------------------|---------------------------|
| Point Detectors | Stop-bar Presence/Count Detectors | Flow, Turning movement |

| | | |
|-----------------------------|---|--|
| | Storage Lane Presence/Count Detectors Mid-lane Presence/Count Detectors RTMS* Sensors Video counters | Arrivals Queue length, shock waves Signal timing (Inferred) |
| Paired Detectors | Bluetooth Sensors Wi-Fi Sensors TRANSMIT sensors Cellular probe vehicles Wireless Magnetometers | Travel time Delay Approach speed OD |
| Trajectory Detectors | GPS Probe Vehicle Advanced Video Sensors Doppler Radar Sensors Connected vehicle BSM/TIM messages | Queue length Turning movement Red-Light movement Speed and flow Signal Timing (Inferred) |

* Remote Traffic Microwave Sensor

Existing Signal Performance Measurement Systems

Three states of Utah, Indiana, and Minnesota lead the country for automated SPMs. The Utah Department of Transportation (UDOT), the INDOT, and Purdue University partnered together to create a management structure for agencies to improve the effectiveness of traffic signal systems and develop automated SPMs. The system is currently using major metrics to evaluate the effectiveness of signal progression, as shown in Table 4. Some of these performance measures are obtained with an advanced vehicle detection device (e.g. radar, loop, wired/wireless magnetometer, video) located between 400 ft. and 600 ft. from the stop bar. This relatively inexpensive infrastructure addition placed in advance of the queue at an intersection can be utilized to optimize mobility, address operational deficiencies, and help proactively manage traffic signal timing and maintenance, all of which contributed to reducing congestion, fuel cost, while potentially improving safety.

Utah SPM Platform

Each year, the American Association of State Highway and Transportation Officials (AASHTO) recognizes the innovative projects with successful outcomes adopted by transportation agencies and state DOTs across the country. In 2013, the UDOT's Traffic Signal Automated Performance Measures program was announced as one of the AASHTO Innovation Initiatives. The UDOT is one of the first in the country to employ RT-SPMs for optimizing traffic signal operations. The program provides UDOT the opportunity to actively manage signal operations, in real-time, at each signal, maintained by the UDOT. Linking SPMs (e.g., corridor travel times, total traffic volume served; and percent of split failure) to agency objectives, it is expected to achieve more efficient traffic flow along a given corridor. Given the fact that UDOT had a strong communications infrastructure investment, the proposed system was expanded quickly all over the state.

Indiana Testbed

The INDOT established signal performance measurements test-bed from 2006 – 2013. As part of this research, INDOT has developed a common platform for collecting real-time traffic signal data and developing performance measures for improving traffic performance. This platform was the foundation for the AASHTO Innovation Initiative on Signal Performance Measures (AASHTO, 2016) that has been deployed at over 3,000 signalized intersections nationwide. The benefits of this data methodology have

been demonstrated in dozens of studies (e.g., Brennan, et al., 2010, Brennan et al., 2011). National vendors who embrace the Purdue traffic signal performance measures have grown from the initial three vendor partners to seven leading manufacturers of traffic control equipment. This work produced two monographs which have become seminal references for signal performance measures across the country (Day et al., 2015, Day et al., 2014).

The College of New Jersey (TCNJ) Testbed

The TCNJ currently has access to Burlington County NJ's centralized traffic signal management system. This system utilizes traffic signal controllers with high-resolution traffic signal data event logging capability along County Route 541. Data from this test site is currently being used to generate real-time performance measures. This testbed is used to demonstrate the types of performance measures that may be available with the existing NJDOT infrastructure as well as what infrastructure improvements may be made to enhance the state's ability to use real-time SPMs. An example of the existing real-time performance monitoring for Irick Road and CR541 in Westhampton, NJ is shown in Figure 1.

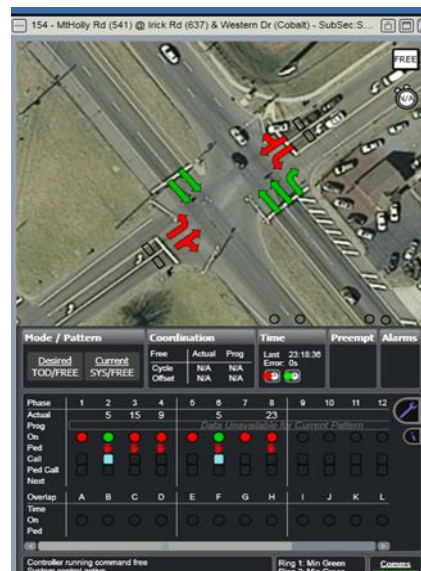


Figure 1. An example real-time performance monitoring on County Road 541 and Irwick Road, Burlington County, NJ.

Performance Metrics: The developed performance metrics will be designed to serve key operational and maintenance needs identified by the NJDOT during the stakeholder meeting in Task 2. The real-time signal performance metrics may include capacity, progression, multimodal, maintenance, and advanced performance measures according to Day et al. (2008). Table 4 lists the potential types of performance metrics along with their measurement tools.

Table 4 Types of performance measures and their measurement tools

| Types of Performance Metrics | Measurement Tool |
|---|---------------------------------|
| <ul style="list-style-type: none"> Purdue Phase Termination Split Monitor | Controller High-Resolution Data |

| | |
|---|---|
| <ul style="list-style-type: none"> • Purdue Coordination Diagram • Approach Volume • Platoon Ratio • Arrivals on Red • Approach Delay | Advanced Count Detection |
| <ul style="list-style-type: none"> • Approach Speed | Advanced Detection with Speed |
| <ul style="list-style-type: none"> • Split Failure | Lane-by-Lane Presence Detection |
| <ul style="list-style-type: none"> • Turning Movement Counts • Red Light Monitoring | Lane-by-Lane Count Detection |
| <ul style="list-style-type: none"> • Purdue Travel Time Diagram | Probe Travel Time Data via GPS or Bluetooth |

Reports and Synthesis

1. Day, C. M., Smaglik, E. J., Bullock, D. M., & Sturdevant, J. R. (2008). Real-Time Arterial Traffic Signal Performance Measures (No. FHWA/IN/JTRP-2008/9). Indiana Department of Transportation (INDOT), Indianapolis, Indiana.

This report focuses on performance measures (i.e., volume-to-capacity ratio and arrival type), defined by the HCM, which can be obtained on a cycle-by-cycle basis using an automated traffic signal controller. Firstly, they reviewed fundamental concepts of traffic operations, such as basic components of traffic signal system, vehicle detection, actuated signal operation, and coordination. Then, they discussed how traffic data was collected and converted into performance measures. It also evaluates the effectiveness of these SPMs in two comparative situations including the effects of actuating a portion of the coordinated phases and traffic signal retiming on coordinated arterial intersections.

The signal performance measures discussed in this report were divided into three categories. The first category is the state of the intersection, including cycle length, green duration, and volume. The second category is based on the concept of intersection capacity comprised of service flow rate, estimated capacity, observed capacity, volume-to-capacity (v/c) Ratio, number of split failures, and critical v/c ratio. The third category is a set of performance metrics that quantify intersection's performance in coordination with vehicle progression, which includes percent of arrivals on green arrival type, and platoon profile.

2. Day, C. M., D. M. Bullock, H. Li, S. M. Remias, A. M. Hainen, R. S. Freije, A. L. Stevens, J. R. Sturdevant, and T. M. Brennan. (2014). Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach. Purdue University, West Lafayette, Indiana.

This report is a synthesis of research performed on traffic signal performance measures based on high-resolution controller event data, assembled into a methodology for performance evaluation of traffic signal systems. The signal event data collection and management methods, as well as the required infrastructure to collect these data, are discussed. It also presents a portfolio of performance measures (e.g., system maintenance and asset management, and signal operations) for both vehicle and non-vehicle modes. This report discussed various types of performance measures for traffic signal systems, including location control, system control. Local control is based on capacity performance measures, comprised of cycle length, green time and capacity allocation, volume and capacity utilization, green occupancy ratio and red occupancy ratio, and degree of intersection saturation. System control is based on progression performance

measures, which includes delay and quality of progression, delay estimates from measured arrival profiles, Purdue coordination diagram, flow profiles, platoon formations and dispersion, and maximum queue length. The methodology adopted three separate tracks to develop performance measurements including computing vehicle MOEs, computing estimated delay, computing non-vehicle MOEs. Vehicle MOEs consist of capacity performance measurements and progression performance measurements. Local control is based on capacity performance measures, comprised of cycle length, green time and capacity allocation, volume and capacity utilization, green occupancy ratio and red occupancy ratio, and degree of intersection saturation. System control is based on progression performance measures, which includes delay and quality of progression, delay estimates from measured arrival profiles, Purdue coordination diagram, flow profiles, platoon formations and dispersion, and maximum queue length. Non-vehicle performance measurements investigated in this report are pedestrians, railroad, and transit. Pedestrian phasing, railroad pre-emption, and transit priority are all adopted in signal controllers, which are considered quite different from vehicle signal performance metrics.

Besides the three types of performance metric, this monograph further discussed two more categories of performance measures to meet additional purposes beyond evaluating signal operations. First one is equipment maintenance measurement, which is to guarantee the signal operation. The second one is the outcome assessment, which is the application of travel time data to measure the transportation system reliability.

3. Grossman, J., & Bullock, D. M. (2013). Performance Measures for Local Agency Traffic Signals. (No. INLTAP-TR-4-2013). Purdue University, West Lafayette, Indiana.

This research project creates a specification language for deploying performance measures in two states of Indiana and West Virginia. It also evaluates the feasibility of implementation of adaptive traffic signal control in a short period, 12 to 18 months. Based on the obtained results, detection placement, detection quality, and agency's commitment to support operations of those systems are factors that significantly affect their applicability and effectiveness. Signal performance measurements described in this report includes Cycle Length, Equivalent Hourly Flow Rate, Green Time Plot, Volume to Capacity Ratio, Split Failures, Purdue Coordination Diagram, Percentage of Phases with Pedestrians. This report also emphasizes the importance of high-quality vehicle detection for Signal Performance Measures and provides recommendations to retrofit existing video detection with thermal cameras to improve the detection quality.

The report also provided a list of recommended performance metrics and their definitions, as shown in Table 5.

Table 5 List of performance measurements and description (Grossman, J., & Bullock, D. M., 2013)

| Performance Measurements | Description |
|--------------------------|--|
| Cycle Length | Cycle length may seem a simple measurement. However, inaccuracies in programming the cycle lengths of coordinated signal systems leads to seriously adverse effects on travel time. Cycle lengths used as a requirement for coordination, allows the engineer to verify that all signals in coordinated systems are operating at the same cycle length during each time of day plan. |
| Equivalent | The equivalent hourly flow rate can provide a quick check of the flow rate on each approach to a signal, which can be used to determine the relative |

| | |
|--|---|
| Hourly Flow Rate | importance of each phase. |
| Green Time Plot | Green Time Plot demonstrates each of the signal phases and plots the assigned amount of green time for each phase during each cycle. This is used to verify the appropriate green time values for a signal. |
| Volume to Capacity Ratio | Volume to Capacity Ratio is used to investigate movements that might require more time. |
| Split Failures | To visualize the number of split failures during a defined period that occurs on each phase, this report uses split failure plot. |
| Purdue Coordination Diagram | Purdue Coordination Diagram is used to measure for coordinated corridors. The differences between good and bad coordination are shown by where the clusters of vehicles arrival. |
| Percentage of Phases with Pedestrians | This measurement helps the engineer to identify which signals, and which phases should have adequate split time for pedestrian usage. |

4. Stephen Remias, Jonathan Waddell, Matt Klawon, Ken Yang (2018). Signal Performance Measures Pilot Implementation (No. SPR-1681). Michigan Department of Transportation, Lansing, Michigan.

The Michigan Department of Transportation implemented ATSPM on two corridors to evaluate and monitor the performance of selected corridors. A cost benefit analysis was conducted to assess potential costs and benefits associated with deployed ATSPM system. The pilot ATSPM pilot project reveals that significant benefits realized by reductions in travel time. The benefit-cost-ratio is estimated as 25 to 1 considering travel time saving, safety benefits, maintenance benefits, continuous operational benefit, and initial optimization benefits.

5. Day, C. M., Bullock, D. M., Li, H., Lavrenz, S. M., Smith, W. B., & Sturdevant, J. R. (2015). Integrating Traffic Signal Performance Measures into Agency Business Processes. Purdue University, West Lafayette, Indiana.

The information contained in the report is meant for transportation agencies to assist with establishing an active traffic management program to advance the using and implementing performance measures to manage traffic signal systems. It briefly provides the current state of the practice and opportunities for improvements as well as business processes in signal system management. This report also presents a variety of performance measures that can be used for quality of progression, quality of local control, and communication and detection system. The performance measures presented in this report include performance measures for assessing detector health in traffic signal systems and performance measures for both assessing local signal control and system control. For single intersection, it contains an evaluation of capacity allocation, safety performance (red light running), pedestrian service, and diagnostic analysis of preemption and advanced control settings. For system performance measures, it includes evaluation of capacity allocation, pedestrian service, safety performance (red light running), and diagnostic analysis of preemption and advanced control settings.

This report also presents a variety of performance measures that can be used for quality of progression, quality of local control, and communication and detection system. The performance measures presented in this report include performance measures for assessing communication status and detector health in traffic signal systems and performance measures for both assessing local signal control and system control.

- The influence of detector health and communication status on traffic control system is assessed primarily based on communication failures, delay for drivers, vehicle progressions, and benefit/cost analysis.
 - For single intersection, the report discussed performance measures for evaluating capacity utilization including cycle length, duration of green and reason for termination, capacity utilization metrics, estimated delay, red light running, pedestrian utilization, and special operational diagnostics.
 - For assessing system control, the report focused on traffic progression. This included visualizations of traffic events and development of quantitative performance measures that can be aggregated. The quantitative performance measures include arrivals on green (AOG)/percent on green (POG), arrivals on red (AOR)/percent on red (POR), platoon ratio, arrival type, and estimated delay.
6. Liu, H. X., Ma, W., Wu, X., & Hu, H. (2008). Development of a real-time arterial performance monitoring system using traffic data available from existing signal systems (No. MN/RC 2009-01). Minnesota Department of Transportation, St. Paul, Minnesota.

The Minnesota Department of Transportation (MnDOT) supported a project to design a system for collecting high-resolution traffic signal data and developing performance measurements. The proposed system, so-called SMART-SIGNAL, can collect and store high-resolution event-based traffic signal data at several intersections, leading to the development of real-time SPMs such as a number of stops, queue length, and travel time.

At each intersection, both vehicle actuation events and signal phase change events would be captured by the Data Collection System. The report uses different performance measures for intersection level and arterial level: arrival type, cyclic volume and occupancy profile, delay, level of service (LOS), queue size and queue length were discussed at intersection level, while travel time, delay, number of stops, stop time and vehicle probe trajectory were discussed at arterial level.

7. Balke, K. N., Charara, H. A., & Parker, R. (2005). Development of a traffic signal performance measurement system (TSPMS) (No. FHWA/TX-05/0-4422-2). Texas Transportation Institute, Texas A & M University System.

The Texas Department of Transportation (TxDOT) sponsored a project to evaluate the different types of intersection-related performance measures and to develop a prototype system for automatically collecting these performance measures in the field. The system was implemented in two locations, with different operating characteristics, to determine the capability of the proposed system in achieving the appropriate performance measures. They developed performance measure report generator, which is a log file analysis software. This performance measure report generator (PMRG) collects events include phase status, phase on, ring status, and vehicle detections. This system enables users to select daily log files through a graphical interface, and the program will display performance measure report created from the log. The outcomes of the program include cycle time, time to service, queue service time, duration of the green, yellow, all-red and red interval for each phase, number of vehicles entering the intersection during each interval, yellow

and all-red violation rates, and phase failure rate. The evaluated performance metrics of the program include cycle time, time to service, queue service time, duration of the green, yellow, all-red and red interval for each phase, number of vehicle entering the intersection during each interval, yellow and all-red violation rates, and phase failure rate.

8. Balke, K. N., & Herrick, C. (2004). Potential Measures of Assessing Signal Timing Performance Using Existing Technologies (No. FHWA/TX-04/0-4422-1). Texas Transportation Institute, Texas A&M University System.

Another study conducted by the TxDOT evaluates potential measures of assessing signal timing performance at isolated intersections using existing detection technologies. This report contains the results of a series of interviews and an examination of existing controllers and detection technologies for collecting SPMs. TxDOT used volume data (and more specifically, turning movement volume counts) to develop and evaluate signal timing plans. The report assessed the capabilities of the existing traffic signal and detection technologies, including Eagle EPAC Traffic Signal Controller, Autoscope Solo System and ORACLE /2 Inductive Loop System. The potential performance Measures includes Measures of Reliability, Measures of Efficacy, and Measures of Safety. The Measures of Efficacy was based on average cycle time, the average duration of each phase, the average time required to service a call, and the average proportion of green used to service queue.

9. Gordon, R. L. (2010). Traffic signal retiming practices in the United States. NCHRP Synthesis 409. Transportation Research Board, Washington, DC.

The report covers the practices that operating agencies currently use to revise traffic signal timing. It includes the planning needed to develop signal timing plans and the processes used to develop, install, verify, fine-tune, and evaluate the plans. The authors collected information for this synthesis through a literature review, a review of two large-scale and two narrowly focused surveys of transit agencies, and a series of project case studies. Of the 17 agencies solicited for the case studies, the authors followed up with the seven agencies that responded and were able to acquire additional statistical and anecdotal information. Performance measurements suggested in this report are summarized as follows: The first performance measures of signal timing are vehicle performance measures including volume, travel time, travel time reliability, delay, stops, throughput, travel time and travel time reliability, queue length, crashes, fuel consumption, vehicle emissions and progression quality intersections. Secondly, the pedestrian LOS measures provided in HCM 2000 are based on pedestrian delay as computed by the equation. Thirdly, traffic signal timing for railroad signal preemption relates to the connection between the activation of the protection devices and the traffic signal clearances that ensure queue clearance from the tracks is also considered. Furthermore, measures used to assist in retiming signals are discussed. The measure involves the average number of times a phase was activated in a given evaluation period, the average number of vehicles served per cycle during a given evaluation period, the average number of vehicles stored per cycle during a given evaluation period (residual queue), the probability of a vehicle having to stop at an approach during a given evaluation period, and the percentage of overloaded cycles (or cycle failures) during a given evaluation period.

10. Shaw, T. (2003). Performance measures of operational effectiveness for highway segments and systems. NCHRP Synthesis 311. Transportation Research Board, Washington, DC.

This synthesis evaluates the use of performance measures to monitor and manage the highway segments and systems. It includes more than 70 performance measures, along with their strengths and weaknesses.

This report does not necessarily cover all the traffic signal performance measures. For instance, the average vehicle delay was recommended as a performance measure for the signalized and unsignalized intersections. In this report, an assessment of the relative strengths and weaknesses of these measurements are performed. This synthesis also summarizes practices use of performance measures, reporting techniques for performance measures, and data collection techniques in support of these performance measures. The following table demonstrates the performance measure comparison criteria.

As pointed out in this synthesis, the performance measures that were most commonly identified were conditions experienced by the traveler, such as travel time, speed, and delay. Measures that are derived from these basic units, primarily indices, were found to be less relevant to the operational environment, but very valuable for transportation planning, policy, and prioritization analysis. Based on the results of the survey of state departments of transportations (DOTs) and metropolitan planning organizations (MPOs), the dimensions of operational performance that were the most relevant were the quantity of travel and the quality of travel.

Academic Papers:

1. Brennan Jr, T.M, Day, C., Sturdevant, J., Raamot, E., & Bullock, D. (2010). Track Clearance Performance Measures for Railroad-Preempted Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (2192), 64-76.

This paper outlines performance measures based on high-resolution, real-time traffic signal event data that can be used to assess the maximum right-of-way transfer time to track clearance green phases as well as the synchronization of the track clearance phase with the railroad gate warning system located at the crossing. Data were collected at an instrumented intersection at US-36 and Carroll Road in McCordsville, Indiana. (An Econolite ASC/3 controller with high-resolution data logging capability was used for this research.) US-36 is a signalized arterial serving commuters in the Indianapolis area. A substantial portion of US-36 runs parallel to dual railroad tracks owned by CSX. Those tracks serve, on average, 20 trains per day in two directions and have a maximum posted speed of 60 mph. The performance evaluation was on track clearance phase that is the termination of the track clearance green interval concerning relationship to the railroad gate descending.

2. Brennan Jr, T.M, Day, C., Sturdevant, J., & Bullock, D. (2011). Visual Education Tools to Illustrate Coordinated System Operation. *Transportation Research Record: Journal of the Transportation Research Board*, (2259), 59-72.

This study develops a series of graphics (e.g., time-of-day schedule change time, observed cycle length, green time and split time, coordinated phase actuation, early return to green, arrivals over advance detection relative to the green indication, and progression quality characteristics related to offset) to visualize coordinated system operation characteristics. These graphics can be used as a new learning tool, as well as a visual feedback tool to confirm that a coordinated system is operating as expected. A series of graphics was developed to visualize coordinated system operation characteristics such as time-of-day schedule change time, observed cycle length, green time and split time, coordinated phase actuation, early return to green, arrivals over advance detection relative to green indication, progression quality characteristics related to offset, adjacent signal synchronization, coordinated phase operation in rest, plan time changes, preemption, impact of queuing, and longitudinal analysis of splits.

The data collection is based on those intersections use commercial off-the-shelf controllers to log all

detection phase and relevant events at a 0.1-s resolution. Advance detectors are located upstream of the stop bar in the coordinated phase and detector status changes at a resolution of 0.1 s logged at intersections. Meanwhile, high-resolution data from a single traffic signal controller under semi-actuated and actuated conditions is also collected.

3. Brennan Jr, T.M, Remias, S. M., & Manili, L. (2015). Performance measures to characterize corridor travel time delay based on probe vehicle data. *Transportation Research Record: Journal of the Transportation Research Board*, (2526), 39-50.

This paper develops performance measures to characterize corridor travel time delay using probe vehicle data. Thanks to a visually intuitive methodology, a series of traffic message channels (TMCs) segments is aggregated, considering a cursory review of congestion hotspots within a corridor. The developed performance measures account for speed variability caused by roadway geometry and other Highway Capacity Manual (HCM) speed-reducing friction factors associated with each TMCs. The traffic performance measures include congestion hours, travel time inflation, and corridor travel time inflation. Visualization techniques were proposed as an intuitive way to relay the congestion along a corridor and better way to archive the data. The study applied an analysis of approximately 90 million speed records collected in 2013 along I-80 in northern New Jersey was performed for this project. Travel time inflation, the time exceeding the expected travel time at 70% of measured free-flow speed, was used to evaluate each of the 166 directional TMCs segments along 70 mi of I-80. This performance measure accounts for speed variability caused by roadway geometry and other Highway Capacity Manual speed-reducing friction factors associated with all TMCs.

The data collection was conducted for the 166 targeted TMCs. Approximately 90 million 1-min speed records were analyzed for the corridor. These speed data were also stored in a database table. Each speed associated with a TMCs was then aggregated into 15-min space mean speed (SMS) bins, 96 total, over a 24-h period for each day in 2013 and subsequently stored in a new database table. The performance measurement involves congestion hours and corridor travel time index.

4. Zheng, J., Liu, H., Misgen, S., & Yu, G. (2013). Performance Diagnosis Tool for Arterial Traffic Signals. *Transportation Research Record: Journal of the Transportation Research Board*, (2356), 109-116.

This paper develops a performance diagnosis tool for arterial traffic signal with the aim of helping agencies to make fine-tuning signal timing adjustments. To evaluate the proposed tool, the authors considered three major parameters of traffic signals including cycle length, offset, and green split, using collected data at intersections along the Trunk Highway 13 in Burnsville, Minnesota.

One major obstacle to performing data collection and analysis is lack of data collection capacity and efficient performance monitoring tool for traffic signal systems. They use cycle-by-cycle and phase-by-phase performance measures for analysis. The entire diagnosis tool includes three modules: the offset, green split, and cycle-length diagnosis modules. The entire diagnosis tool includes three modules: the offset, green split, and cycle-length diagnosis modules.

5. Ardestani, S. M., Jin, P. J.1, and Feeley, C. (2016). Signal Timing Detection Based on Spatial-Temporal Map Generated from CCTV Surveillance Video. *Transportation Research Record: Journal of the Transportation Research Board*.

This paper develops some signal timing detection methods based on the NJDOT closed-circuit television camera (CCTV) footage at a major arterial intersection on US-1. This paper applied ST map-based algorithm to detect signal timing from regular low-resolution CCTV cameras available at major arterial intersections. The algorithm detects vehicle trajectories by using the accurate time information recorded at the ST map. According to the detected static vehicles on the scanline and their stalling durations, the proposed algorithm detects the starting and ending time of red lights efficiently. The results are compared with the InSync system output, and satisfactory results are achieved. The paper proposes performance metrics such as Type I and Type II error for signal cycle detection and numeric error such as mean error and mean absolute error to evaluate the detection accuracy on starting and ending times. The method can be potentially extended to locations where the CCTV camera is installed but the signal timing data are not transmitted to centralized arterial management centers.

6. Cheng, Y., Qin, X., Jin, P. J., Ran, B., & Anderson, J. (2011). Cycle-by-cycle queue length estimation for signalized intersections using sampled trajectory data. *Transportation Research Record: Journal of the Transportation Research Board*, (2257), 87-94.

This paper presents the measurement method for the one SPM, queue length, based on sampled GPS probe vehicle data. The estimation method uses traffic flow and shockwave characteristics in response to the traffic signal and queuing dynamics. This paper introduces the concept of critical point (CP), which is used to indicate the changing vehicle dynamics. Based on the queue formation and dissipation related to Critical Points (CP), the author developed queue length estimation method from Lighthill–Whitham–Richards shock wave theory. This model can offer cycle-by-cycle queue length estimation and provide instantaneous arterial traffic performance measurements in real-time applications.

In their method, sampled trajectory data is the only input for real-time queue length estimation. The proposed critical point (CP) extraction model helps to convert the microscopic detections into macroscopic performance measures. A CP extraction algorithm is introduced to identify CPs from raw trajectories. Using the CPs related to queue formation and dissipation, the authors propose an improved queue length estimation method based on shock waves. The performance of this approach is evaluated with several data sets under different flow and signal timing scenarios.

7. Mirchandani, P. and Head, L. (2001). A real-time traffic signal control system: architecture, algorithms, and analysis. *Transportation Research Part C: Emerging Technologies*, 9(6), pp.415-432.

This paper discussed a real-time traffic-adaptive signal control system, which is named as RHODES. The architecture of RHODES system has been decomposed into several subsets, including intersection optimization, link flow prediction, network flow prediction, platoon flow prediction, and parameter and state parameter estimation. The RHODES system predicts both short-term and medium-range fluctuations of traffic flows. Their analogy of traffic control by comparing effective capacity and offering loads suggests that there is a need to consider signal control performances under different loading levels.

Their input database contains three types of information: 1) Dynamic data refers to real-time detector information, past and planned signal control states, and traffic flow predictions; 2) Model parameter refers to parameters that either constant or change slowly over time, which is usually used in traffic flow theory and signal control algorithms, such as turning percentages, queue departure rates, and average link travel speeds, and other signal timing constraints; and 3) Static data refers to constant information including infrastructure geometry such as number of lanes, network nodes, arterial length, and locations of detectors.

In this paper, factors to be considered for performance measurements included types of network, traffic demand, statistic issues such as how to characterize traffic demand, and how to statistically support conclusions and statements.

8. Smaglik, E., Sharma, A., Bullock, D., Sturdevant, J. and Duncan, G. (2007). Event-Based Data Collection for Generating Actuated Controller Performance Measures. *Transportation Research Record: Journal of the Transportation Research Board*, 2035, pp.97-106.

In this paper, the authors conducted an analysis to collect cycle-by-cycle traffic data to deal with the problem that typical data collectors usually collect data on an hourly or 15 min basis, leading to the impossibility of evaluating the performance of individual phases and splits on a cycle-by-cycle basis. This paper described a general-purpose data collection module within a National Electrical Manufacturers Association (NEMA) actuated traffic signal controller with some hardware enhancements. The performance measurements that can be pulled from controllers include Equivalent Hourly Volume (EHV), Arrival Type (AT) Data, and Delay Data.

9. Liu, H. and Ma, W. (2009). A virtual vehicle probe model for time-dependent travel time estimation on signalized arterials. *Transportation Research Part C: Emerging Technologies*, 17(1), pp.11-26.

Liu and Ma (2009) proposed a virtual probe vehicle model for signalized arterials for a real-time arterial data collection and archival system. The virtual probe car can be traced to estimate time-dependent travel time along an arterial using high-resolution “event data” from the simultaneously data collection system. They also introduced a real-time arterial performance measurement system SMART-SIGNAL, referring to Systematic Monitoring of Arterial Road Traffic Signals, which includes data collection, storage, and analysis system. Both signal status data and vehicle detection data were utilized to determine the state of virtual probe vehicle. The virtual probe results can be applied to estimate other performance measures, such as number of stops, control delay at intersections, LOS and queue length in the oversaturated situation.

10. Comert, G. (2013). Simple analytical models for estimating the queue lengths from probe vehicles at traffic signals. *Transportation Research Part B: Methodological*, 55, pp.59-74.

Queue length is an important measurement that can be used as input to estimate delay and travel time at a signalized intersection. Probe vehicle methods have been used widely to gather travel time and traffic speeds, while the queue length and delays are more challenging to be derived given the information from PVs. This study has developed a mathematical model to estimate queue lengths utilizing traffic mobile sensing data from probe vehicle (vehicles with GPS and wireless communication tools). It should be noted that the queue length is estimated by using the location and time of probe cars.

11. Wu, X., Liu, H. and Gettman, D. (2010). Identification of oversaturated intersections using high-resolution traffic signal data. *Transportation Research Part C: Emerging Technologies*, 18(4), pp.626-638.

Wu et al. (2010) have developed an algorithm to identify oversaturated intersection using high-resolution signal data, which quantitatively measures the severity of oversaturation at a signalized intersection. In this paper, the authors created the oversaturation severity index (OSI) for signal performance measurements, including temporal dimension (T-OSI) and spatial dimension (S-OSI). The focus of this OSI shifts from measuring travel demand to measuring the detrimental effects of congestion both temporarily and spatially. The designed OSI algorithm mainly composed of two parts— residual queue length estimation and the

detection of spill-over conditions. They also assumed that high-resolution (second-by-second or event-based) traffic data can be acquired. An experiment was designed to test their method on a selected arterial.

12. Hao, P. and Ban, X. (2015). Long queue estimation for signalized intersections using mobile data. *Transportation Research Part B: Methodological*, 82, pp.54-73.

Hao and Ban (2015) have investigated how to use mobile data to estimate queue length for the signalized intersection, especially when the queue is very long. The long queue problem is defined as the queue exceeds the area of detection. The advantage of using mobile data to cope with the “long queue” problem is that mobile data is capable to detect queue far from the intersection. To deal with undetected acceleration or deceleration delay, car following models were applied in the process to reconstruct queue profile. They divide vehicle arriving types into four categories based on three parts of intersection delay, consisting of deceleration delay, queuing delay, and acceleration delay. Based on the delay-based method, long queue problem was reduced to short queue problem, which can be solved with existing solutions.

System Framework

System Description

Traffic signal performance measurement and visualization provide insights as operational tools to help traffic management center get more benefits from infrastructure investment. However, evaluating and monitoring signal performance are challenging in real time, which requires immediate data collection and analysis capability. Due to the variation of traffic demand, the efficiency of traffic signal timing plan has been greatly reduced. Previous traffic signal maintenance and operations is expensive and lagging. The system is a development of automated traffic signal performance measurement system (ATSPM) considering existing implementation options according to agency capabilities and resources. The research team specifically designed the system based on ATSPM open-source software to develop an economically justifiable ATSPM for arterial traffic management in New Jersey. To acquire a high-resolution data-logging capability, the designed system implements innovative data analysis techniques to adopt existing traffic signal infrastructure. In support of New Jersey DOT's safety and mobility goals, this designed system can provide information to proactively identify deficiencies, and then enable them to efficiently manage tuning process of signal timing plan. This developed ATSPM system bridge the gap between collected traffic data (e.g., signal controller data, detector data and historical data) and needed performance information for decision-making. In this section, we will discuss system components, required hardware and software, system management and validation.

ATSPM Dataflow

The entire system operates as shown in Figure 2, the high-resolution controller belonging to existing infrastructure is connected to AMC at each signalized intersection. The controller event log file containing signal state is transported to AMC database, where our program can automatically retrieve these data logs and translate these unprocessed data into standard event code. Converted event file will be inserted into ATSPM databased managed by MSSQL database software. Following this, the ATSPM software can generate signal performance metrics and produce visualization on web page to support performance-based maintenance and operations.

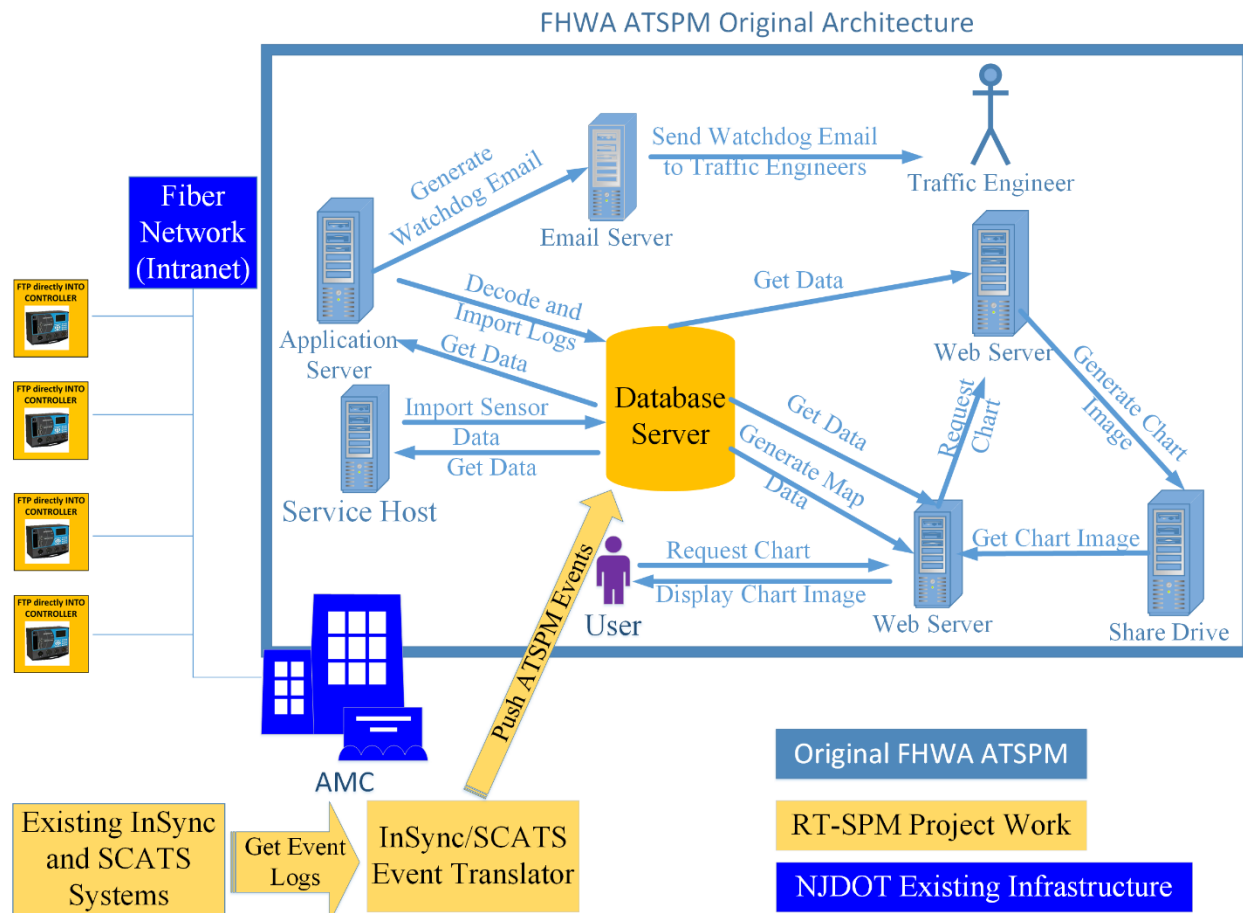


Figure 2 System Operation Dataflow Chart

This SCATS/ InSync system collects data from traffic signal controllers and export data log into “.csv” file. Then the developed program will interact with database to translate the event logs into high-resolution event code that can be recognized by ATSPM system. ATSPM system will generate signal split diagram, PCD diagram, pedestrian signal diagram through web server. Traffic engineer can use web server to monitor/optimize signal control strategy to make better decisions. There are three main benefits of designed system operation dataflow:

1) Use existing IT and communication infrastructure

To generate SPM, the developed RT-SPM system does not rely on specific high-resolution controller inputs, such as EconoliteCobalt, EconoliteASC3 NEMA, and Intelight Maxtime, etc. However, the developed system is managed to incorporate current InSync and SCATS into ATSPM software.

2) Centralized deployment at AMCs

All deployments are made at Arterial Management Center, where the InSync and SCATS adaptive traffic signal control consoles are accessible. There is no need to install any hardware or software on-site to facilitate communication and data storage.

3) Minimal changes to ATSPM software packages

The original ATSPM software packages are written in C#, while our event translation program was written in python. The program was developed as an additional package, which avoids the significant change of ATSPM software packages.

ATSPM System Validation

A test bed was assembled to evaluate the ATSPM system to validate the operational dataflow defined in Figure 2.

Test Bed Intersections

New Jersey has over 2,500 NJDOT-maintained signals, while only 76 signals are on Adaptive Traffic Signal Systems. From these controllers, specific routes were selected where ATS data could be obtained. With reference to Figure 3, several intersections were chosen to validate the data flow and data conversation program. The selected intersections include two InSync controlled intersections on US-1 and one SCATS (Hillsdale Road) controlled intersection on SR-18.

Route 1 has InSync system installed and NJ18 has SCATS system installed. Both routes serve as main corridors in New Jersey. US1 at Henderson has AADT (Average Annual Daily Traffic) of 57,139. US1 at Henderson has AADT of 87,479, while NJ18 at Hillsdale has AADT of 52,838.

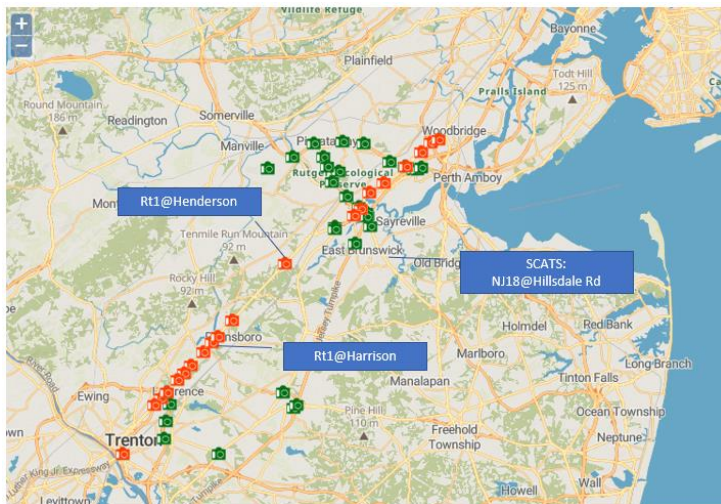


Figure 3 Testing Corridors and Intersections

Validation Method

The team has pulled historical data from the ATC signal controllers and translated the datafile to ATSPM event code. From this code, chart images are generated through the ATSPM system. By analyzing the PCDs, phase termination and phase split diagram, and comparing them with real traffic scenarios, signal performance is characterized. Figure 4 shows the ATSPM outputs, which were subsequently examined to conduct system validation based on real world traffic scenario.



a

Left/Through Running Protected

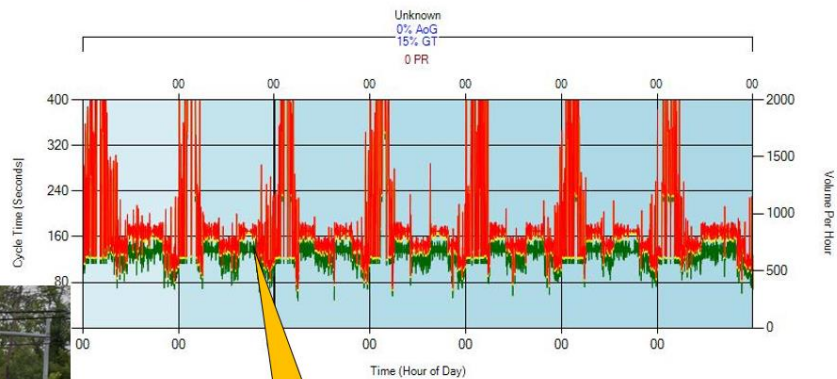
Purdue Coordination Diagram

TCNJ_INSYNC @ InSyncTEST - SIG#101
 Sunday, August 12, 2018 12:00 AM - Saturday, August 18, 2018 11:59 PM
 Advanced detector located ft. upstream of stop bar

Phase 8: Westbound

AoG = 0%

- Volume Per Hour
- Detector Activation
- Change to Green
- Change to Yellow
- Change to Red
- AoG - Arrival On Green
- GT - Green Time
- PR - Platoon Ratio



Green Ball...Green Arrow

Less Green Time

b

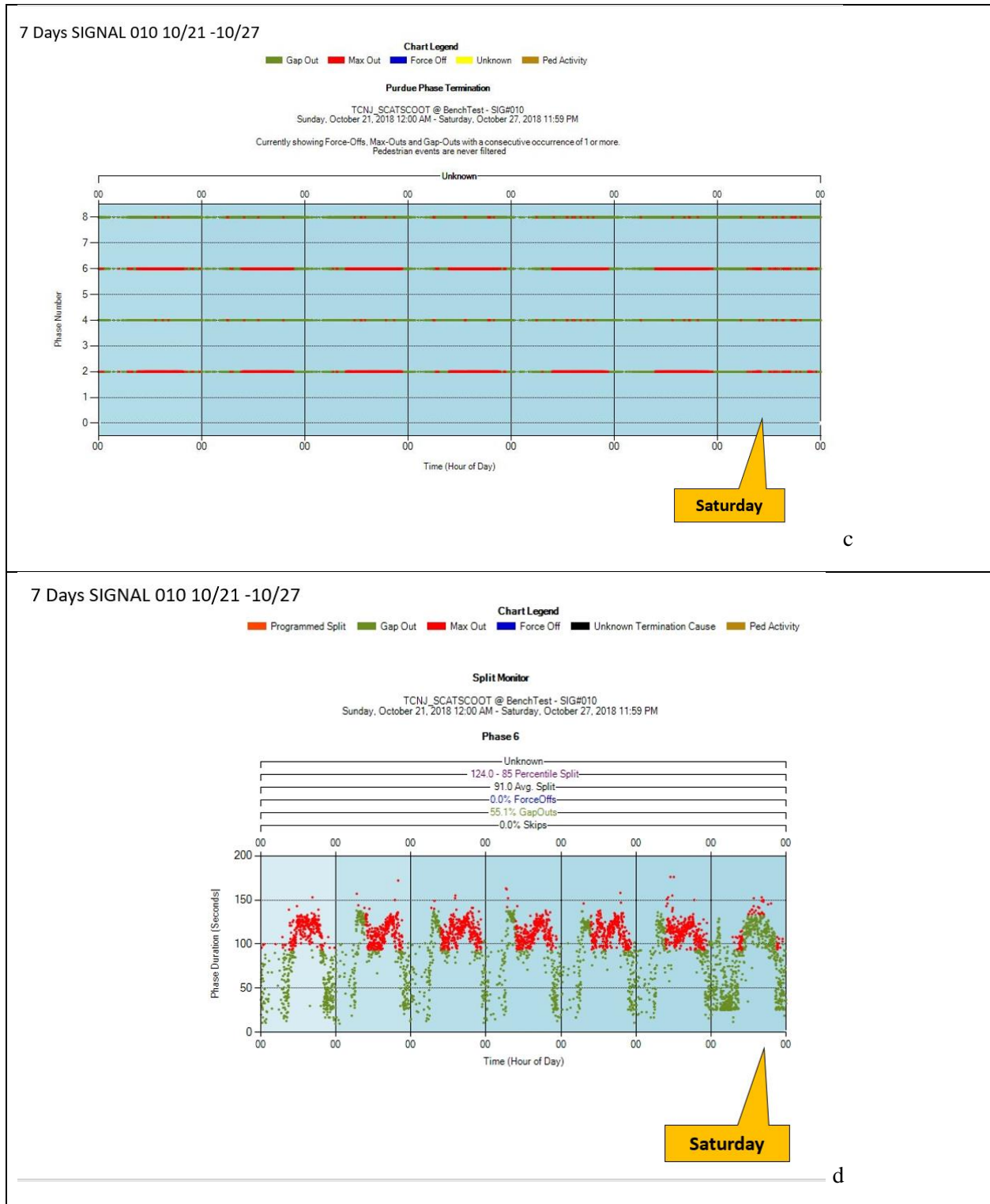


Figure 4 System Validation: (a) Intersection location on Google Earth (b) sample PCD Chart for a random approach (c) Sample Phase Termination Chart (d) Sample Split Monitor Chart

Event Translator Methods

Introduction

The ATSPM system relies on specific high-resolution signal controllers, which is not readily available in New Jersey (only one found in city of Trenton). However, the ATSPM system is flexible enough to accept alternative data sources. The research team explored customized data processing modules for the ATSPM so that the non-high-resolution controller data could be used. The session presents designed algorithms that are used to convert InSync/SCATS log files to ATSPM event files that can feed into ATSPM software. Event type and event code range are presented in Table 6.

Table 6 Traffic Signal Hi-Resolution Data Logger Enumerations

| Event Type | Event Code Range |
|--------------------------|------------------|
| Active Phase Events | 0 –20 |
| Active Pedestrian Events | 21 –30 |
| Barrier / Ring Events | 31 –40 |
| Phase Control Events | 41 –60 |
| Overlap Events | 61 –80 |
| Detector Events | 81 –100 |
| Preemption Events | 101 –130 |
| Coordination Events | 131 –170 |
| Cabinet / System Events | 171 -199 |

The focus of this study is on Active Phase Events and pedestrian-related events, which is elaborated in the Table 7.

Table 7 High-Resolution Active Phase Events and Codes

| Event Code | Event Descriptor | Event Code | Event Descriptor |
|------------|-------------------------|------------|------------------------------|
| 0 | Phase On | 8 | Phase Begin Yellow Clearance |
| 1 | Phase Begin Green | 9 | Phase End Yellow Clearance |
| 2 | Phase Check | 10 | Phase Begin Red Clearance |
| 3 | Phase Min Complete | 11 | Phase End Red Clearance |
| 4 | Phase Gap Out | 12 | Phase Inactive |
| 5 | Phase Max Out | 21 | Pedestrian Begin Walk |
| 6 | Phase Force Off | 45 | Pedestrian Call Registered |
| 7 | Phase Green Termination | 43 | Phase Call Registered |

InSync: Event Translator Algorithm

The signal event conversion for InSync system are listed in Table 8: A detailed description about how the algorithm converts InSync data for use in the ATSPM. Both InSync file and converted file, as well as python algorithm are presented.

Table 8 Convertible Signal Event

| Code | Event | Insync Translator Logic |
|------|------------------------------|---|
| 0 | Phase On | Get from movement start time |
| 1 | Phase Begin Green | Get from movement start time |
| 2 | Phase Check | Get from conflicting movement |
| 3 | Phase Min Complete | Duration > Minimum Green time |
| 4 | Phase Gap-Out | Movement is Truncated Based on Insync Log |
| 5 | Phase Max-Out | if not Gap-out, then it will be Max-out |
| 7 | Phase Green Termination | Approach End Timestamp |
| 8 | Phase Begin Yellow Clearance | Begin Yellow is the same as green termination |
| 9 | Phase End Yellow Clearance | Phase end time + yellow change interval |
| 10 | Phase Begin Red Clearance | Begin Red Clearance is the same as end of Yellow Interval |
| 11 | Phase End Red Clearance | Begin of Red + Red Clearance Interval |
| 12 | Phase Inactive | If a phase was skipped in a certain cycle, then create phaseInactive |
| 21 | Pedestrian Begin Walk | Event 21 is created at the timestamp of the following record containing the string of "pedestrian Sent" with the through movements (as shown in the algorithm description below). |
| 43 | Phase Call Registered | For InSync System, it logs the estimated waiting time for each movement. If the waiting time for the movement is not "0" in the history file, then create phase call registered for the phase. The timestamp would be the current time stamp for the movement, minus the seconds of Wait Time for |

| | | |
|----|----------------------------|---|
| | | that same movement |
| 45 | Pedestrian Call Registered | The Insync log contain the string of "Pedestrian Called", then we create event 45 at the timestamp of that record |

Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11 explained how original InSync Log file can be converted to ATSPM standard event code.

Event 0 and Event 1: Phase on and Phase Begin Green

Insync Signal Event Conversion (06:00:00-06:10:00)

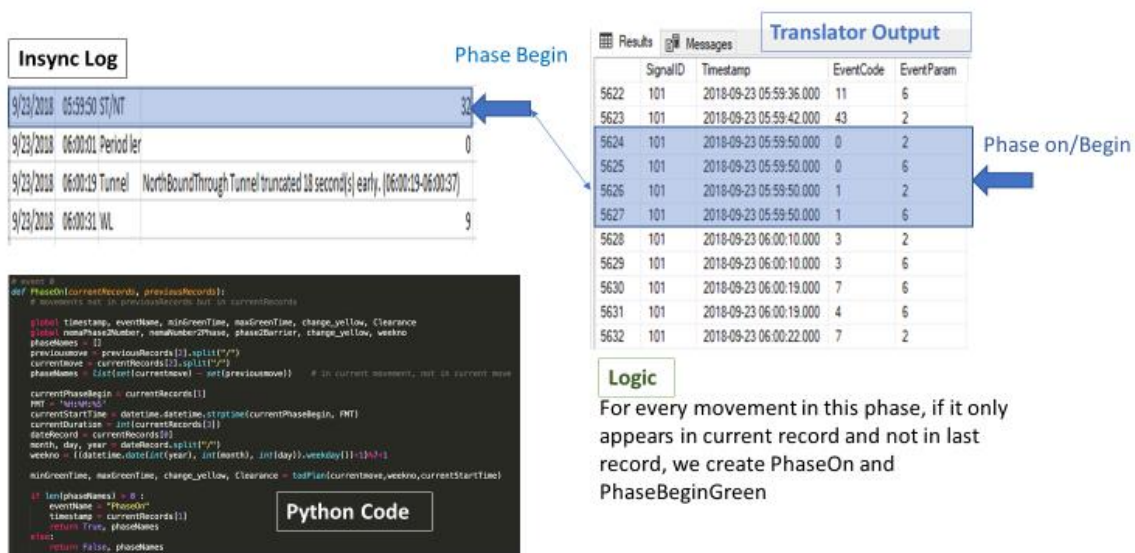


Figure 5 InSync Log Conversion for Event #0 and #1

Event 3: Phase Min Complete

Note: The minimum green time is read from metafile. In this case, the minimum green time for mainline traffic is 75 seconds.

Insync Signal Event Conversion (06:00:00-06:10:00)

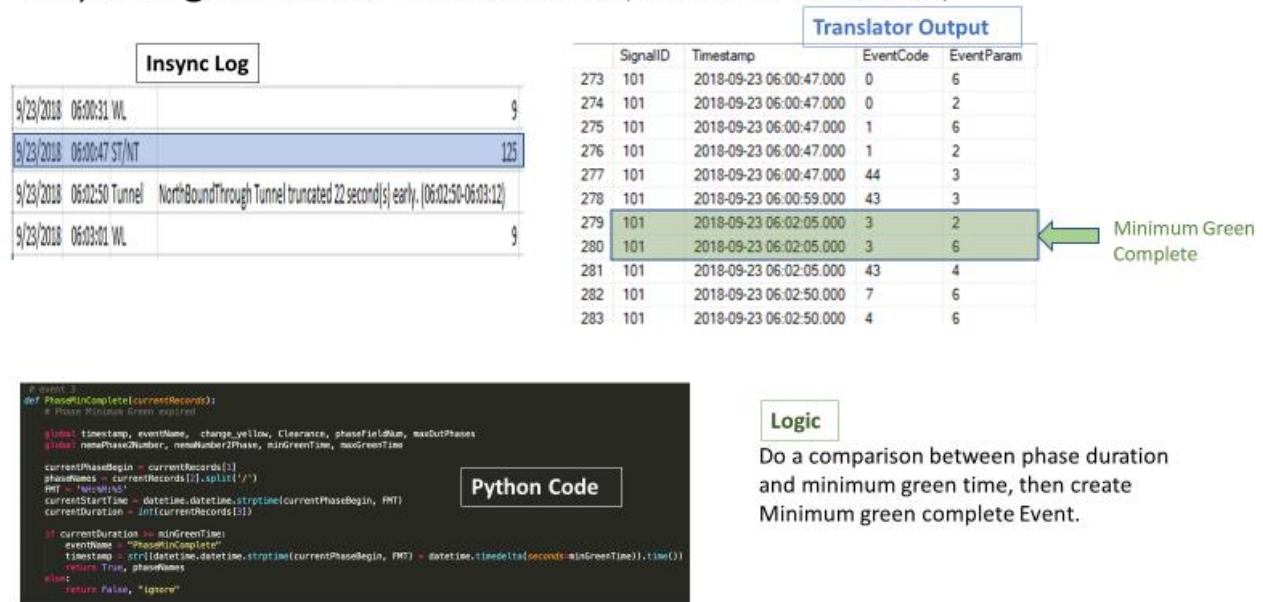


Figure 6 InSync Log Conversion for Event #3

Event 4 and 5: Phase Gap-out

Insync Signal Event Conversion (06:00:00-06:10:00)

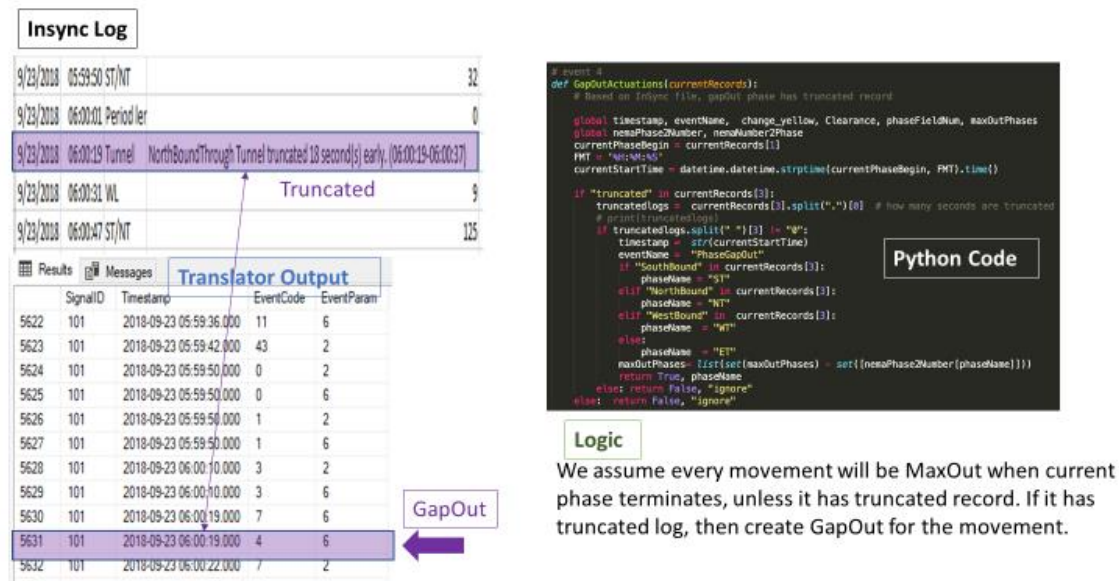


Figure 7 InSync Log Conversion for Event #4 and #5

Event 7: Phase Green Termination

Insync Signal Event Conversion (06:00:00-06:10:00)

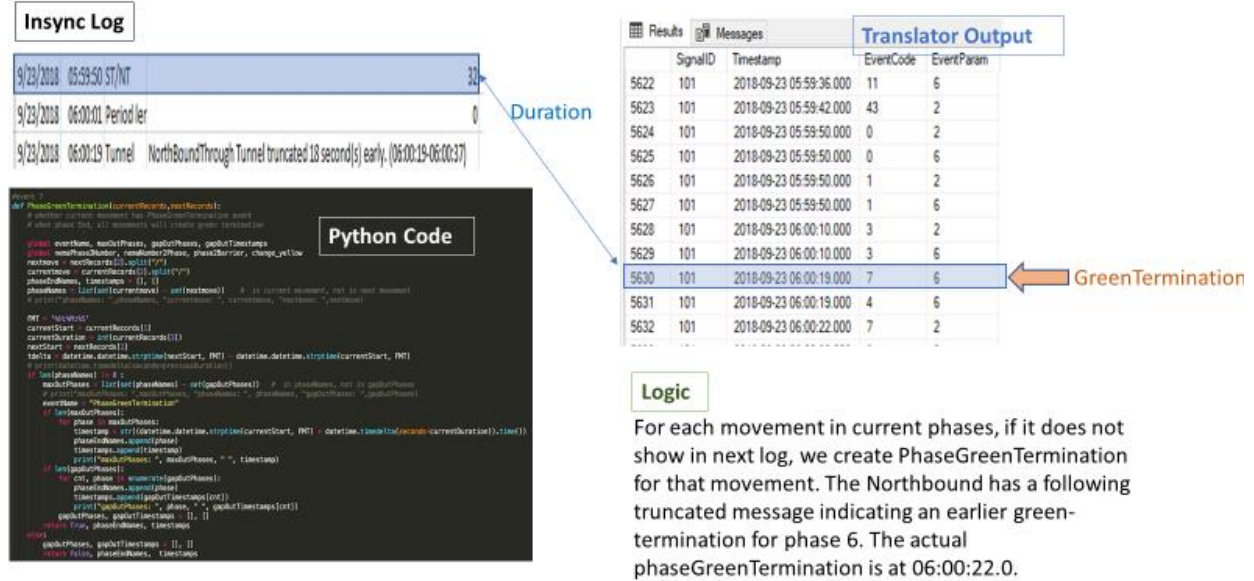


Figure 8 InSync Log Conversion for Event #7

Event 8 and 9: Phase Begin Yellow Clearance and Phase End Yellow Clearance

Note: Because the InSync log does not record the actual yellow interval time, the yellow change duration is read from metadata.

Insync Log Phase North/South Bound

[illegible]

For each movement that ends with current phase, we create yellow interval. The yellow interval duration is read from MetaData

YellowBegin
←
←
YellowEnd

Event 10 and 11: Phase Begin Red Clearance and Phase End Red Clearance

Insync Signal Event Conversion (06:00:00-06:10:00)

```
def PseudoRandomize(learnRate, numIterations):
    """
    Returns a pseudo-randomized version of the input matrix.
    """
    # Create a copy of the input matrix
    pseudoRandomizedMatrix = np.zeros((numIterations, numIterations))

    # Iterate over the input matrix
    for i in range(numIterations):
        # Iterate over the input matrix
        for j in range(numIterations):
            # Generate a random value
            randomValue = np.random.rand()

            # Calculate the pseudo-randomized value
            pseudoRandomizedValue = (randomValue * learnRate) + pseudoRandomizedMatrix[i][j]

            # Update the pseudo-randomized matrix
            pseudoRandomizedMatrix[i][j] = pseudoRandomizedValue

    return pseudoRandomizedMatrix

def PseudoRandomize(learnRate, numIterations):
    """
    Returns a pseudo-randomized version of the input matrix.
    """
    # Create a copy of the input matrix
    pseudoRandomizedMatrix = np.zeros((numIterations, numIterations))

    # Iterate over the input matrix
    for i in range(numIterations):
        # Iterate over the input matrix
        for j in range(numIterations):
            # Generate a random value
            randomValue = np.random.rand()

            # Calculate the pseudo-randomized value
            pseudoRandomizedValue = (randomValue * learnRate) + pseudoRandomizedMatrix[i][j]

            # Update the pseudo-randomized matrix
            pseudoRandomizedMatrix[i][j] = pseudoRandomizedValue

    return pseudoRandomizedMatrix
```

RedBegin
←
←
RedEnd

For each movement that ends with current phase, we create red clearance after yellow interval. The red clearance duration is read from Meta Data

30

Event for Pedestrians 21, 45: Pedestrian Begin Walk and Pedestrian Call Registered

Insync Signal Event Conversion

Event #21(Pedestrian Begin Walk), #45 (Pedestrian Call Registered)

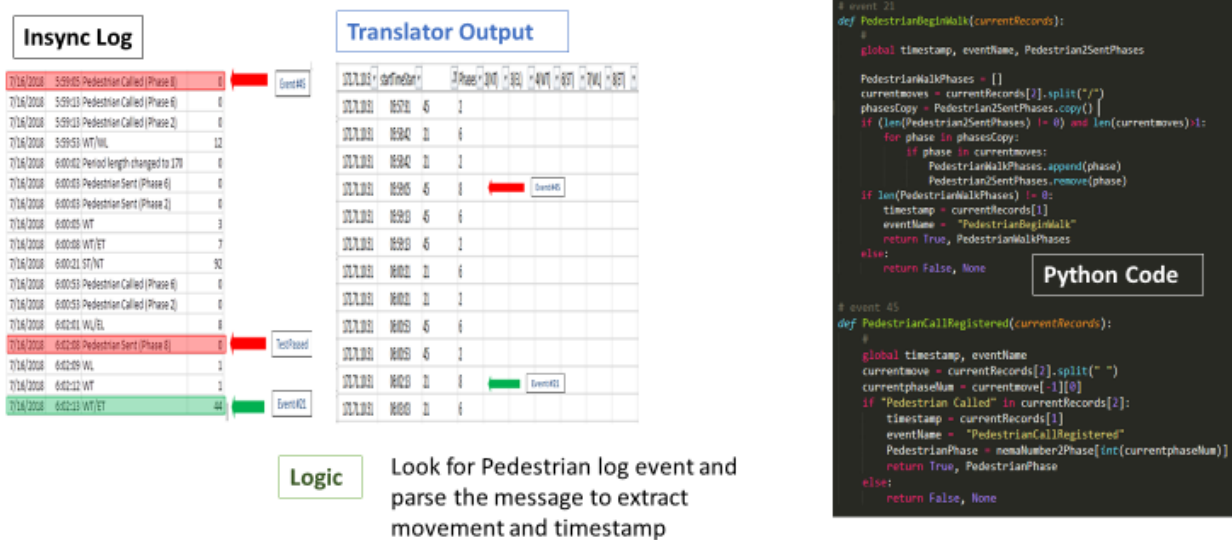


Figure 11 InSync Log Conversion for Event #21 and #45

SCATS: Event Translator Algorithm

All converted signal events for SCATS system are listed in Table 9.

Table 9 Converted Signal Events for SCATS System

| Code | Event | SCATS Translator Logic |
|------|-------------------------|---|
| 0 | Phase On | "Current Running" in SCATS message |
| 1 | Phase Begin Green | "Current Running" in SCATS message |
| 2 | Phase Check | "Phase demand" in SCATS message |
| 3 | Phase Min Complete | "Signal Group: SGx=off" in SCATS message |
| 4 | Phase Gap-Out | Green Duration < Maximum Green |
| 5 | Phase Max-Out | Green Duration > Maximum Green |
| 7 | Phase Green Termination | "Phase interval: Yellow" in SCATS message |

| | | |
|----|------------------------------|--|
| 8 | Phase Begin Yellow Clearance | "Phase interval: Yellow" in SCATS message |
| 9 | Phase End Yellow Clearance | "Phase interval: All Red" in SCATS message |
| 10 | Phase Begin Red Clearance | "Phase interval: All Red" in SCATS message |
| 11 | Phase End Red Clearance | keyword: "Phase termination" |
| 12 | Phase Inactive | If a movement not exist in a certain cycle, then create Phase Inactive |
| 21 | Pedestrian Begin Walk | keywords: "Walk" + "Active=On" |
| 22 | Pedestrian Begin Clearance | Keywords: "Walk" + "Active=Off" |
| 45 | Pedestrian Call Registered | keywords: "Walk" + "Demand=On" |

Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17 and Figure 18 explain how original SCATS log file can be converted to ATSPM standard event code.

Event 0 and 1: Phase on and Phase Begin Green

SCATS Signal Event Conversion

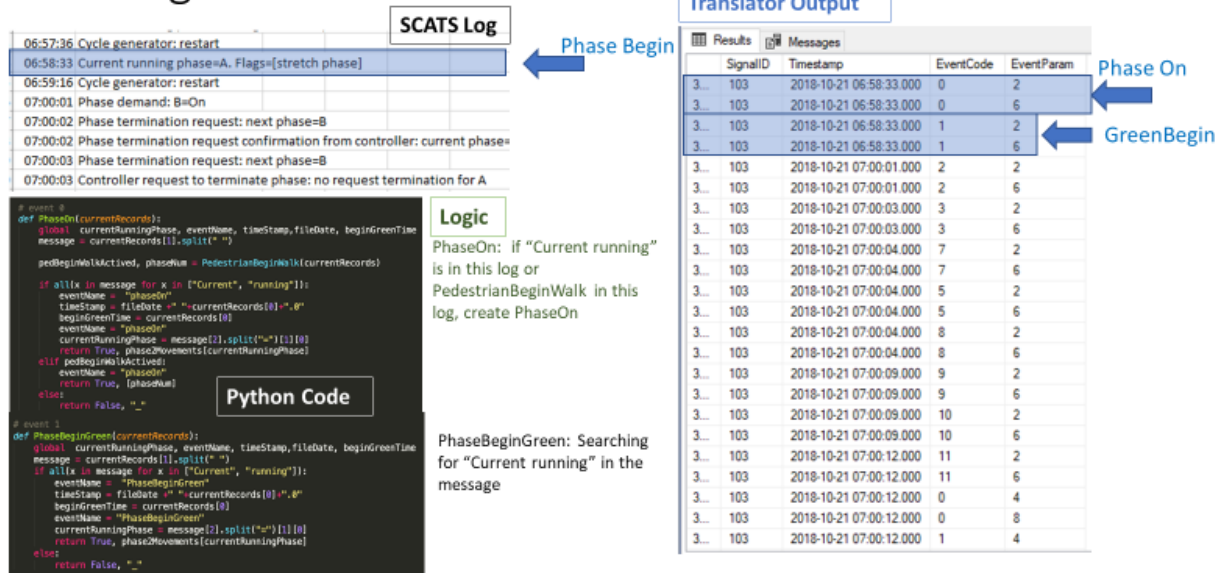


Figure 12 SCATS Log Conversion for Event #0 and #1

Event 2: Phase Check

SCATS Signal Event Conversion

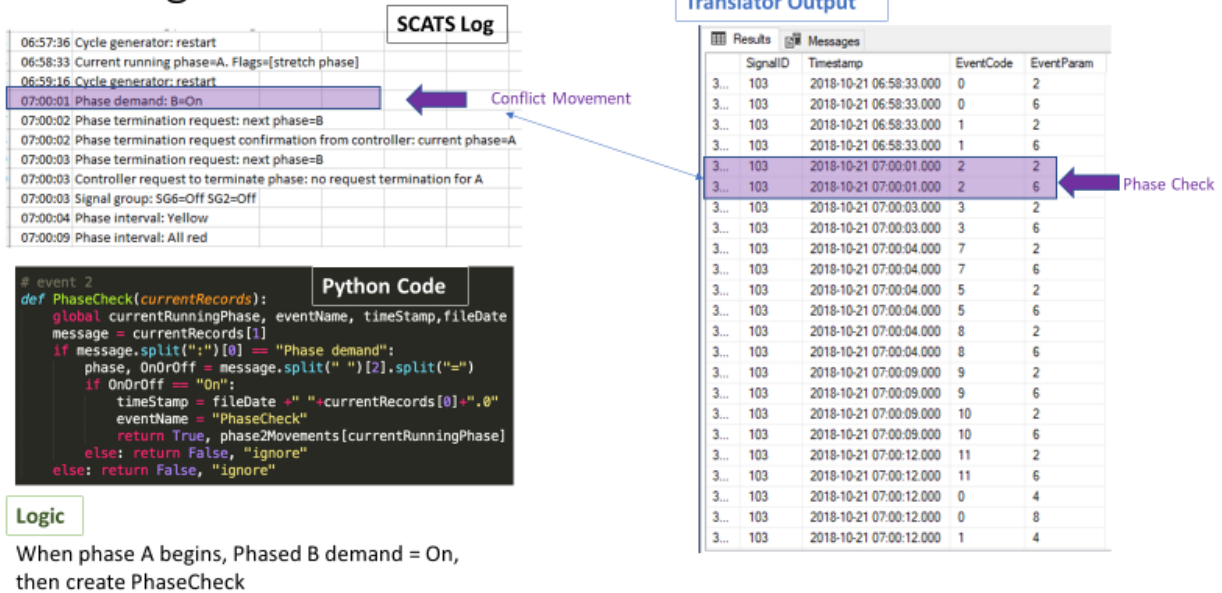


Figure 13 SCATS Log Conversion for Event #2

Event 3: Phase Min Complete

For SCATS, to calculate the phase minimum green, need to load minimum green time from metafile.

SCATS Signal Event Conversion

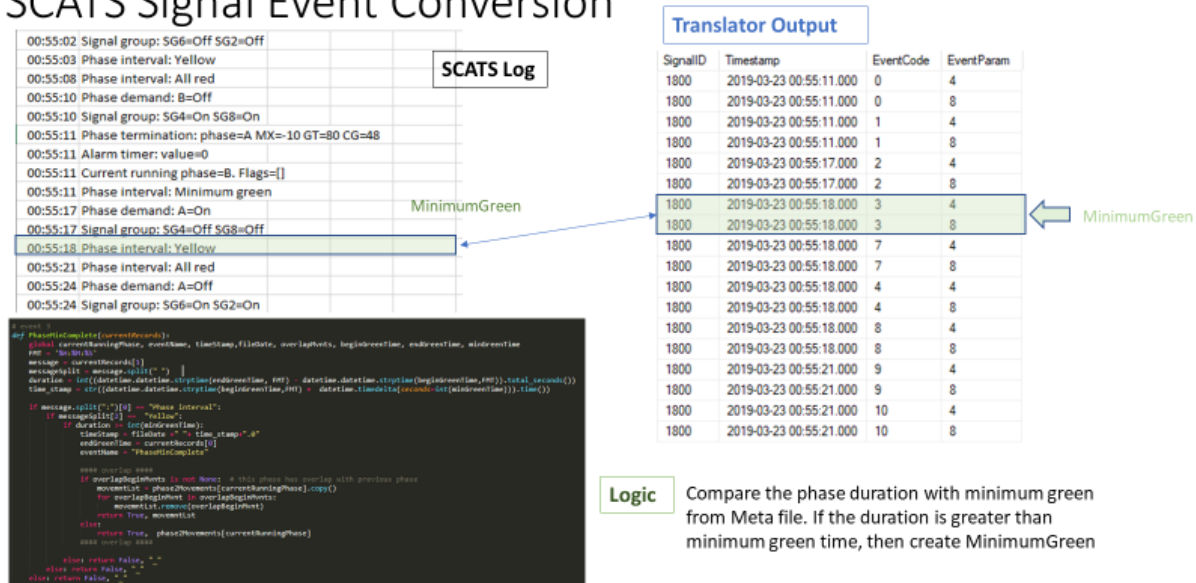


Figure 14 SCATS Log Conversion for Event #3

Event 4/5 and 7: Phase Gap-out/Phase Max-out, Phase Green Termination

SCATS Signal Event Conversion

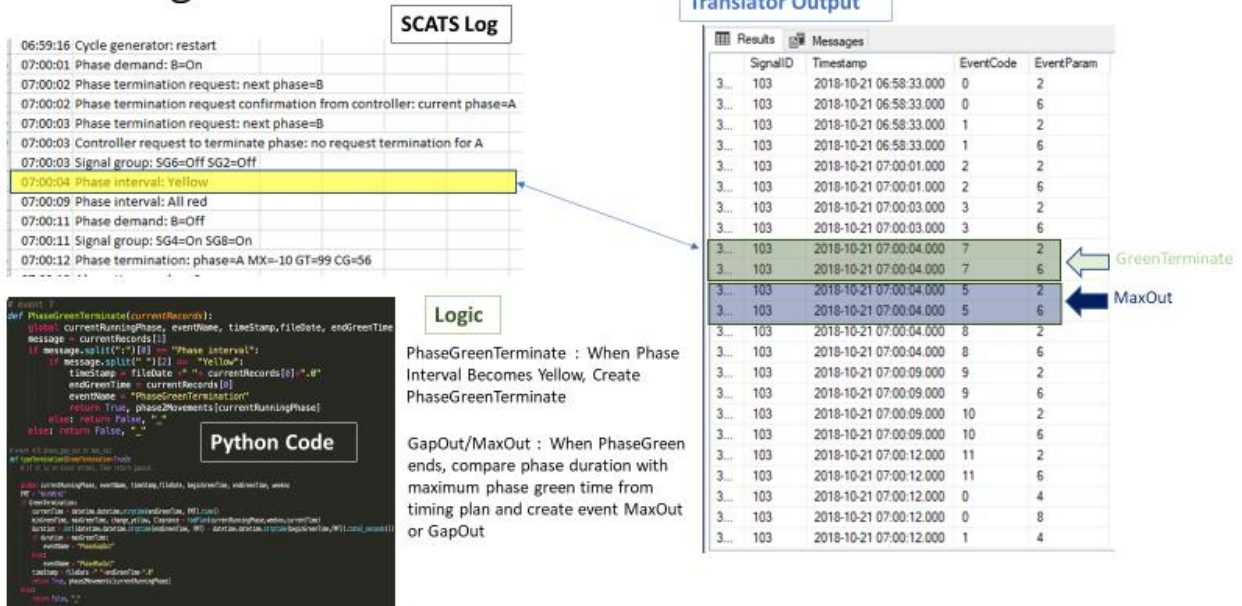


Figure 15 SCATS Log Conversion for Event # 4, #5 and #7

Event 8, 9 and 10: Phase Begin Yellow, End Yellow Clearance and Phase Red Clearance

SCATS Signal Event Conversion

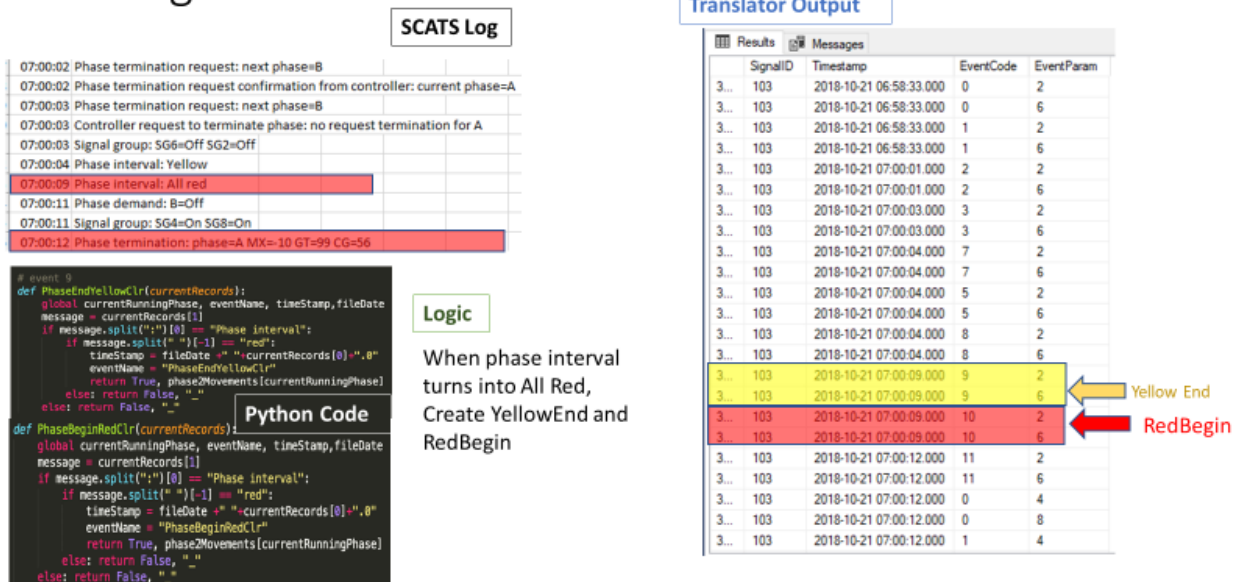


Figure 16 SCATS Log Conversion for Event #8, #9 and #10

Event 11: Phase End Red Clearance

SCATS Signal Event Conversion

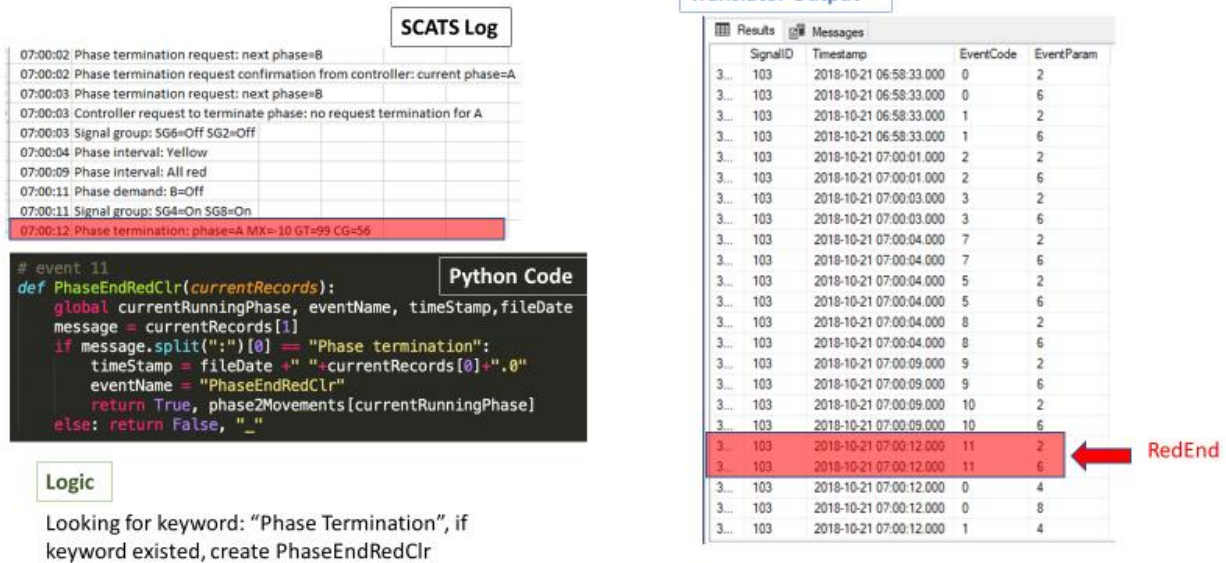


Figure 17 SCATS Log Conversion for Event #11

Event for Pedestrians 21 and 22: Pedestrian Begin Walk and Pedestrian Begin Clearance

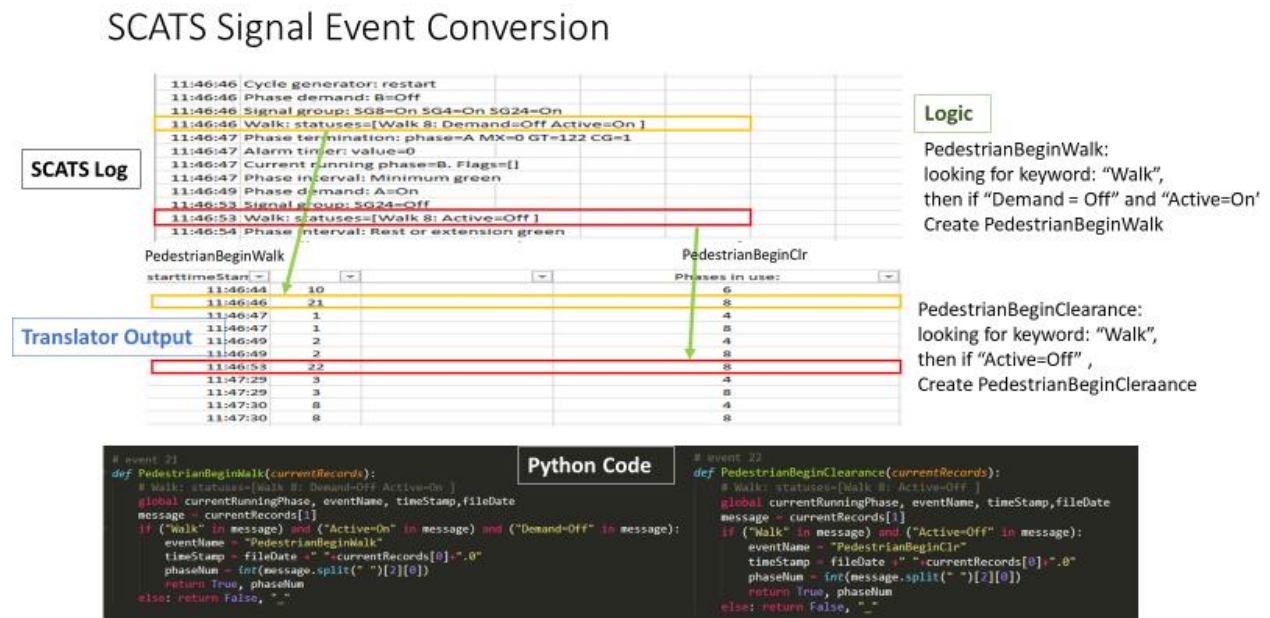


Figure 18 SCATS Log Conversion for Event #21 and #22

System Implementation

Introduction

NJDOT is actively deploying adaptive signal control technology. Figure 19 shows the existing, forthcoming and planned adaptive traffic signal control system in New Jersey for year 2019. The 11 blue corridors, consisting of 122 signals, are in concept design. Of the 5 operational corridors, the 76 signals are fully controlled by either InSync or SCATS. While 3 additional corridors (68 total signals) are under construction or in final design. 11 corridors consisting of 122 signals are in concept design stage.



Figure 19. NJDOT Adaptive Traffic Signal Control (ATSC) system, 2019 (Red: In Full Operation; Yellow: In Construction and Final Design; Blue: concept Development)

When to implement Automated Traffic Signal Performance Measures (ATSPM), it is important to take into account those existing, forthcoming and planned infrastructure. Things need to consider when deploying ATSPM:

- ATSPM Controller Setup
- ATSPM Server and Database Setup
- Intersection setup within the ATSPM Software
- Arterial network monitoring and assessment applications
- Detector Types and Layout

Figure 20 describes how the implemented ATSPM will impact traffic signal and system design process. From Figure 20, the feedback loop 1 is traditional traffic signal design process, where model parameters were designed and adjusted through Highway Capacity Software (HCS) or Synchro software. However, after implementing the ATSPM system, by continuously monitoring the system performance (Degree of Saturation, Queue, and Wait Times) will enable traffic management center to adjust and evaluate signal timing more efficiently with quick response.

Impact on Traffic Signal (and System) Design

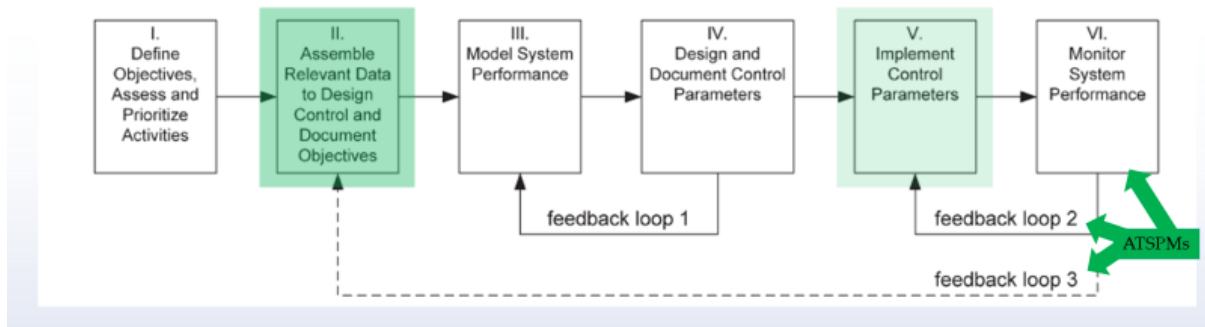


Figure 20 Impact of ATSPM on Traffic Signal and System Design

. Based on investigation of candidate corridors, the research teams provide instruction for the controller setup, web server, server, and database setup. The intersection setup and transportation network monitoring and assessment will be presented in the long-term deployment strategy section of this report. Figure 21 shows the location of candidate corridors, while intersections along Route 18 are shown in Figure 34.

Candidate Corridors

1. For route 1, NJDOT has InSync adaptive signal control system and good detector coverage, except for stop-bar detection. NJDOT has lane group detection and 5 advance detectors. It allows the generation of PCD, Phase Termination Chart, split failure, etc.
2. For route 31 and 36, which are two isolated signal control corridors, there are no detectors and only signal control data can be obtained. Four advanced performance measurements can be generated (Phase Termination Chart, Split Monitor, Preemption Details, Pedestrian Delay).
3. For Route 130 and 32, NJDOT have all types of detectors that can be used to generate different types of performance measurements.
4. Route 18: NJDOT has SCATS systems deployed on route 18. Route 18 has been selected as a main corridor for testing SCATS signal performance measurements.

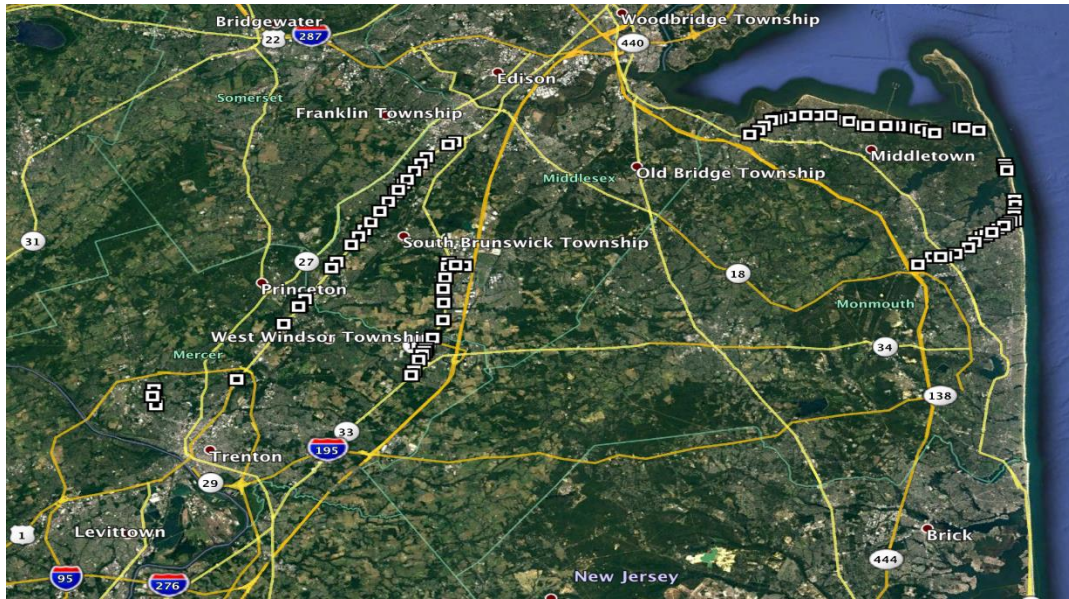


Figure 21 Investigated Signal Controlled Intersections

Route 1 has installed Peak ATC-1000 controllers used by Insync Adaptive Signal Control System. Route 130 has installed Naztec controllers used by SCATS system. Route 31, 32, and 36 have variable controller types. The total number of controllers is 92 for selected corridors, with controller types reflected in Figure 22. Deployment strategies take into consideration the infrastructure layout and controller types. Where controllers are installed with detectors, more advanced performance metrics can be obtained from the additional detector data.

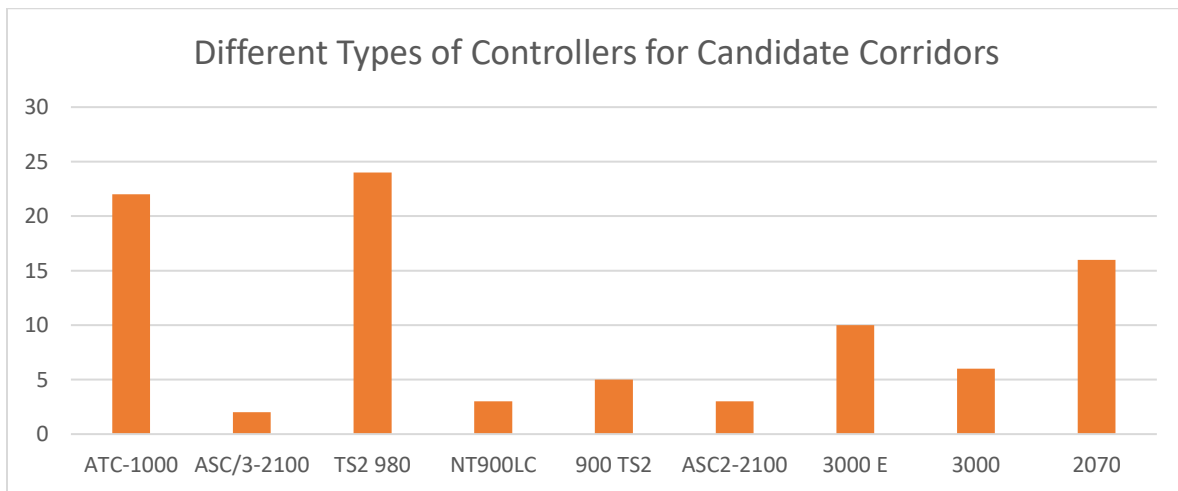


Figure 22 Controller Types on Candidate Corridors

Controller Setup

In the controller setup portion of this chapter, the controller investigation results are summarized to characterize the typical controllers used on a main corridor. Deployment strategies are presented based on four scenarios: existing low-resolution data system, existing adaptive system with high-resolution controllers, planned high-resolution controllers, and controllers with midblock detectors.

Existing low-resolution Controller ATSPM Open Source software can process data from any Linux-based controller. Non-Linux based low-resolution controllers will require extra translator for data file export. It also requires the installation of communication hardware to facilitate data transmission. Other hardware, such as Arduino board, may be used for data exportation/network/ftp setup.

Existing adaptive traffic control system (ATCS) For, existing high-resolution controllers, a data translation program was developed by the research team to translate Sydney Coordinated Adaptive Traffic System (SCATS) and InSync historical data into event records that can be recognized by ATSPM software.

- a. The SCATS system operates in near real-time, adjusting signal timings based on degree of saturation, traffic volumes and flows at intersections using inductive loop detector data. This data is then used to automatically adapt operation of traffic signal.
- b. The InSync ATCS constantly gathers traffic condition data, such as queue length and waiting time, to adapt to actual traffic demand. It analyzes, optimizes and adapts the signal timings to fluctuating traffic demands.

The procedure to configure event translation programs for SCATS and InSync are presented in the appendix.

Planned High-resolution Controller Considering the high-resolution controller, including Econolite ASC/3-2100/1000, this ATSPM software is free through the web-based FHWA Open Source Application Data Portal (OSADP) (FHWA, 2017). The open source code requires DOT to procure their own data storage hardware and database software. The other way is through packages provided by Vendors. However, the vendor options have recurring fees, so life cycle costs should be considered.

Controllers with Midblock Detectors and Probe Data For those controllers with midblock detectors or probe data, it requires the operating agency to configure detector when deploying an ATSPM system. ATSPM will work with any type of detector that is capable of counting vehicles (i.e. loops, video, pucks, radar). The only exception to this is the speed measure, where Utah DOT's Automated Signal Performance Measures for speeds will only work with the Wavetronix Advance Smartsensor) (Georgia DOT, 2016).

Server and Database Setup

The agency managing the ATSPM needs to acquire equipment that can store the unprocessed hi-resolution data, database software, and ATSPM software. This type of data storage requires a server with the appropriate processing power, memory, and disk configuration to install it at the Arterial Management Center (AMC) office. It is critical to coordinate with IT for integration into the network and to make it accessible to the necessary stakeholders. The other option is to deploy software using Cloud services to avoid maintaining physical equipment at the central office. Many cloud service companies can provide cloud-based solutions. Cloud-based solutions require IT coordination for firewall access.

Long-term Development Plan

The long-term deployment plan or system lifecycle is described in the V-model (Figure 23). Firstly, the long-term operational goal based on national or statewide initiative needs to be identified. Performance metrics will be established with consideration for operation goals. After which an infrastructure investigation will be conducted, followed by both high-level and low-level design. Implementation is at the bottom part of this life-cycle. On the right-hand side of the V-model is the verification and validation process. The testing phases include intersection testing, corridor testing and network testing. The majority of the hardware and software compatibility issues will be addressed during verification and testing.

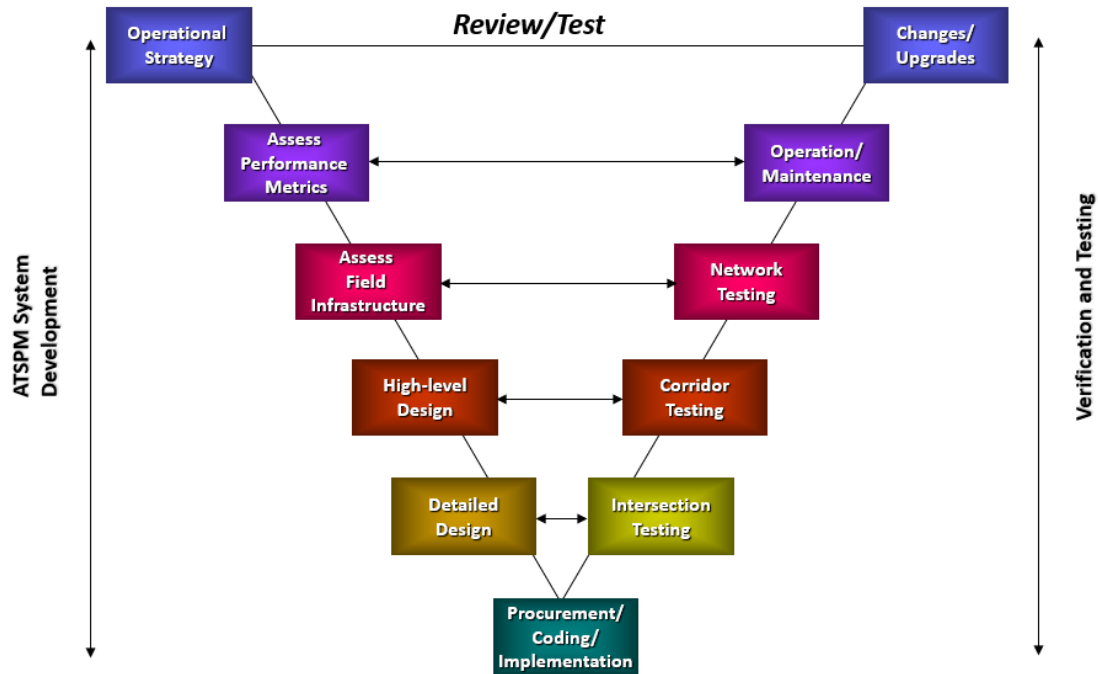


Figure 23 Long-term Deployment Plan

The Table 10 summarizes how to setup software and hardware for different controllers.

Table 10 ATSPM System Components for Different Controller Types

| Controller Tier | Controller Examples | ATSPM | Event Translators | Hardware | Performance Metrics |
|-------------------------------------|--|---------------------------------------|---------------------------|---|--|
| Existing ATSC Controllers | InSync, SCATS | Original Version | ATSC Translator | Database servers, Web servers | <i>Purdue Coordination Diagram</i> , <i>Purdue Phase Termination Charts</i> , <i>Split Monitor</i> , <i>Pedestrian Delay</i> |
| Planned High-Resolution Controllers | Econolite ASC/3-2100/1000 Peek ATC-1000 | Original Version + controller config. | ATSPM built-in translator | <i>Cellular communication and modem</i> at controller boxes | Same as the above |
| With Midblock, Advance | RTMS, Wavetrionix | Original Version + Detector | Detector translator | Detectors and communication/ftp, Server | + Approach volumes, speeds, delay, travel time |

| Detectors (PCDs) and Probe Data | | config. | | data | + PCDs (Advanced) |
|-------------------------------------|------------|---|-------------------------------|---|-------------------------------|
| Existing Low-Resolution Controllers | Peek 3000E | Original Version + controller probe + communication + ftp config. | Low-res controller translator | Cellular/Fiber communication, Arduino board for data extraction/network/ftp | Potentially, PCD, PPTC, Split |

Result Analysis

In this section, the performance metrics generated are presented along with a discussing on issues of signal performance measurements. Three important performance measurements that characterize the cycle by cycle traffic signal performance (Purdue Coordination Diagrams (PCD's), Purdue Phase Termination (PPT), and Split Monitor) are presented. The Pedestrian delay is also demonstrated in this session.

- **PCD:** The PCD's are used to identify oversaturated or under saturated splits for the coordinated phases, the effects of early return of green and coordinated phase actuations, impacts of queuing, adjacent signal synchronization, etc. In reading the PCD's, the green duration is shown between the green and yellow lines; The yellow duration is shown between the yellow and red lines; and the red phase duration is underneath the green line. On the PCD chart, Arrival on Green (AoG) is the percent of vehicles arriving during the green phase, which requires vehicle detector information. Another important indicator is Green Time (GT), which is the percent of green split time for the phase and PR is the Platoon Ratio, which also requires vehicle detection.
- **PPT:** PPT chart shows how each phase terminates when it changes from green to red, if the termination occurred by a gapout, a maxout / forceoff, or skip. A gapout means that not all of the programmed time was used. All the programmed time was used will lead to either a maxout or forceoff depending on the signal configuration. A maxout occurs during fully actuated (free) operations, while forceoff occurs during coordination. A skip means that the phase was not active and did not turn on, usually a function of the vehicle detection at the approach. In addition, the termination can be evaluated by consecutive occurrences in an approach. For example, if three (range is between 1 and 5) gapouts or skips occurred in an approach. This feature is helpful in areas where traffic volume fluctuations are high. Also shown the pedestrian activations for each phase. What this measure does not show is the amount of gapout time remaining if a gapout occurred.
- **Split Monitor:** This split monitor is used to show the amount of split time each phase uses. This measure shows the amount of split time (green, yellow and all-red) used by the various phases at the intersection.

InSync ATSPM Results

InSync Results: US 1 at Henderson Rd. Intersection (See Figure 24).

InSync controller can provide queue length estimation through Samsung camera detector, estimate waiting time through stop bar detector, anticipate the rate of vehicles, estimated arrival rates.

The meta data for this intersection is reflected in Table 11.

Table 11 Meta data for US-1 at Henderson Intersection

| intersectionID | phaseID | phaseNumber | phaseMove | minGreen | maxGreen | planID | planStartTime | planEndTime | PlanDOW | Change | Clearance |
|----------------|---------|-------------|-----------|----------|----------|--------|---------------|-------------|---------------|--------|-----------|
| 102 | 1 | 2/6 | ST/NT | 95 | 131 | None | None | None | 1-2-3-4-5-6-7 | 6 | 2 |
| 102 | 2 | 3/8 | EL/ET | 5 | 14 | None | None | None | 1-2-3-4-5-6-7 | 3 | 3 |
| 102 | 4 | 8 | ET | 5 | 14 | None | None | None | 1-2-3-4-5-6-7 | 3 | 3 |

| | | | | | | | | | | | |
|-----|---|-----|-------|---|----|------|------|------|---------------|---|---|
| 102 | 3 | 4/8 | WT/ET | 7 | 44 | None | None | None | 1-2-3-4-5-6-7 | 4 | 2 |
|-----|---|-----|-------|---|----|------|------|------|---------------|---|---|

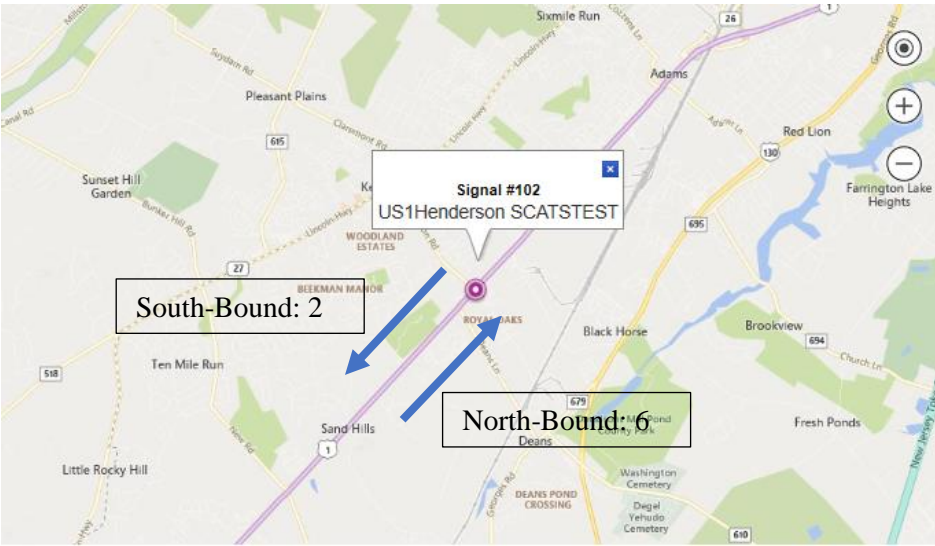
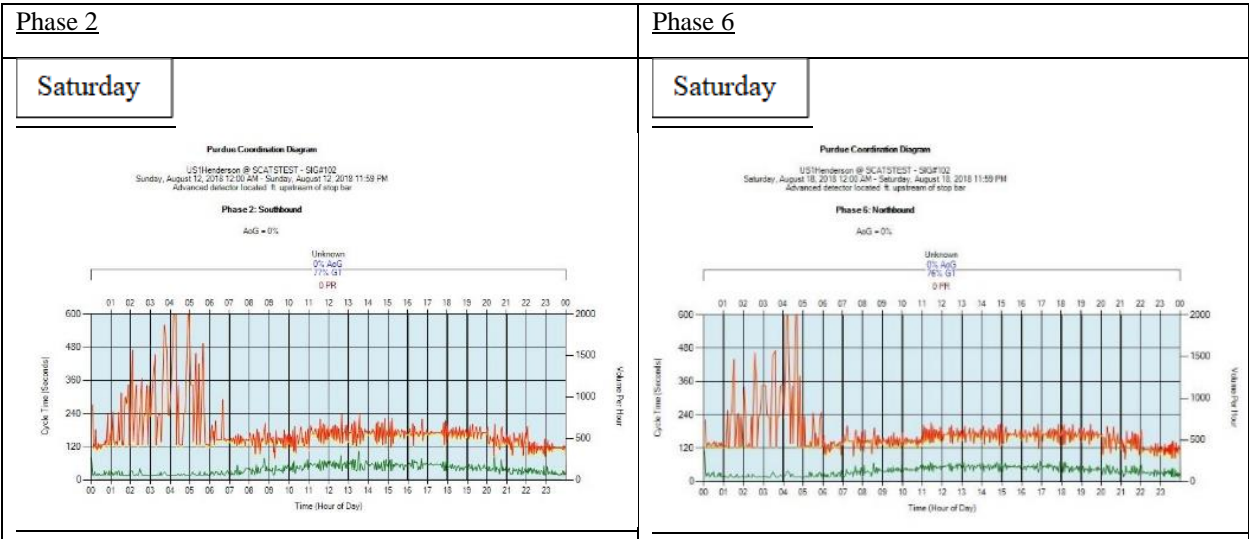


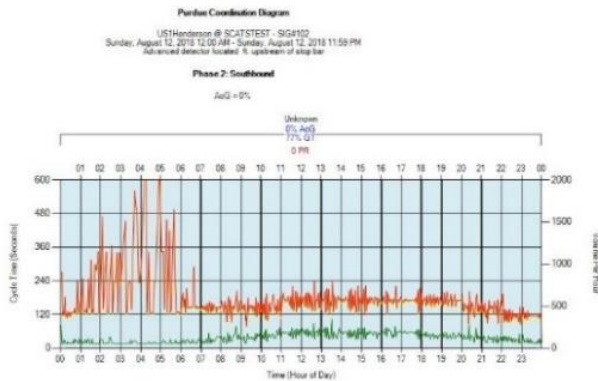
Figure 24 US 1 at Henderson Rd Intersection

The PCD for US1 & Henderson is shown in Figure 25 (Phase 2 &6) and Figure 26 (Phase 4 & 8o).

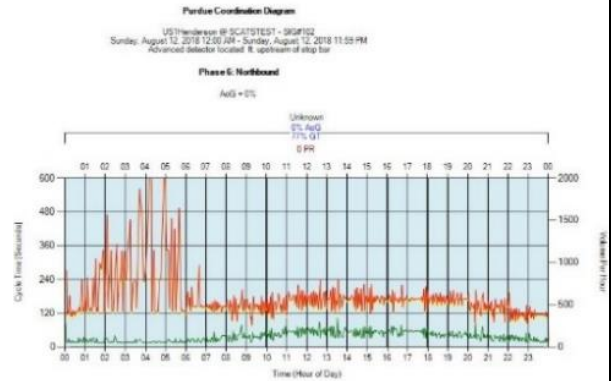
1. Phase 2&6 PCDs



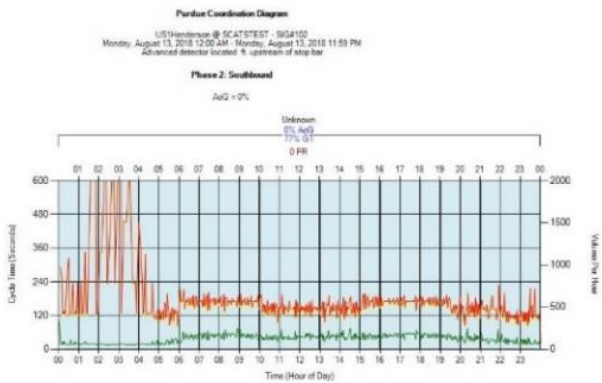
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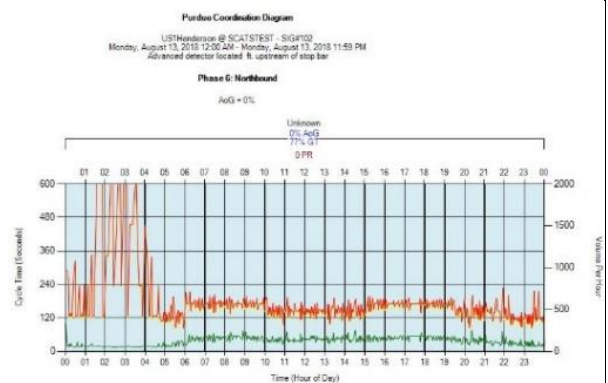
Sunday



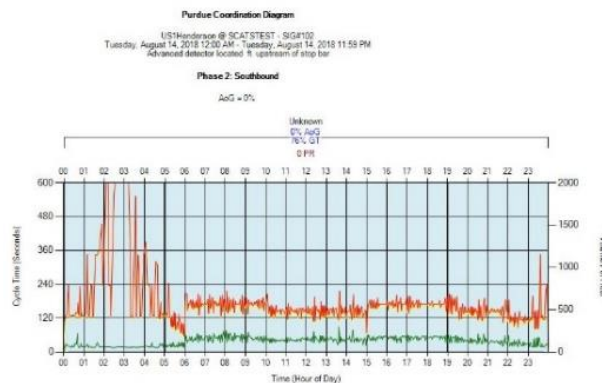
Monday



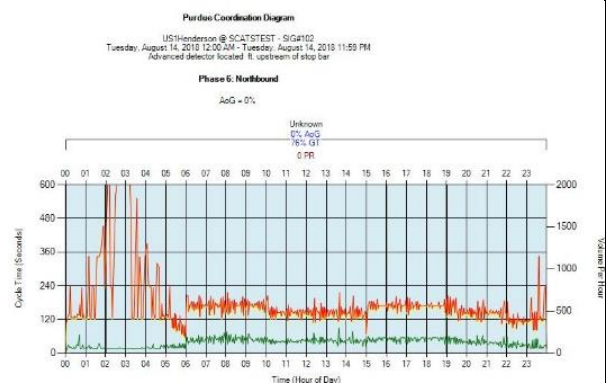
Monday



Tuesday



Tuesday



Wednesday

Wednesday

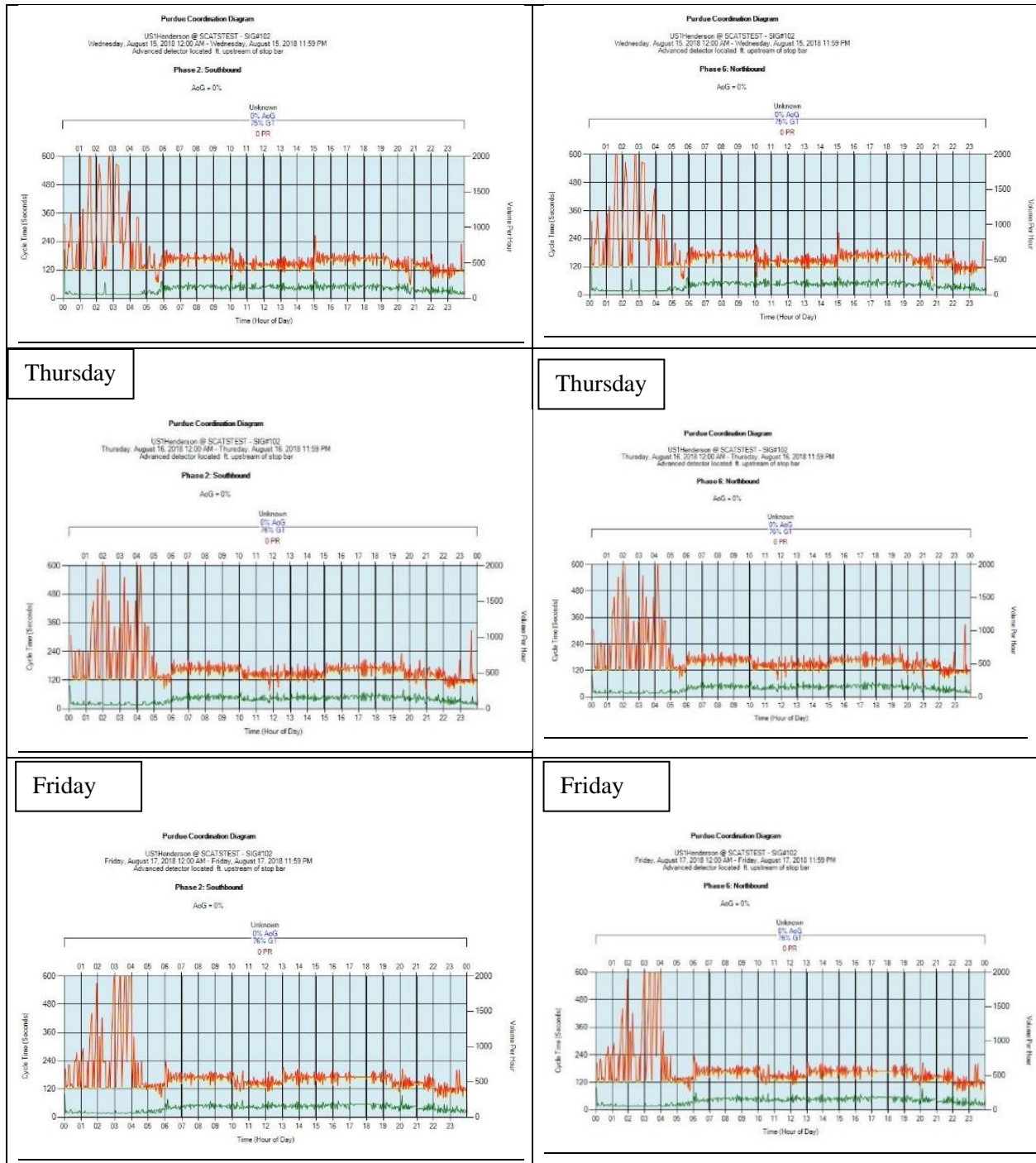
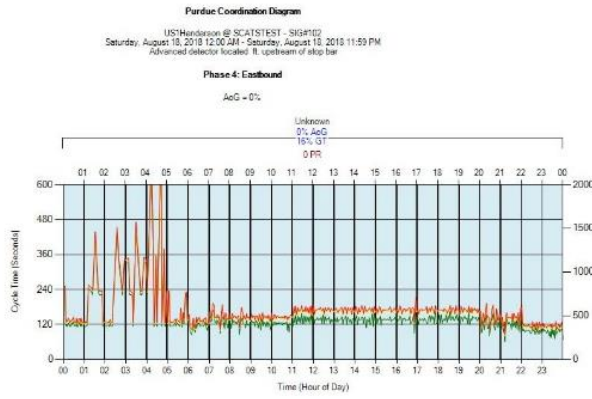
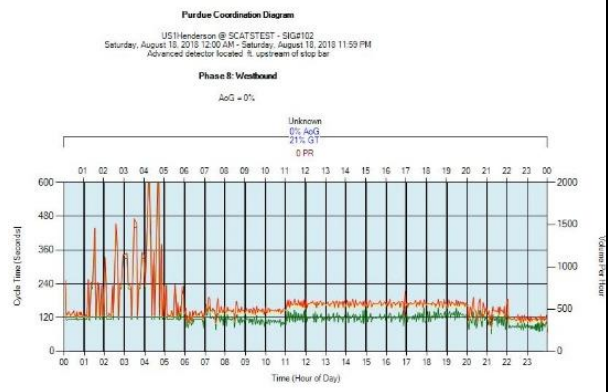


Figure 25 One-week PCDs from US 1 at Henderson Rd Intersection for Phase 2 and Phase 6

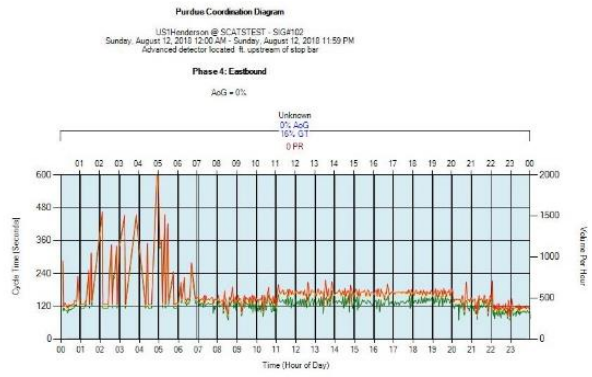
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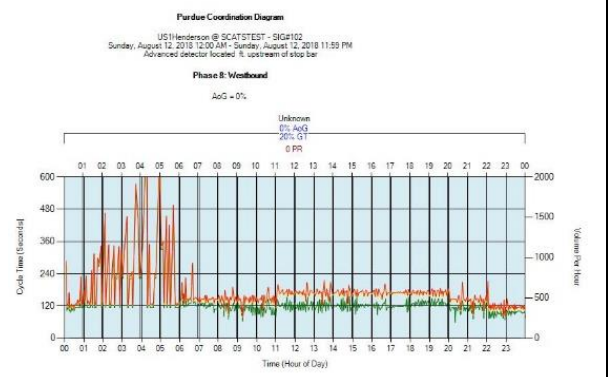
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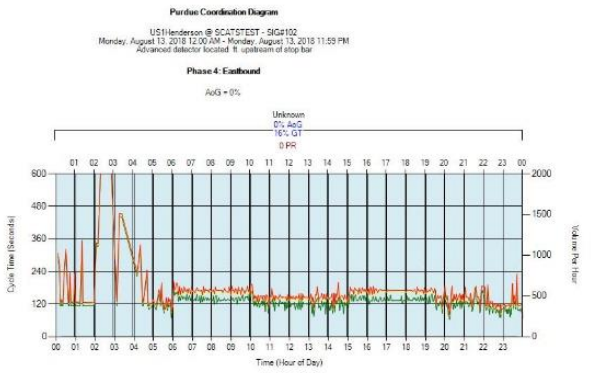
Sunday



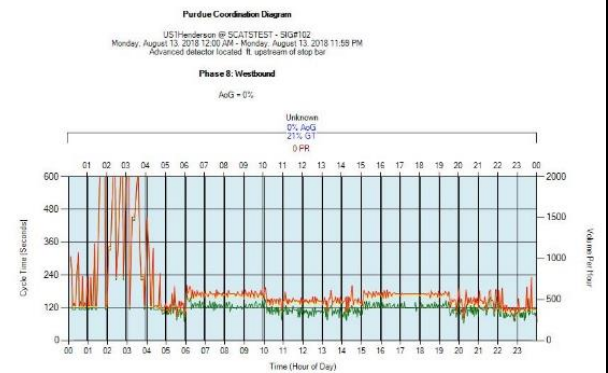
Sunday



Monday

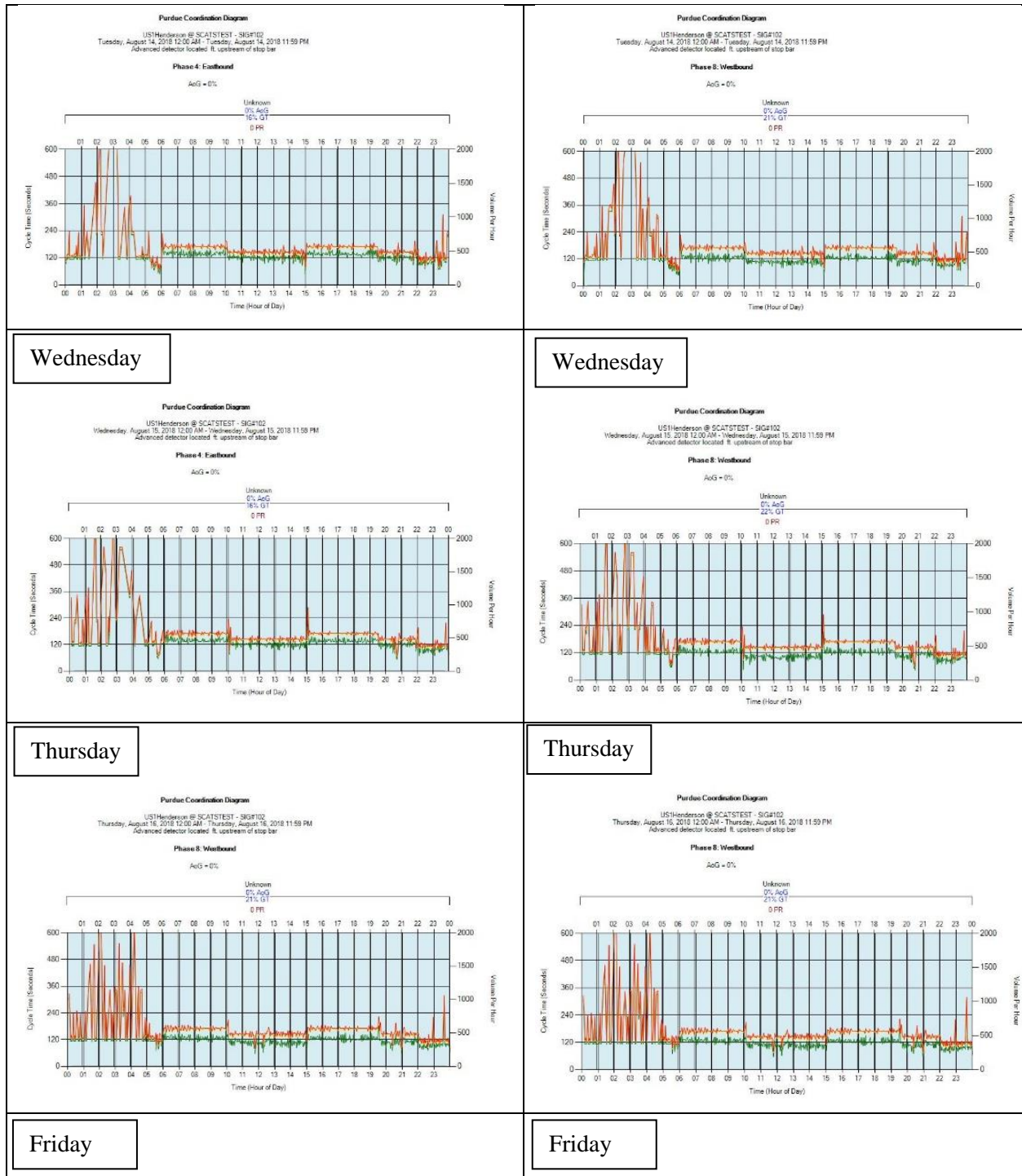


Monday



Tuesday

Tuesday



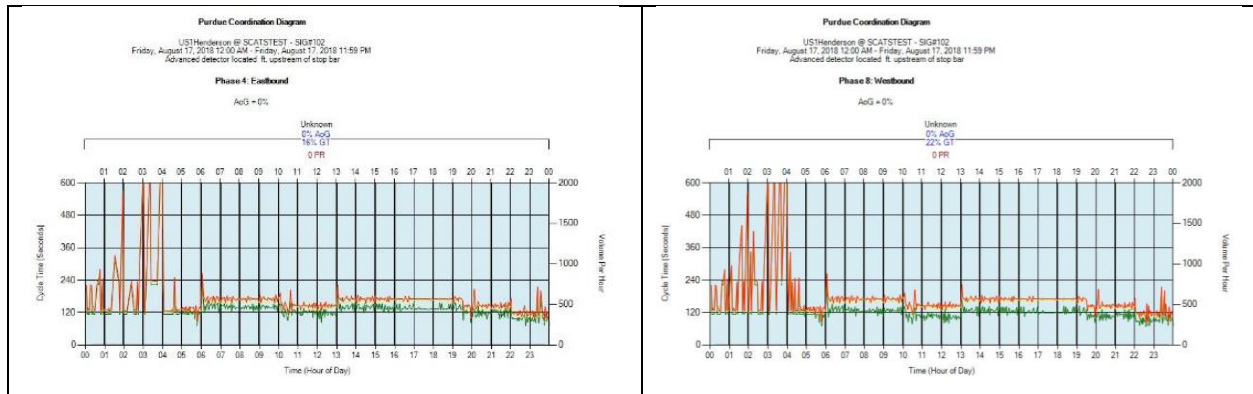
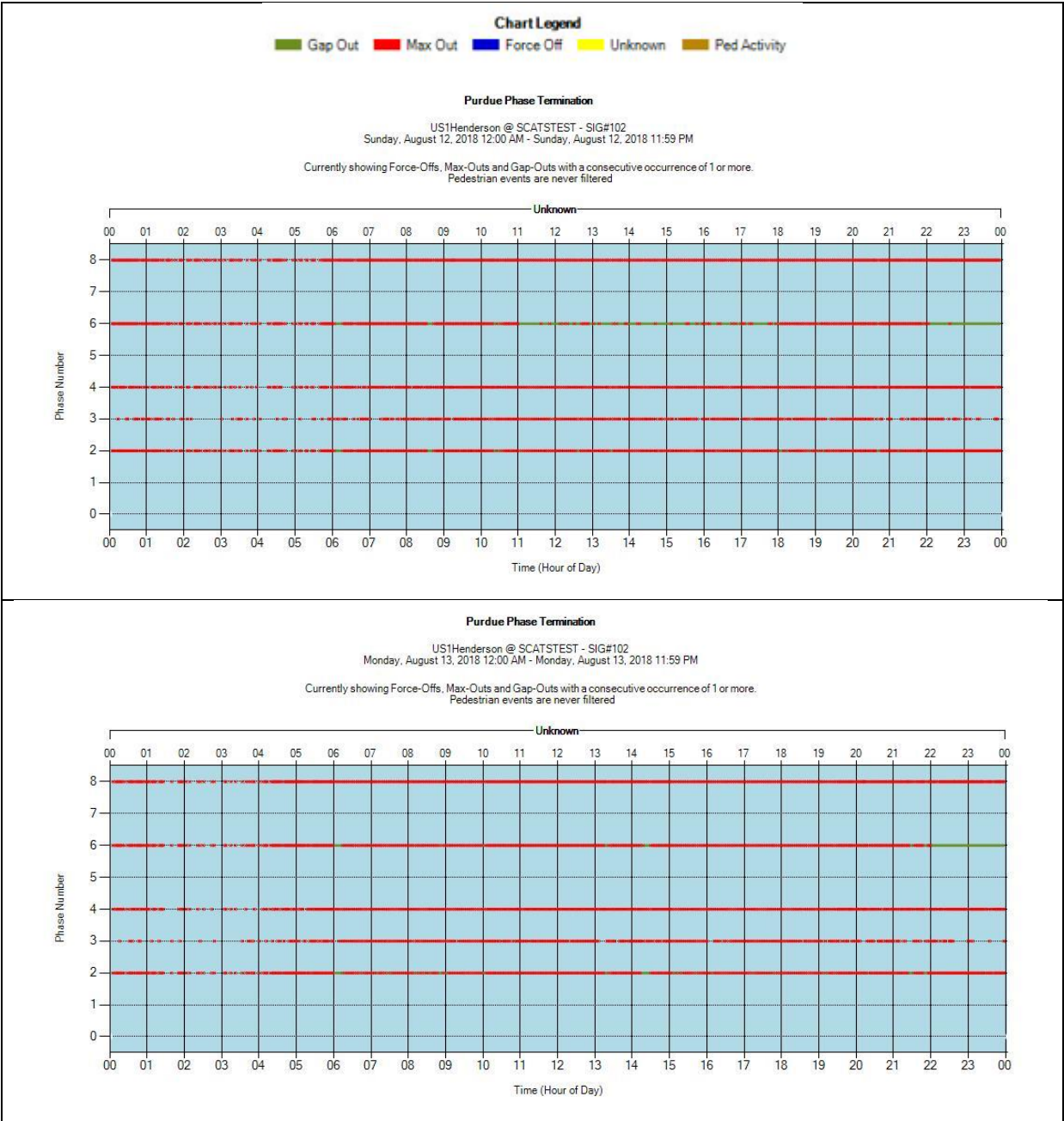


Figure 26 One-week PCDs from US 1 at Henderson Rd Intersection for Phase 4 and Phase 8

From the PCDs in Figure 25 and Figure 26, the InSync system cycle and phase operations are characterized and appear to be functioning as expected. Phase 2 & 6 are exactly the same (as expected) based on the directive, but the real difference is in the Phase 4 and 8, where 8 is given more green time. The main street sitting in green as the side streets and left turns are being skipped during the late-night hours, as demonstrated by the long vertical red lines. The short vertical red lines show skipping of the side street/left turns or a late start of green for the side street or left turn.

In Figure 27, phase 6 (northbound through) has the most gap out.

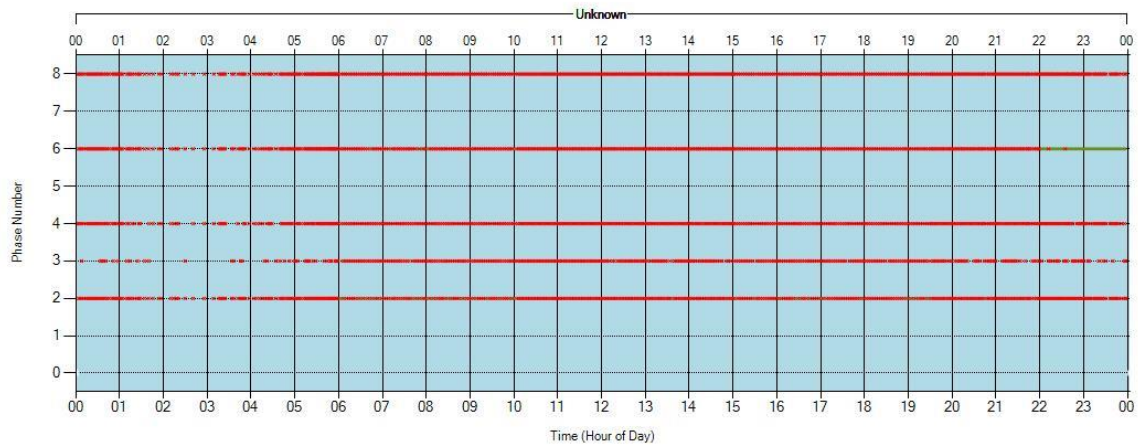
In the Figure 28, we can read the split information for each phase, including 85% split percentage, average split duration, split termination type, and the percentage of skipped cycles. Greens show gapouts, reds show maxouts, blues show forceoffs and yellows show pedestrian activations.



Purdue Phase Termination

US1Henderson @ SCATSTEST - SIG#102
Tuesday, August 14, 2018 12:00 AM - Tuesday, August 14, 2018 11:59 PM

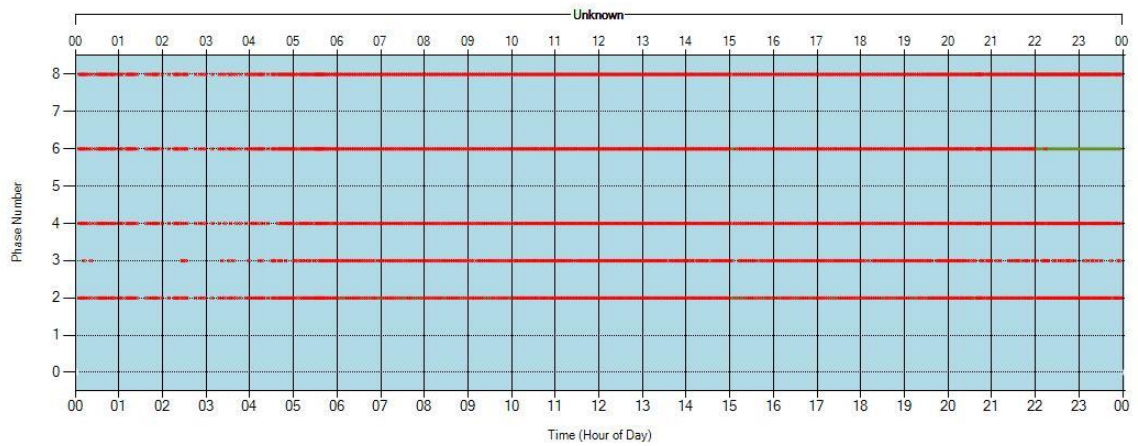
Currently showing Force-Offs, Max-Outs and Gap-Outs with a consecutive occurrence of 1 or more.
Pedestrian events are never filtered

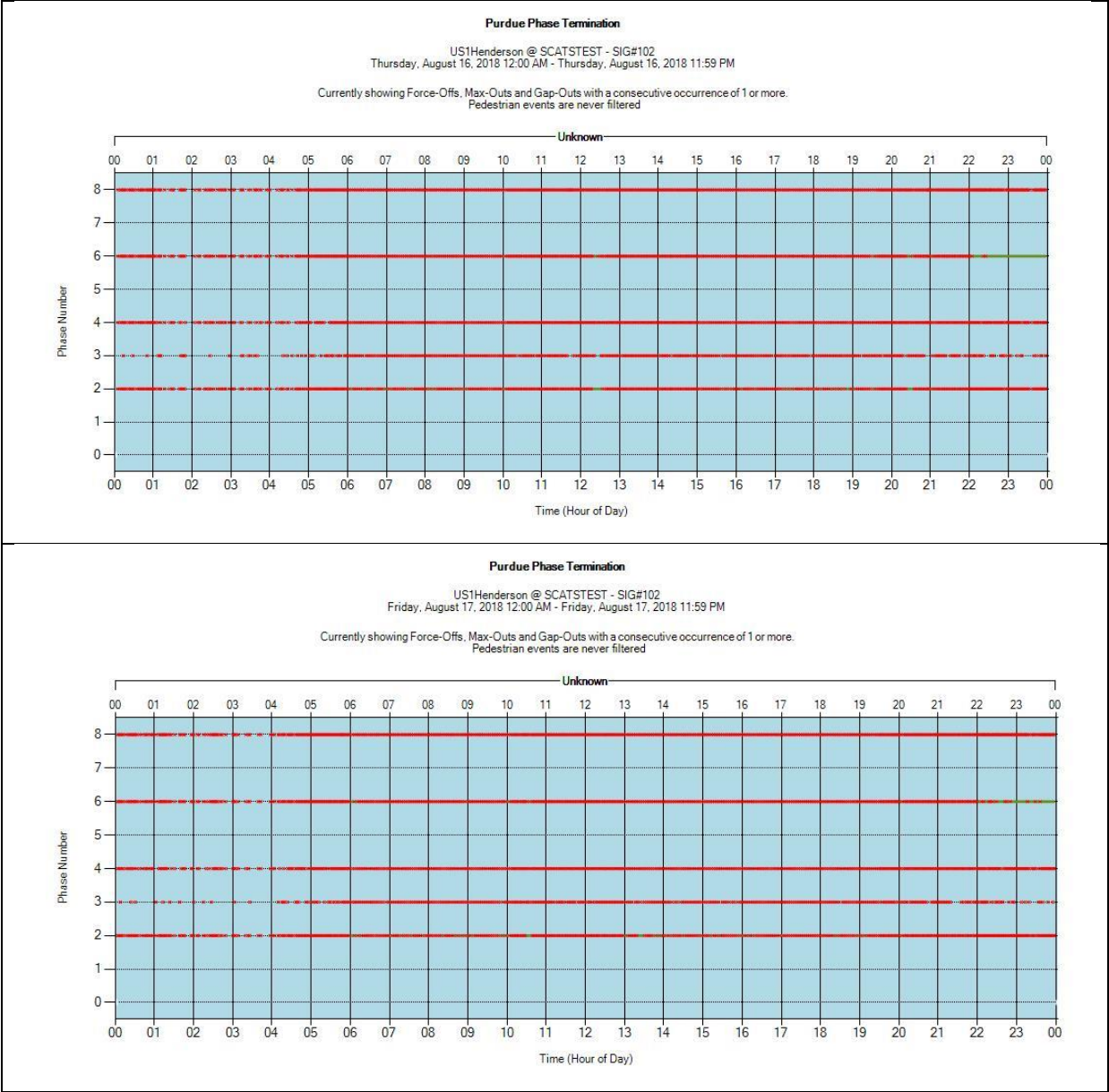


Purdue Phase Termination

US1Henderson @ SCATSTEST - SIG#102
Wednesday, August 15, 2018 12:00 AM - Wednesday, August 15, 2018 11:59 PM

Currently showing Force-Offs, Max-Outs and Gap-Outs with a consecutive occurrence of 1 or more.
Pedestrian events are never filtered





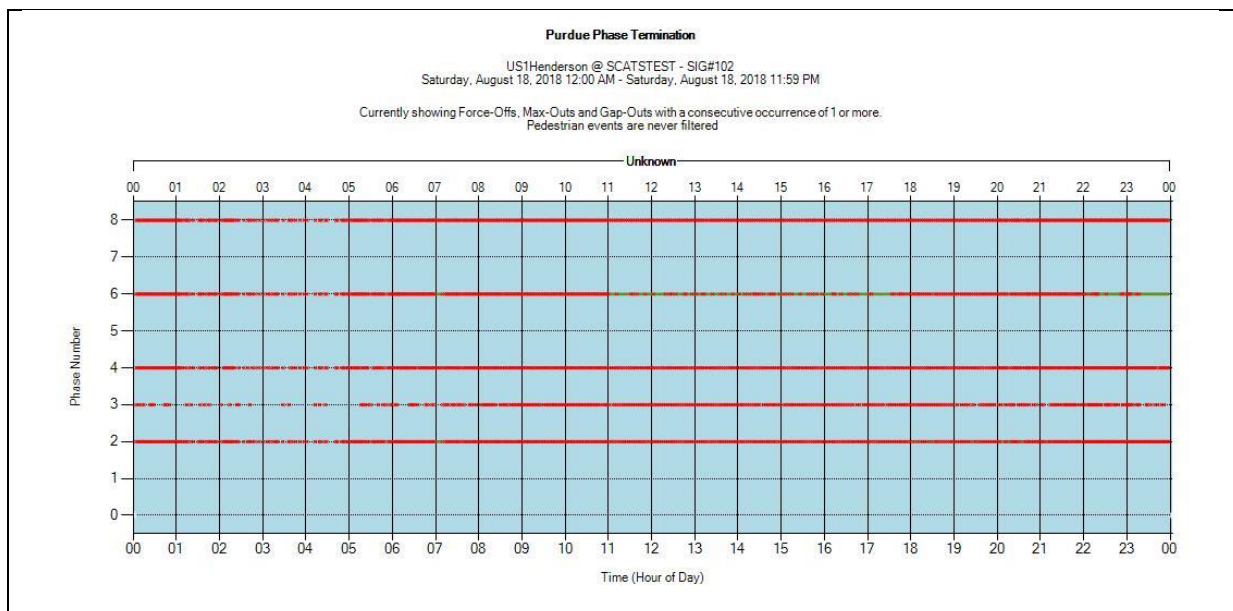
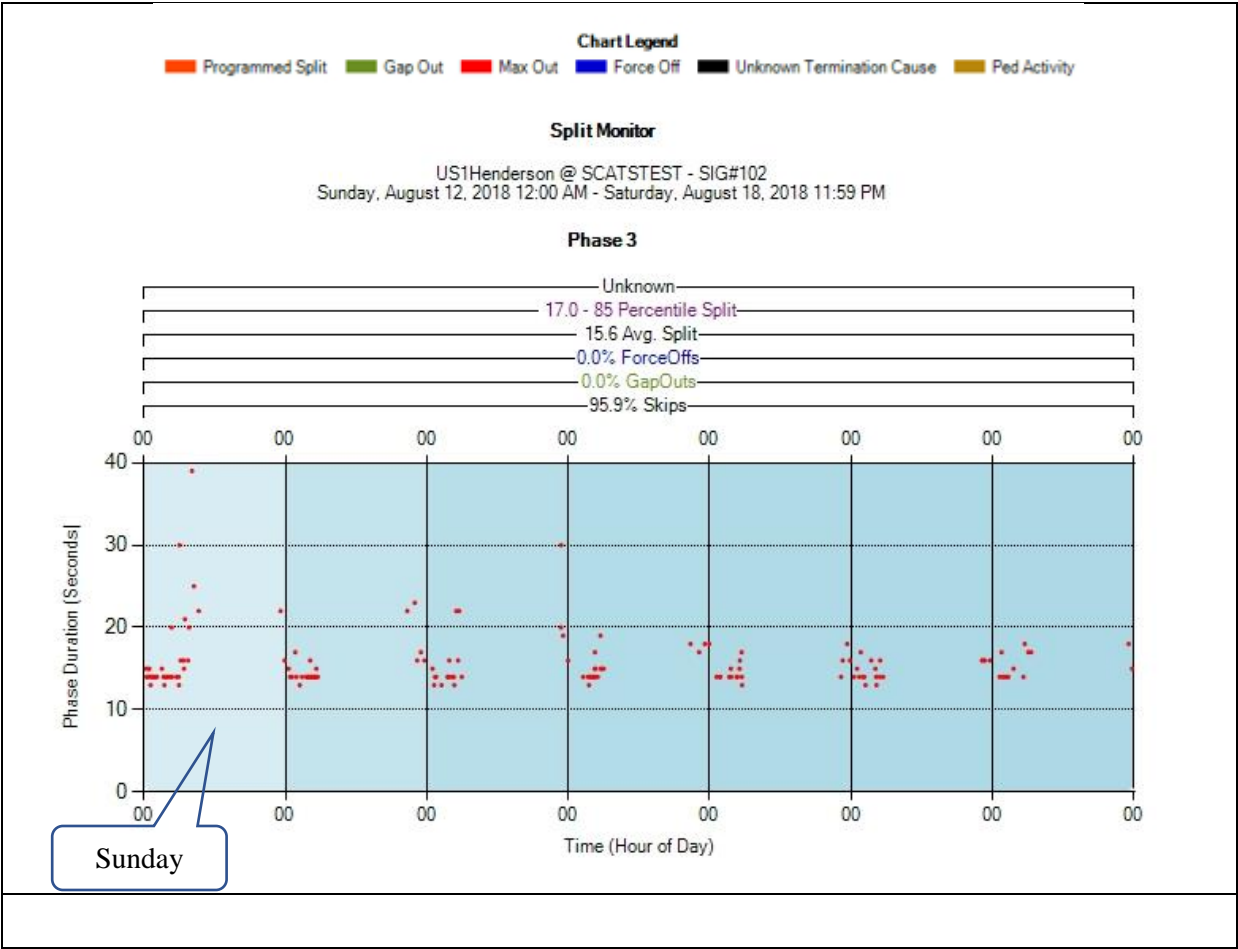


Figure 27 One-week PPTs from US 1 at Henderson Rd Intersection



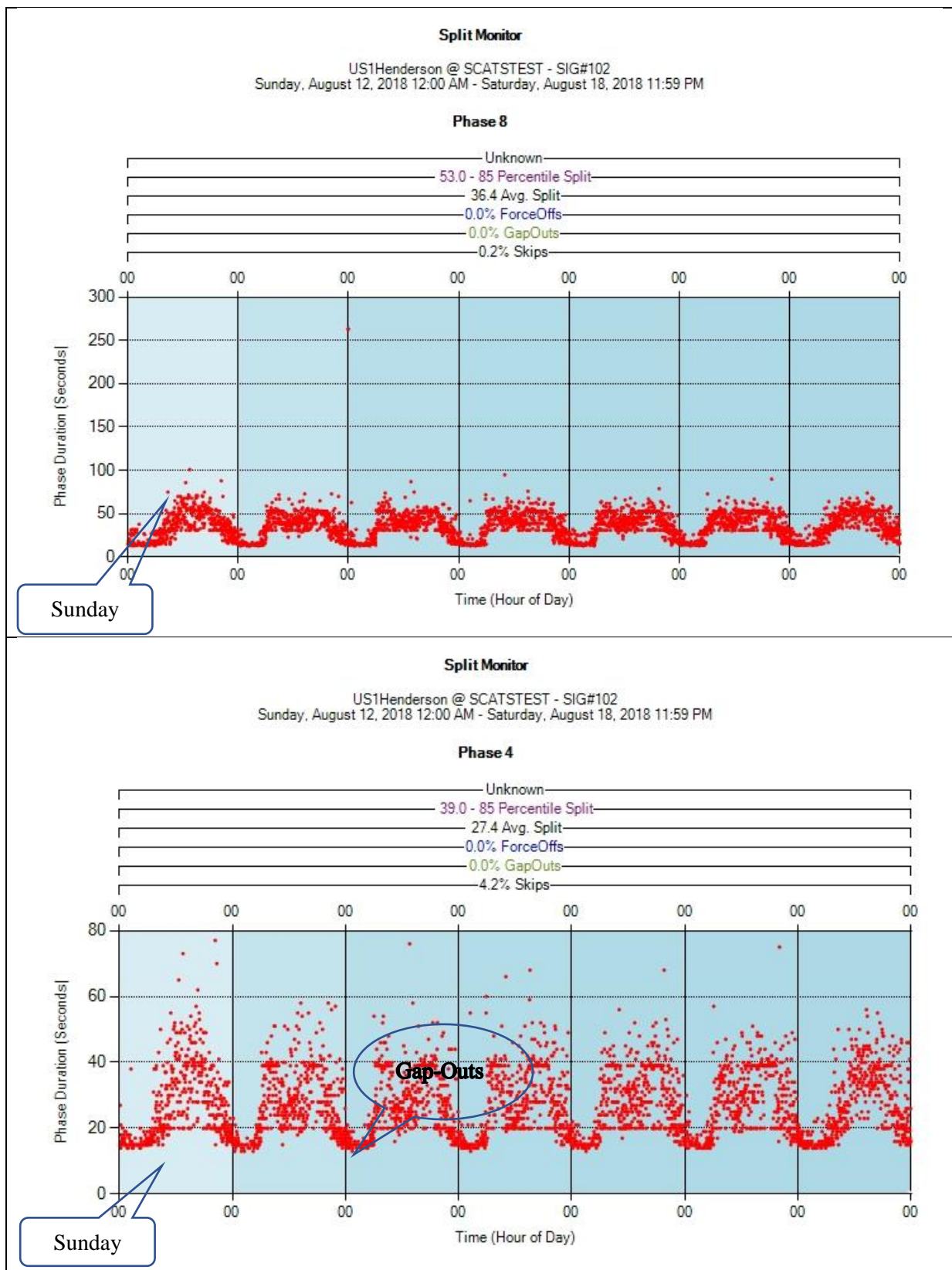


Figure 28 Split Monitor for Different Phases in One Week

InSync Results: US 1 at Harrison Rd Intersection

The meta data for Harrison intersection (Figure 29) is presented in Table 12. There is no WT (westbound through) in this intersection.

Table 12 Meta Data Table for Harrison

| intersectionID | phaseID | phaseNum | phaseMove | minGreen | maxGreen | planID | planStartTime | planEndTime | planDOW | Change | Clearance |
|----------------|---------|----------|-----------|----------|----------|--------|---------------|-------------|---------------|--------|-----------|
| 101 | 1 | 2/6 | ST/NT | 78 | 170 | none | none | none | 1-2-3-4-5-6-7 | 6 | 2 |
| 101 | 2 | 3 | WL | 7 | 32 | none | none | none | 1-2-3-4-5-6-7 | 4 | 2 |
| 101 | 3 | 4 | ET | 12 | 25 | none | none | none | 1-2-3-4-5-6-7 | 4 | 2 |

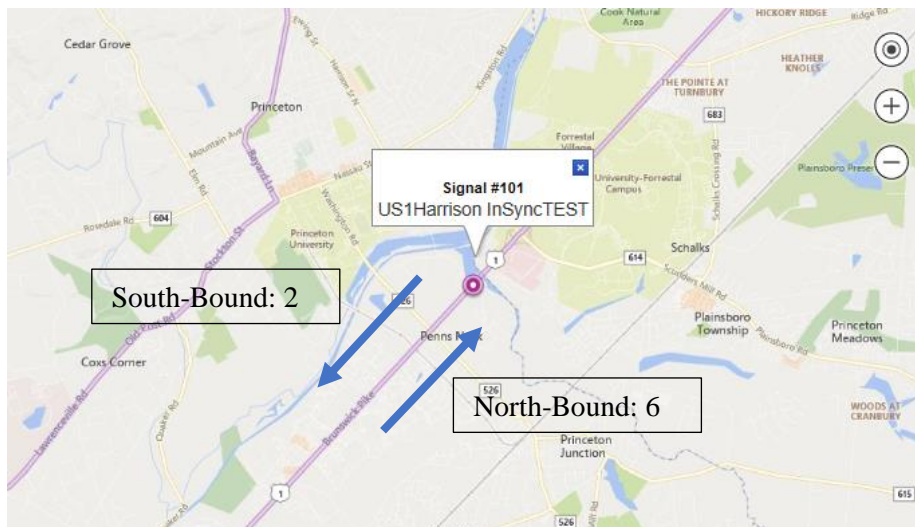
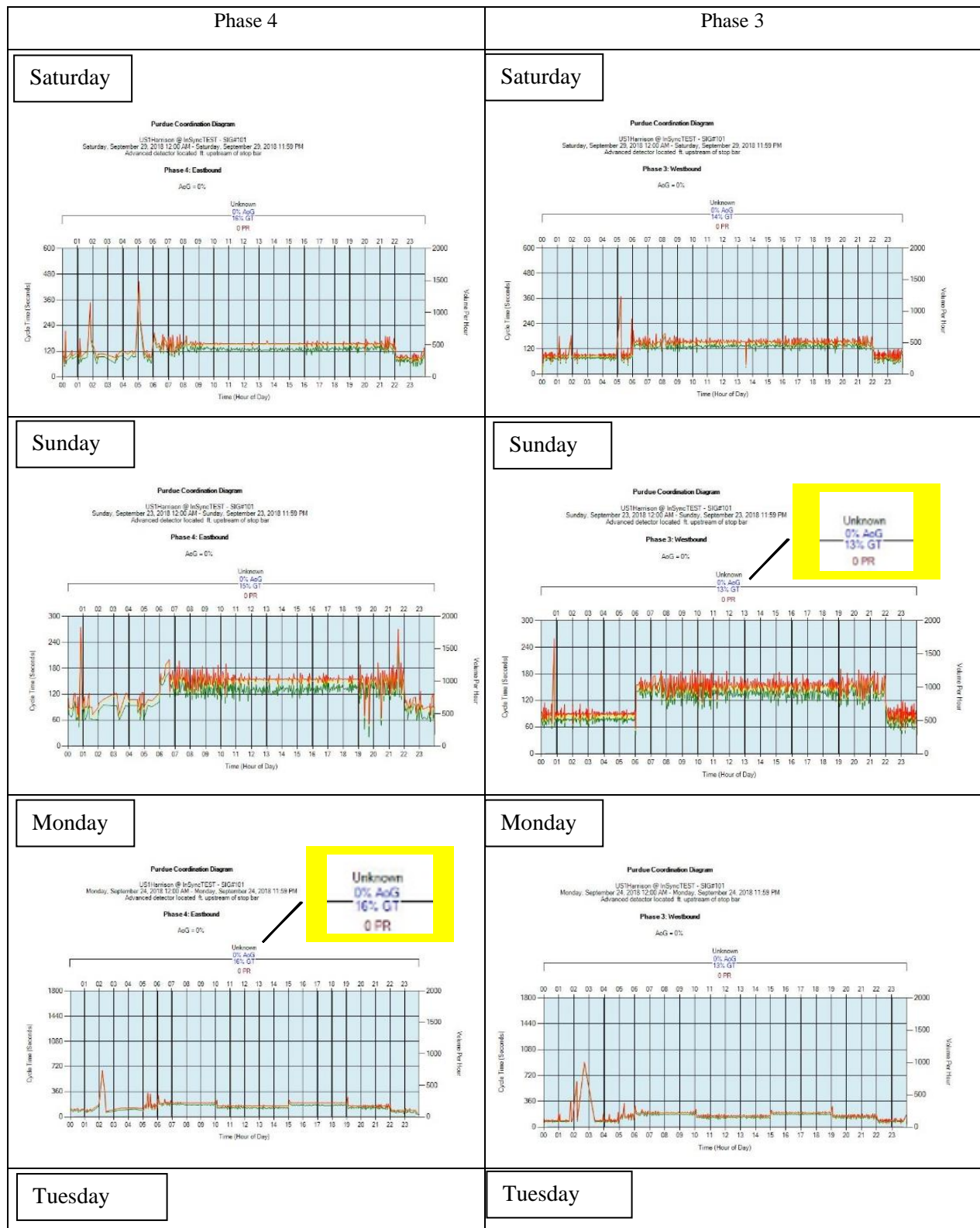
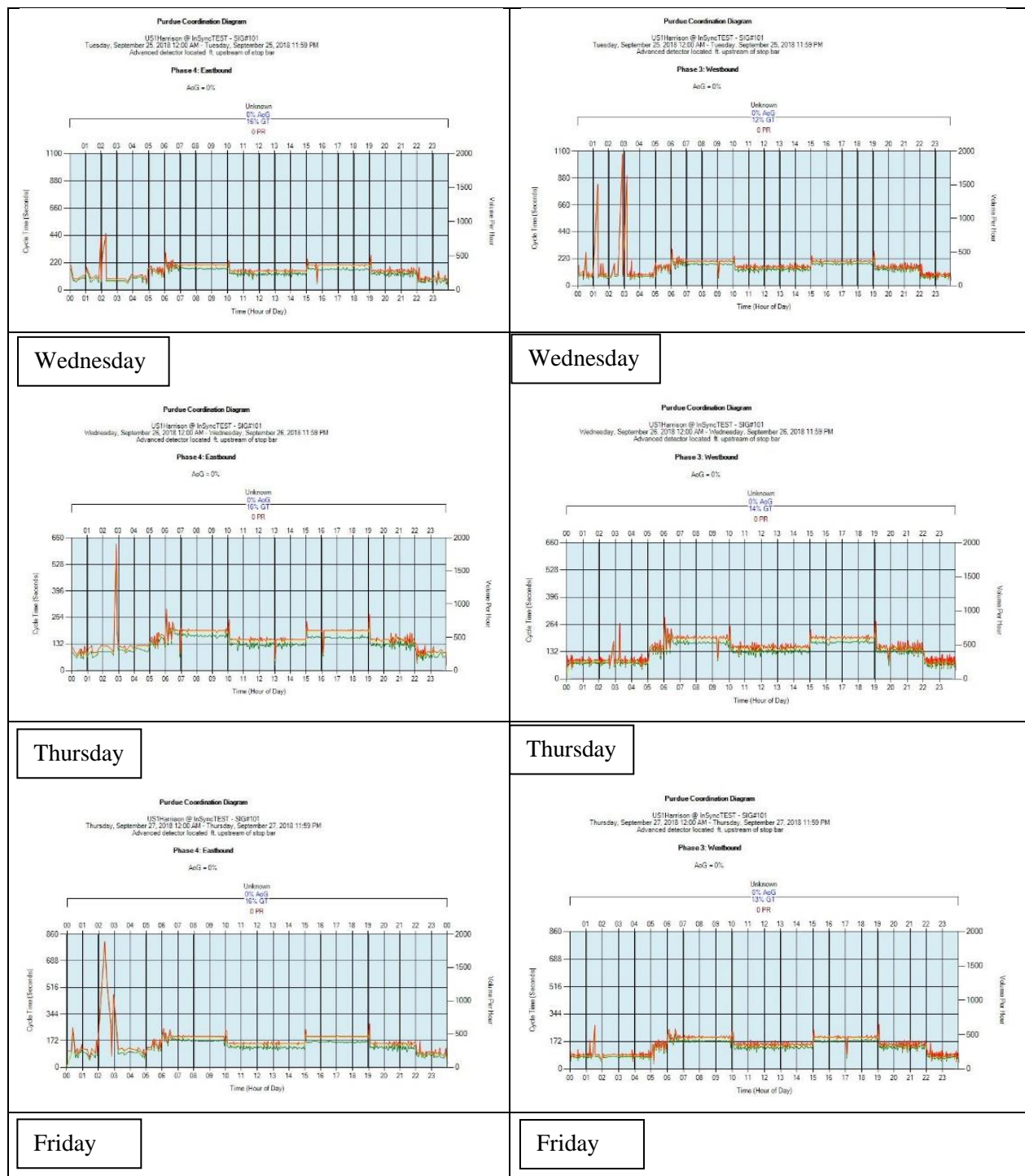


Figure 29 US1 at Harrison Rd. Intersection

From the PCDs in Figure 30 (Phase 4/3) and Figure 31 (Phase 2/6), the InSync operation during morning and afternoon peak on weekdays are clearly observed. And During weekends, there is no obvious peak hour pattern. During weekdays, for the major road, InSync assign 70% total green time to Southbound and Northbound traffic. InSync allocate about 16% green time for eastbound and 13% green time for westbound left turn. On the Purdue phase termination diagram (Figure 32), the southbound through has the most gap-outs. Most of gap outs happen during midnight. Purdue phase termination is used to identify movements where split time may need to be taken from some phases and given to other phases. This measure is also very useful in identifying problems with vehicle and pedestrian detection. For example, if the phase is showing constant maxouts all night long, it is assumed that there is a detection problem.

On the split monitor diagram (Figure 33), we can read the split information for each phase, including 85% split percentage, average split duration, split termination type, and the percentage of skipped cycles.





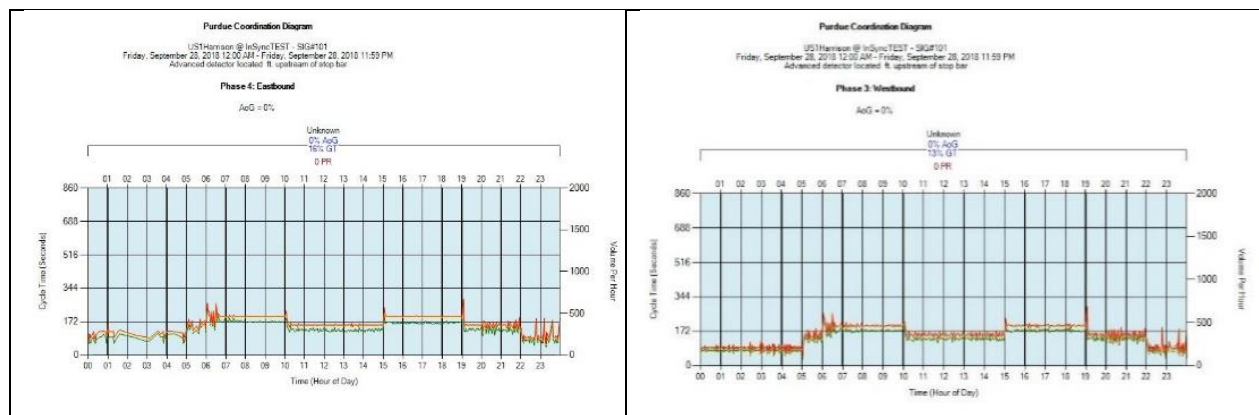
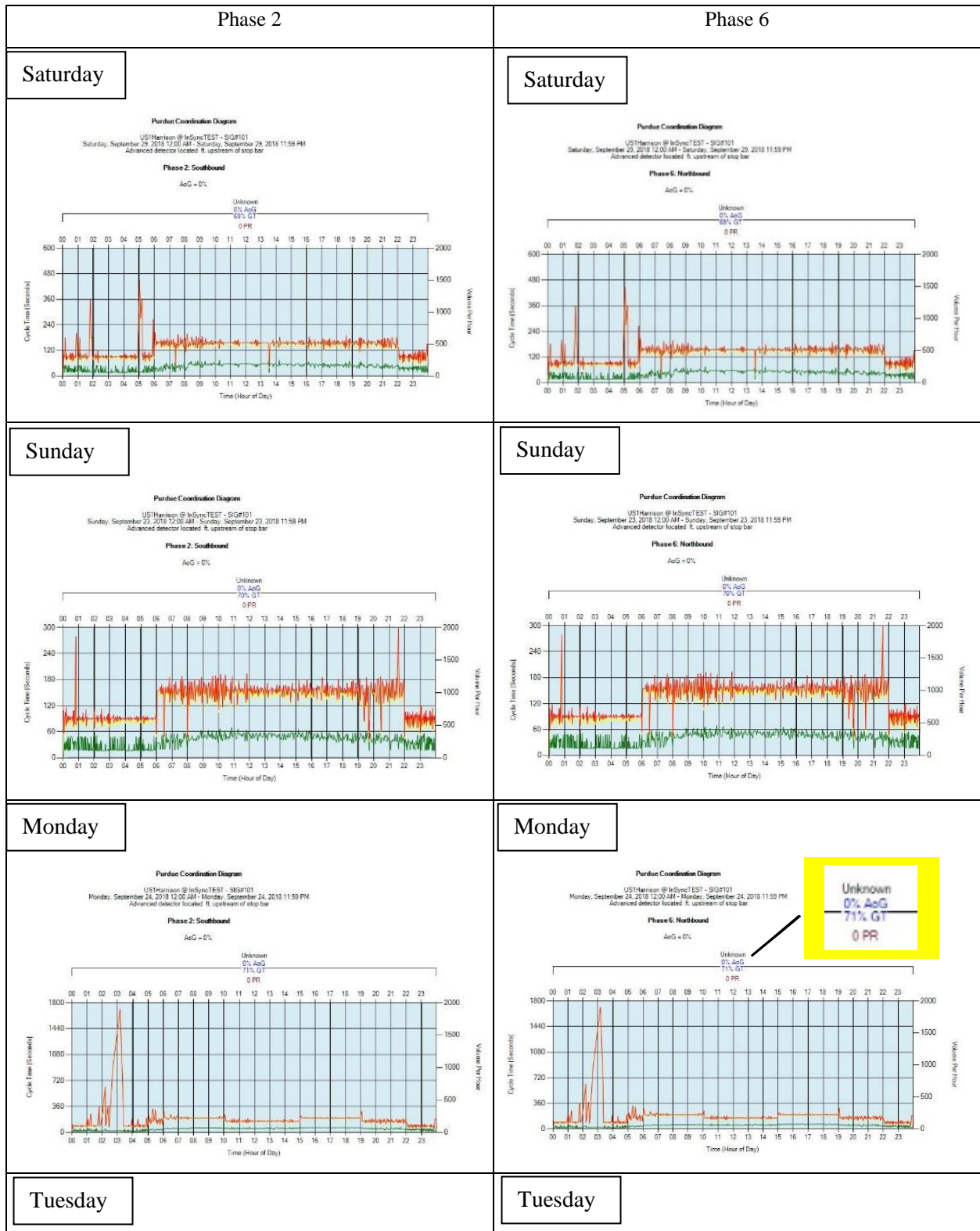
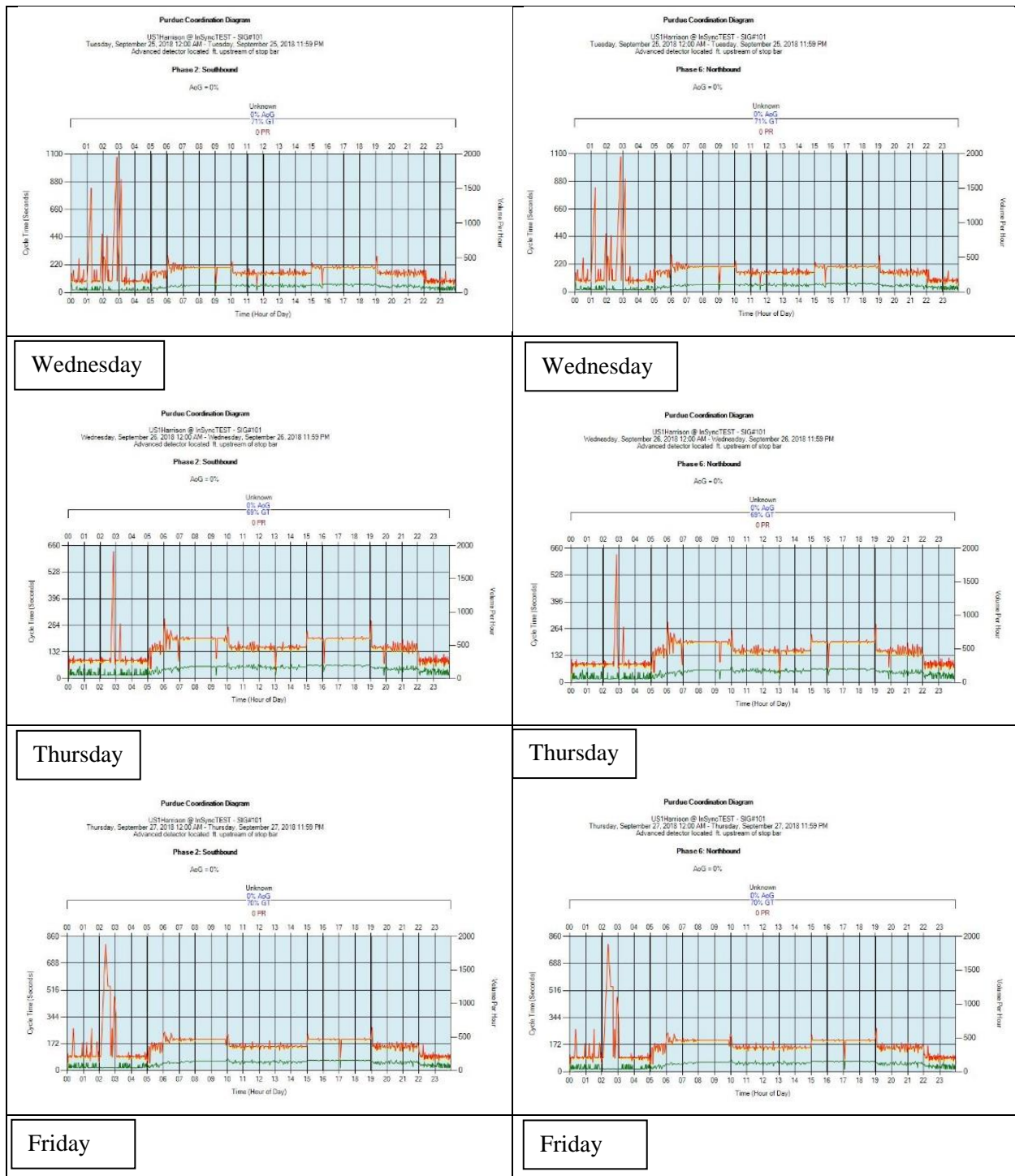


Figure 30 One Week PCDs from US1-Harrison Intersection for Phase 3&4





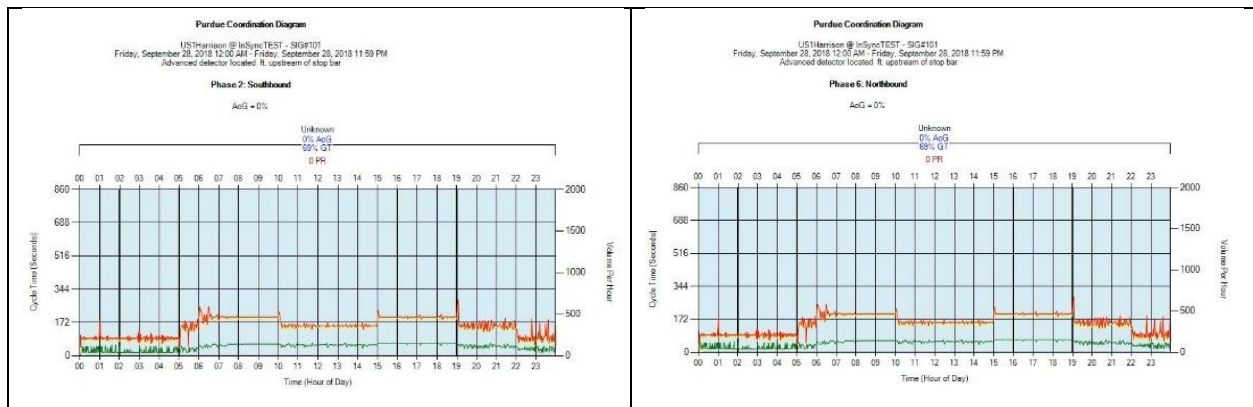


Figure 31 One Week PCDs from US1-Harrison for Phase 2&6

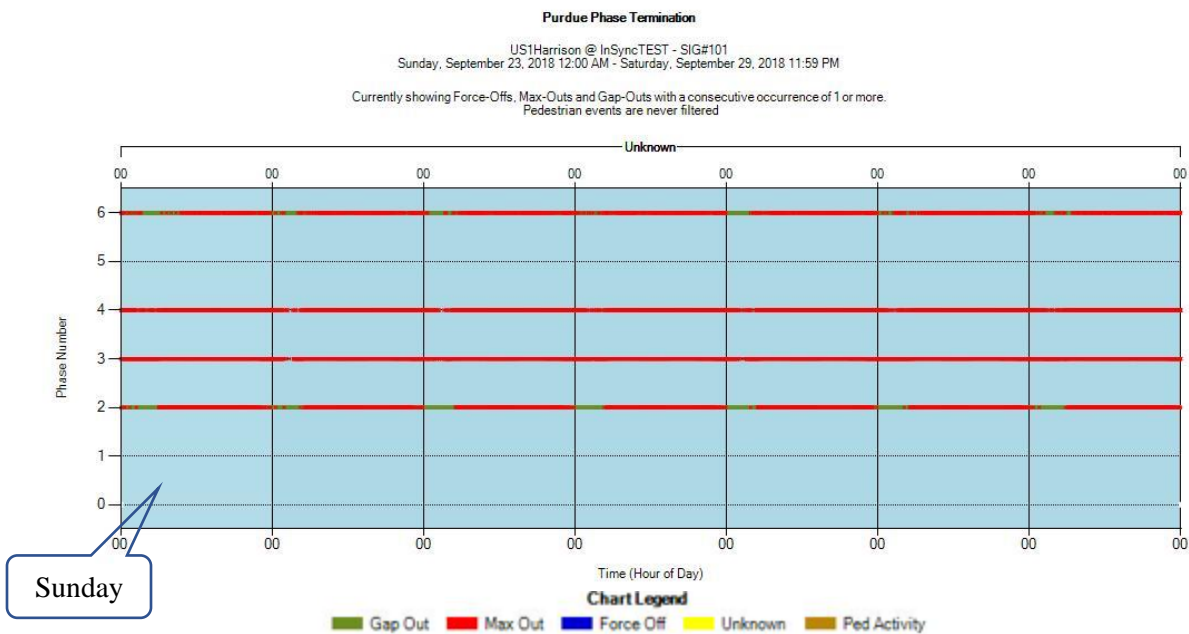
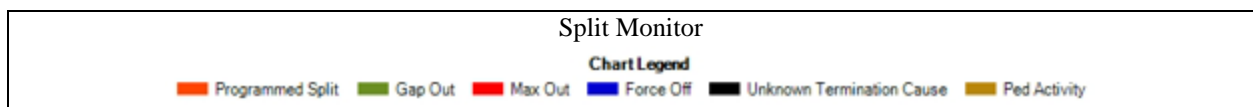


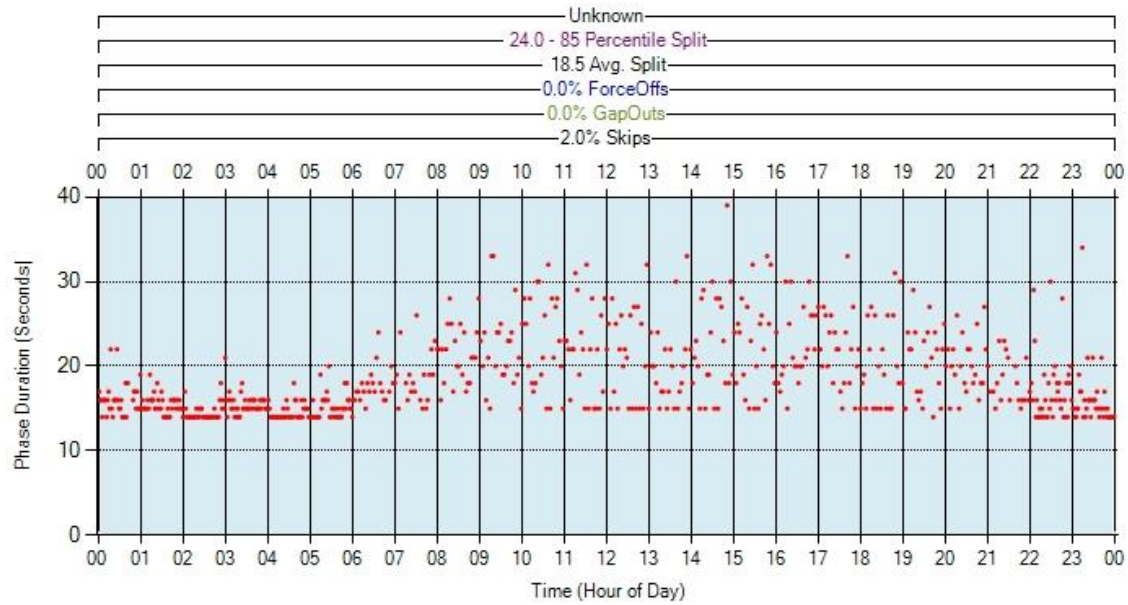
Figure 32 Purdue Phase Termination for One Week at US1-Harrison Intersection



Split Monitor

US1Harrison @ InSyncTEST - SIG#101
Sunday, September 23, 2018 12:00 AM - Sunday, September 23, 2018 11:59 PM

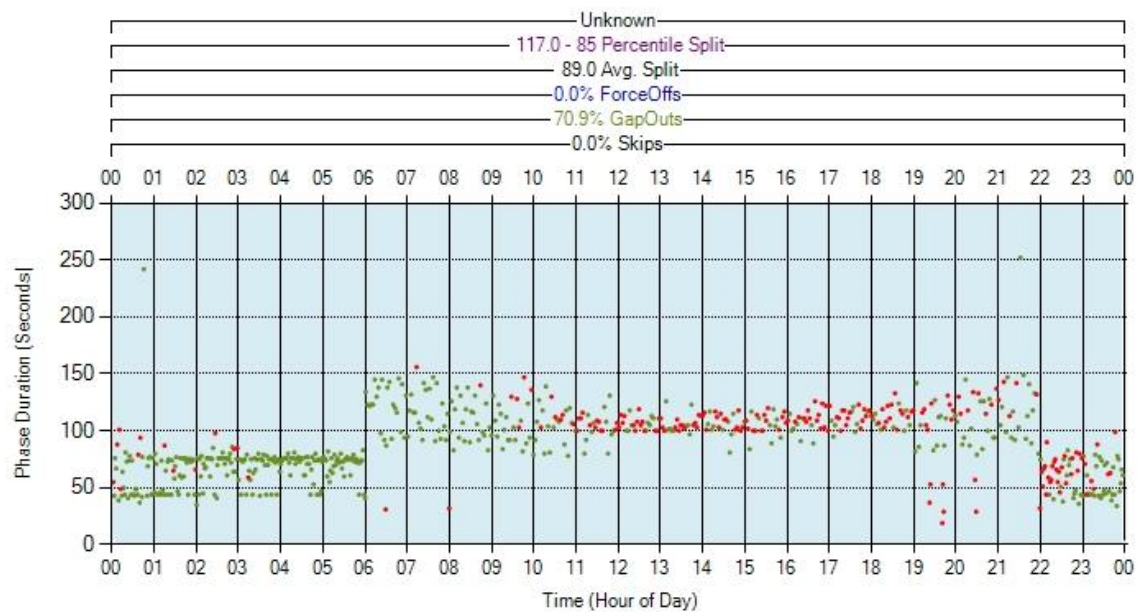
Phase 3



Split Monitor

US1Harrison @ InSyncTEST - SIG#101
Sunday, September 23, 2018 12:00 AM - Sunday, September 23, 2018 11:59 PM

Phase 6



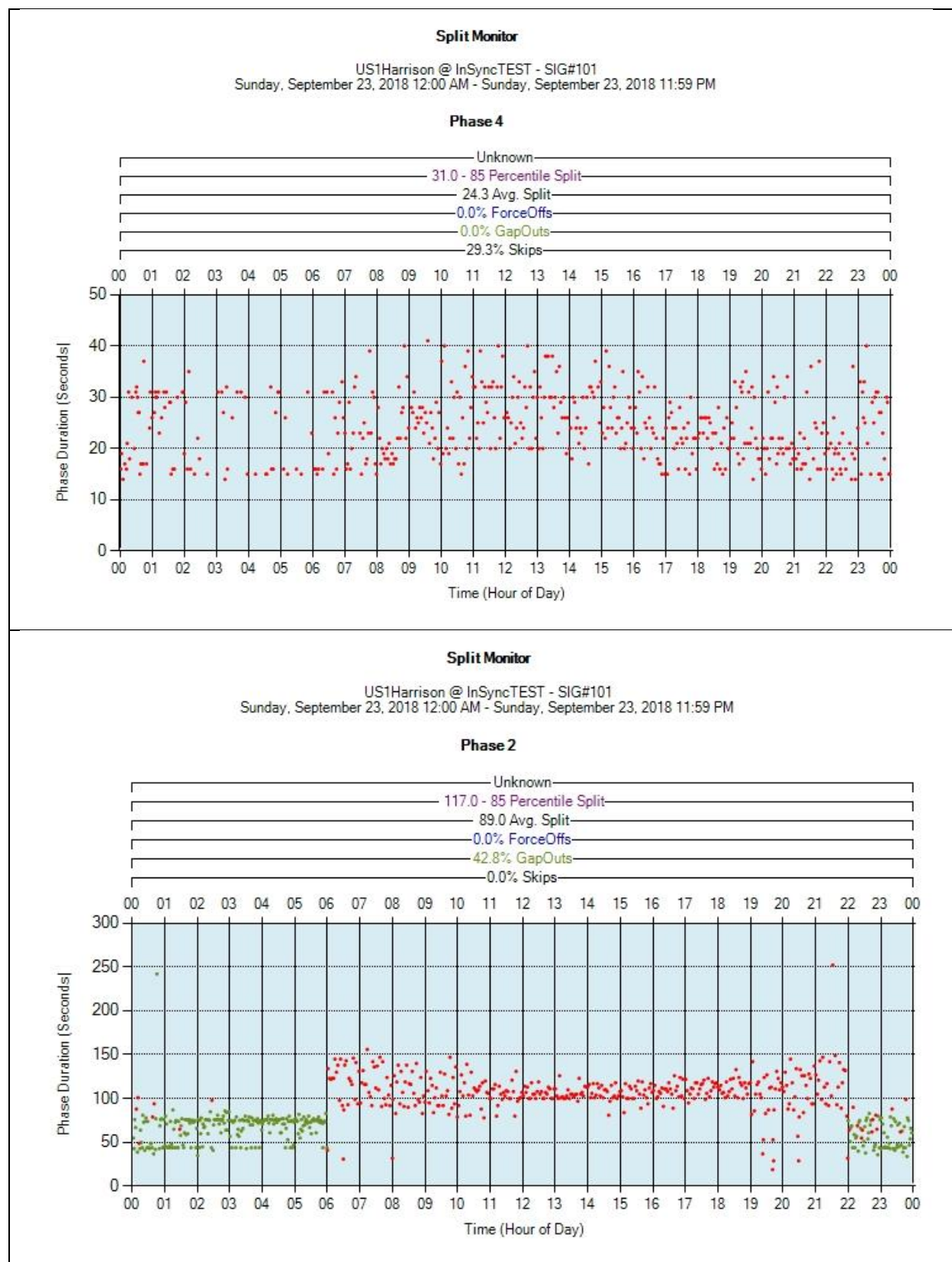


Figure 33 Split Monitor for One Week at US1-Harrison Intersection

SCATS ATSPM Results

Intersections along Route-18 are controlled through SCATS adaptive signal control system. SCATS controllers already provide a few performance metrics like the degree of saturation, arrival on green, and offset/cycle. The team conducted a case study at 13 SCATS controlled intersections, which is shown in Figure 34. Then, the results of one of those intersections (Hillsdale as shown in Figure 35) is presented to demonstrate the results.

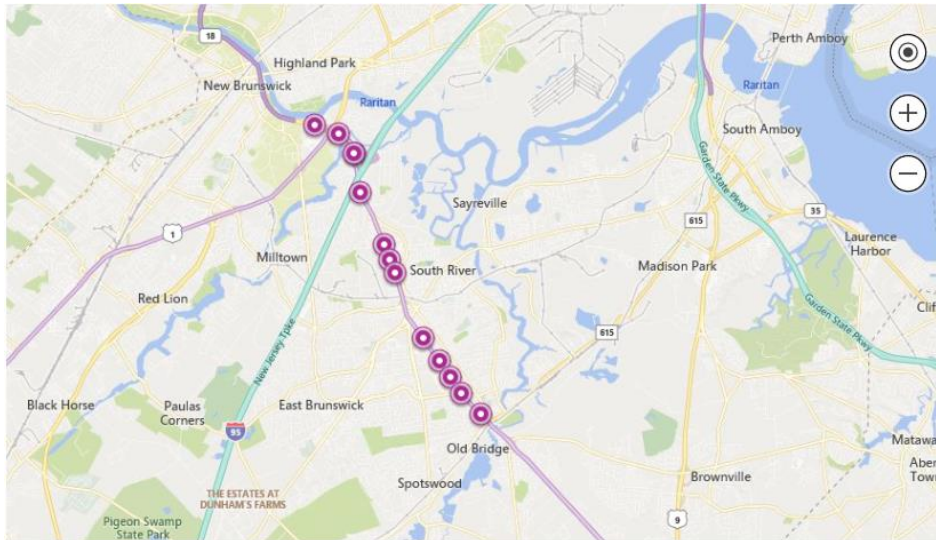


Figure 34 Intersections for Case Study of SCATS Along Route 18

Then, the result of Hillsdale intersection is presented to demonstrate the results. The SCATS meta data for Hillsdale is presented in the Table 13.

Table 13 Meta Data for Hillsdale Intersection

| intersectionID | phaseID | phaseLetter | Movements (Phase num) | minGreen | maxGreen | planID | planStartTime | planEndTime | PlanDOW | Change | Clearance |
|----------------|---------|-------------|-----------------------|----------|----------|--------|---------------|-------------|---------------|--------|-----------|
| 1800 | 1 | B | EL(4), WL(8) | 7 | 42 | None | None | None | 1-2-3-4-5-6-7 | 3 | 4 |
| 1800 | 2 | A | NT(6), ST(2) | 18 | None | None | None | None | 1-2-3-4-5-6-7 | 5 | 3 |

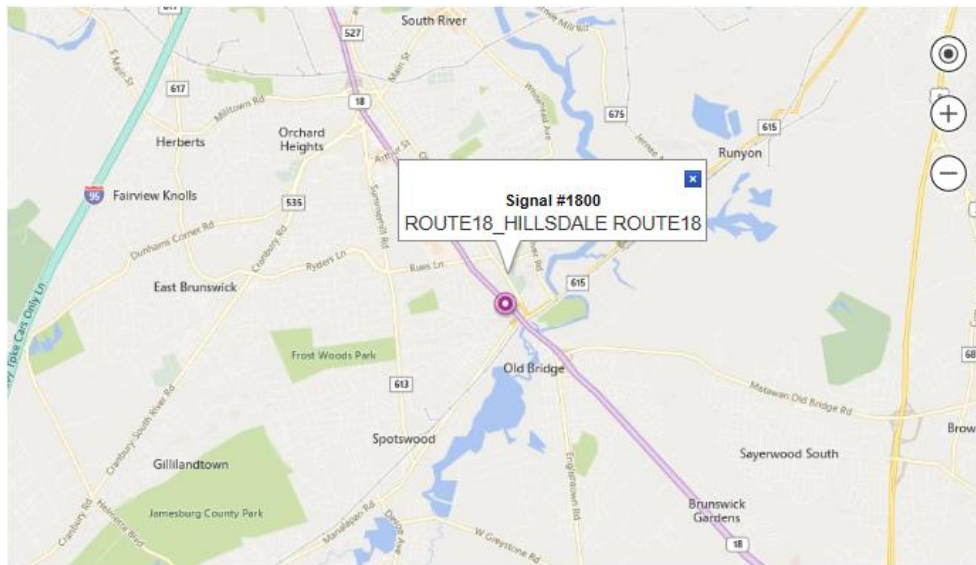


Figure 35 Route-18 at Hillside Intersection

The PCDs of the SCATS signal system (Figure 36), show that the signals rest on the main road during midnight, giving much more green time on the major arterial (Route 18) throughout the day. The PCDs quantify this green time at the top of the graph which show that 85% green time is allocated to Route 18. After 20:00, the SCATS server reduces the cycle length to better serve different approaches for this intersection.

The graphical representation of a PCD can be observed for a number of days in a row, allowing the user to evaluate the pattern changes from day to day. As shown in the one-week PCDs (Figure 37) it is observed that SCATS systematically assign more green time to arterial corridor during weekday morning and afternoon peak hour, while lowering this allocation mid-day. The same graphical representation of the phase termination as well as the split monitor was demonstrated in InSync was applied to SCATS. On the PPT (Figure 39), each phase shares a high percentage of gap-outs (with phases 8 & 4 having some max outs). On the split monitor diagram (Figure 38), the split shows the distribution of the green times for each phase. There are a few max outs (red dots) that end at 50 seconds on during Phases 4 and 8. The max outs on Phase 4 and 8 on the PPT coincide with the Pedestrian actuations on Phase 8 in Figure 40b, where pedestrian delay is timed from the point when a pedestrian button is pushed till the ped phase is served. When the ped actuation occurs, the green on Phase 4 and 8 is held to a maximum amount of 50 seconds. In Figure 40a, the pedestrian time is on phase recall and appears throughout the day, running with the Phase 2 and 6 splits. For Figure 41, the Yellow, All Red, and Red times are documented in the server. There are a few instances where the yellow time increases from 3 seconds to 4 seconds. This is the result of a delay in the communication between the signal controller and the SCATS server, thus providing an alternative means to evaluate the communication reliability between the two systems.

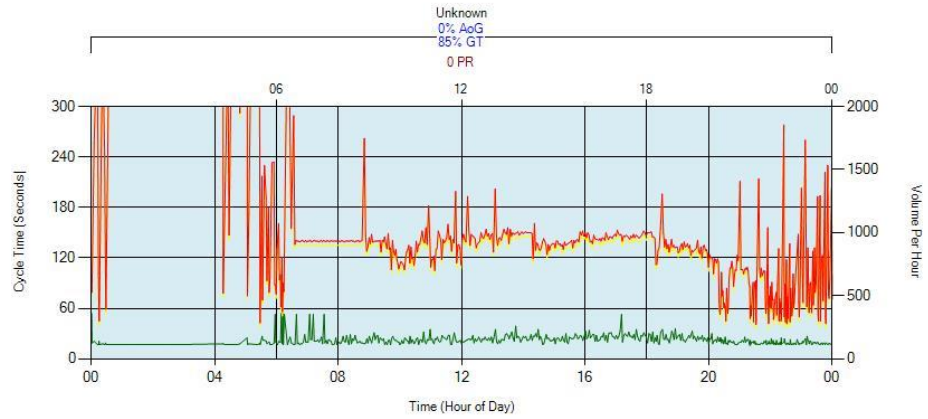
Purdue Coordination Diagram

ROUTE18, HILLSDALE @ ROUTE18 - SIG#1800
Friday, March 1, 2019 12:00 AM - Saturday, March 2, 2019 12:00 AM
Advanced detector located ft. upstream of stop bar

Phase 2: Northbound

AoG = 0%

- Volume Per Hour
- Detector Activation
- Change to Green
- Change to Yellow
- Change to Red
- AoG - Arrival On Green
- GT - Green Time
- PR - Platoon Ratio



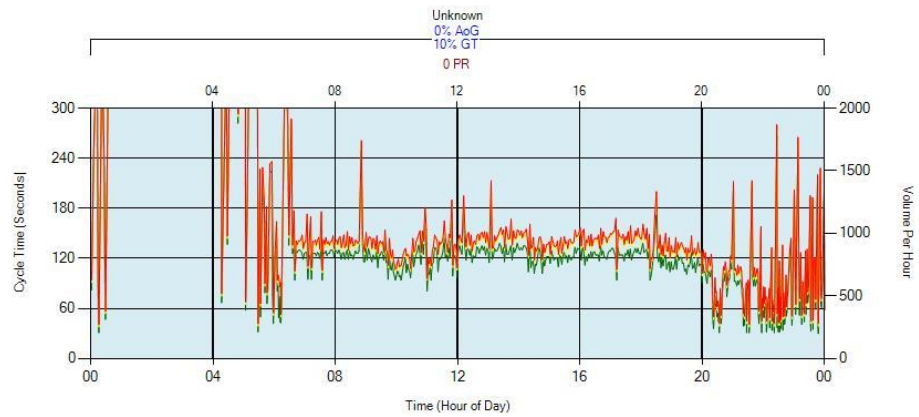
Purdue Coordination Diagram

ROUTE18, HILLSDALE @ ROUTE18 - SIG#1800
Friday, March 1, 2019 12:00 AM - Saturday, March 2, 2019 12:00 AM
Advanced detector located ft. upstream of stop bar

Phase 4: Westbound

AoG = 0%

- Volume Per Hour
- Detector Activation
- Change to Green
- Change to Yellow
- Change to Red
- AoG - Arrival On Green
- GT - Green Time
- PR - Platoon Ratio



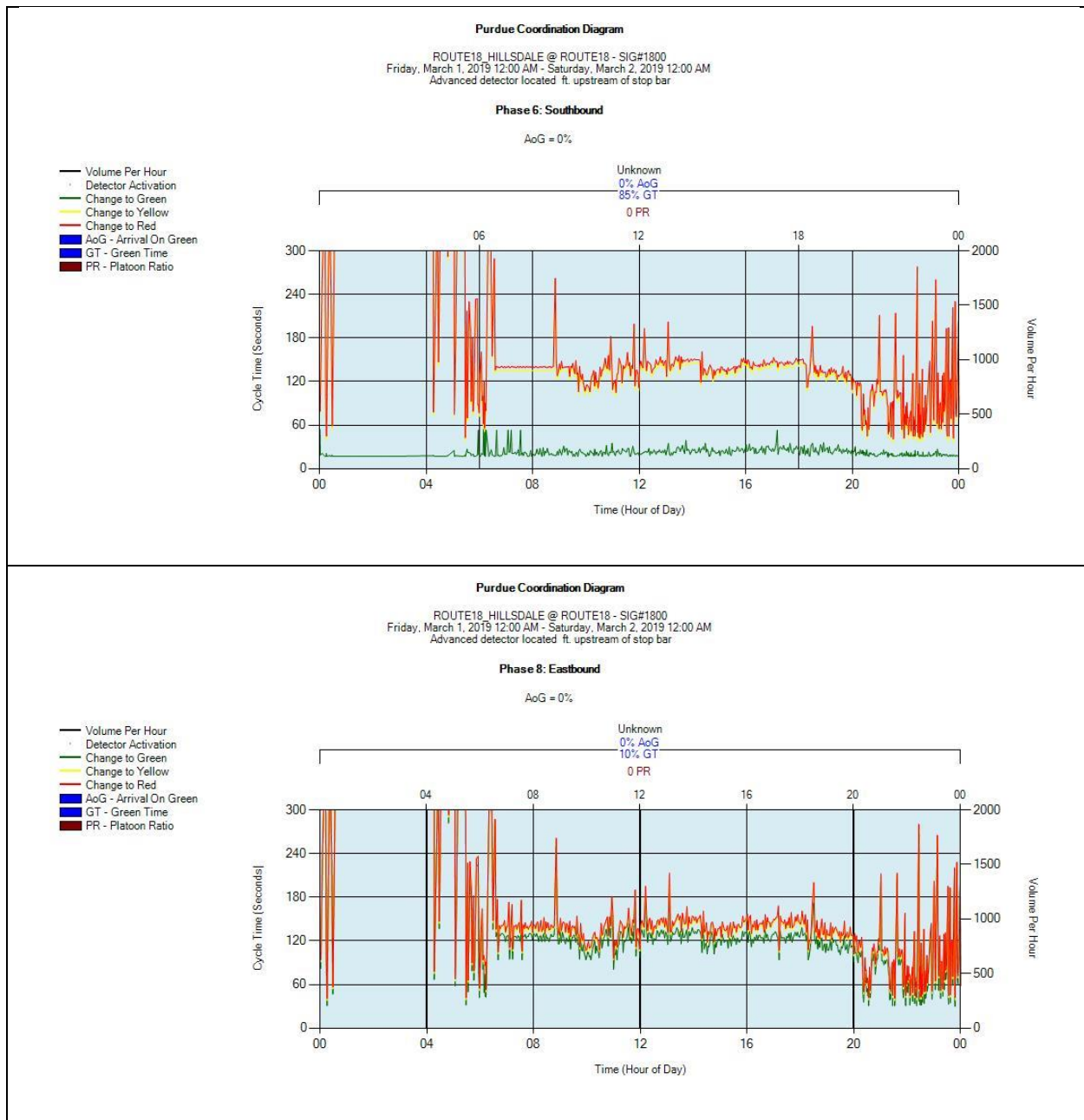
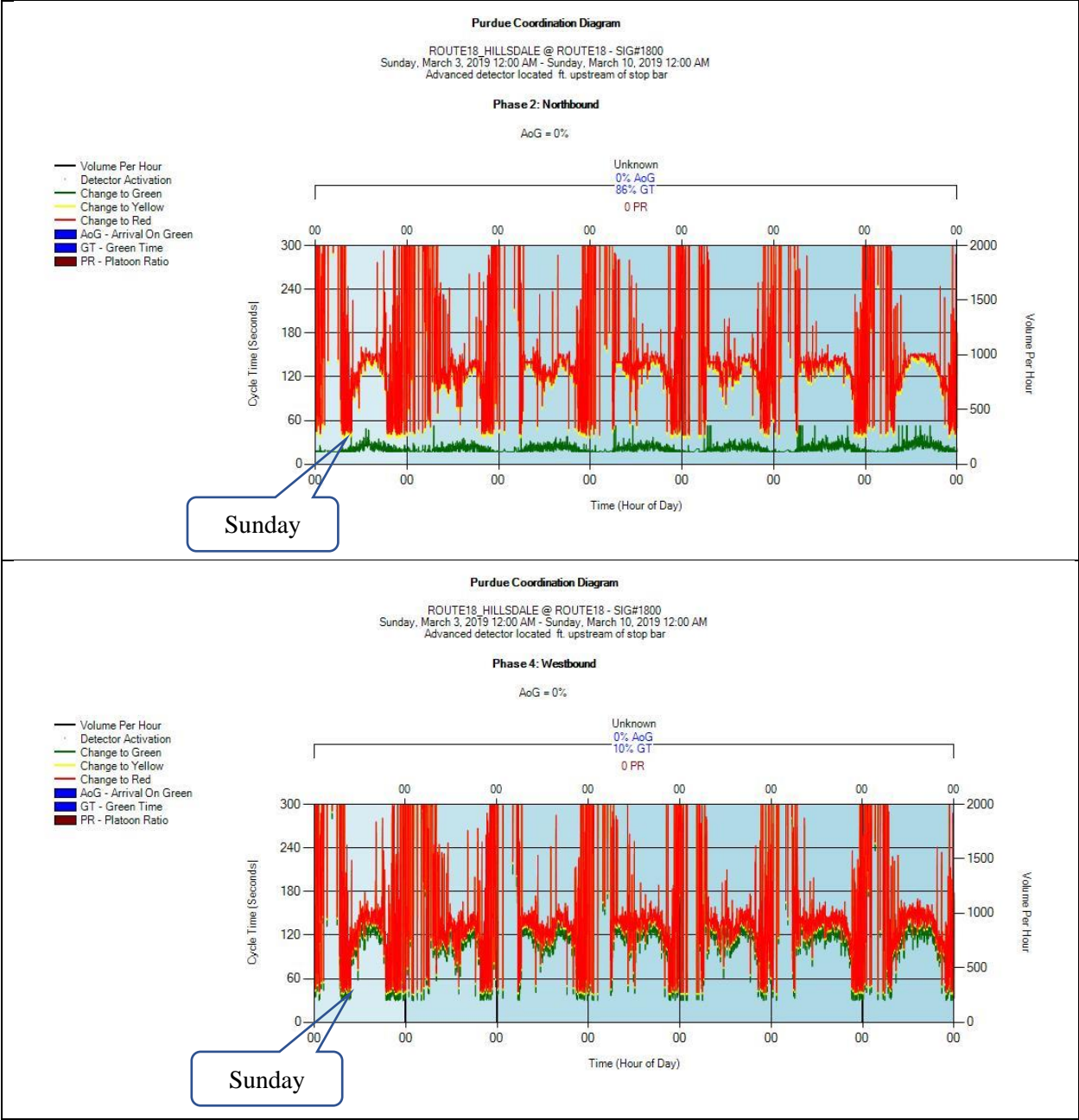


Figure 36 One-day PCDs for Route 18 at Hillsdale Intersection



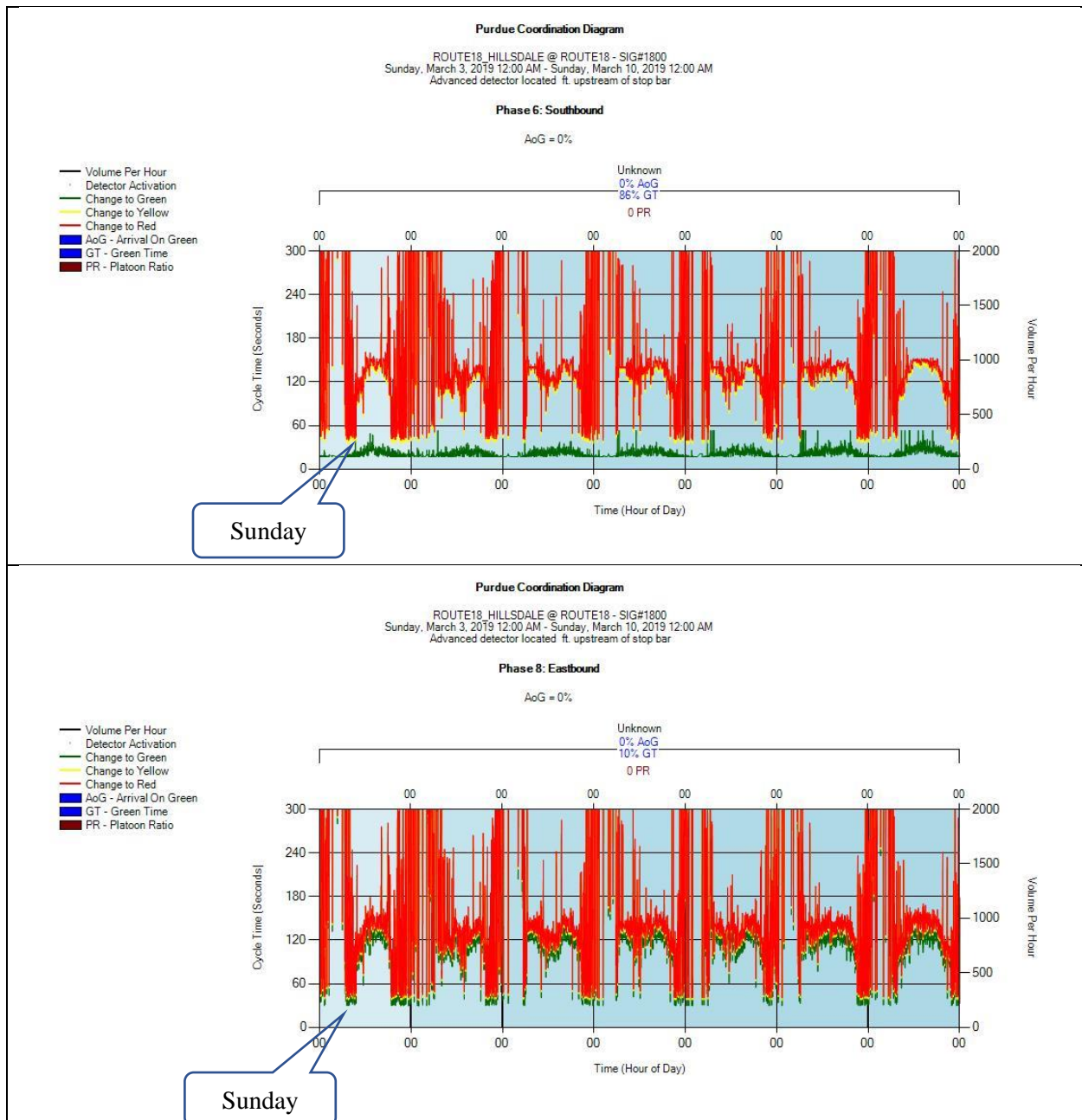
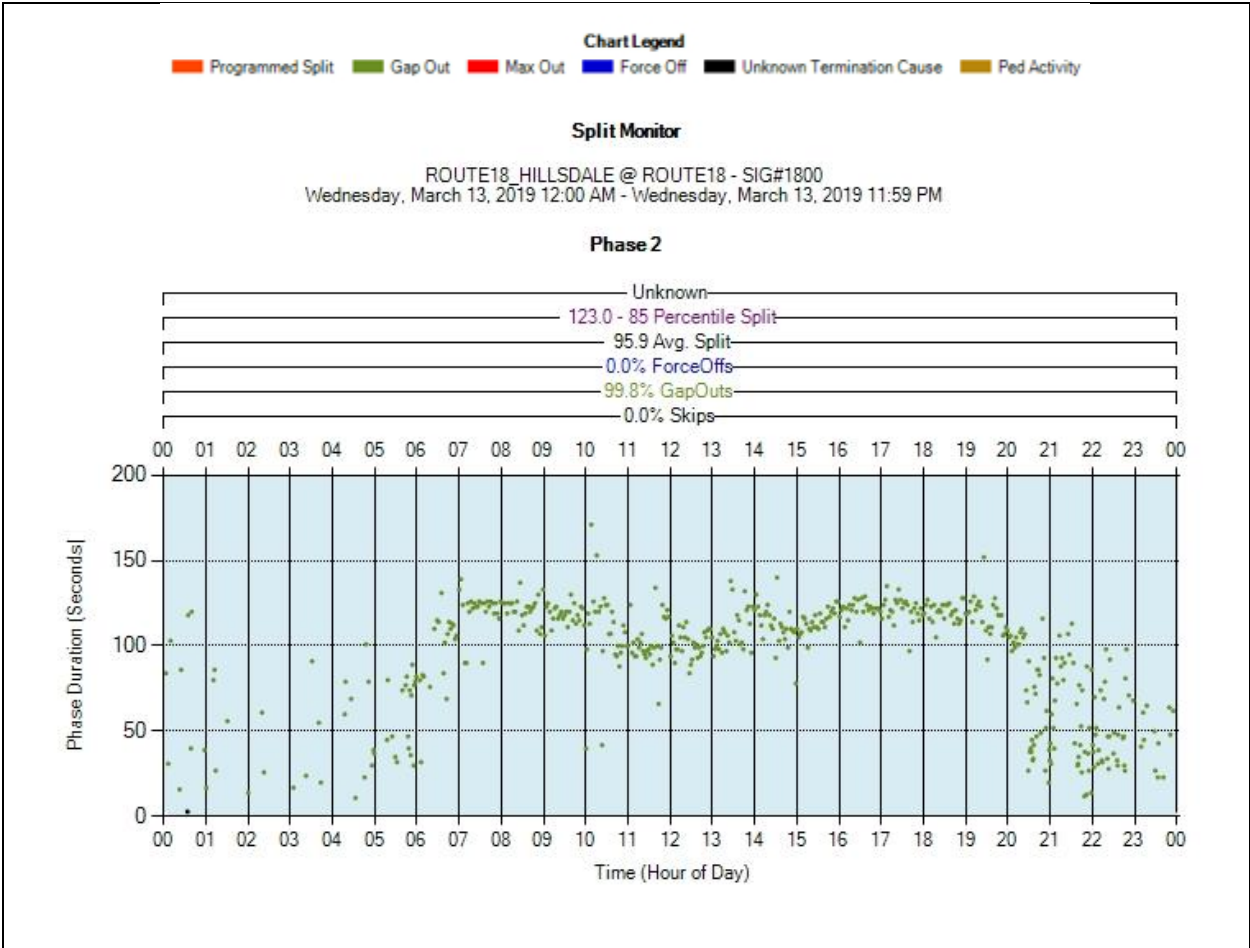


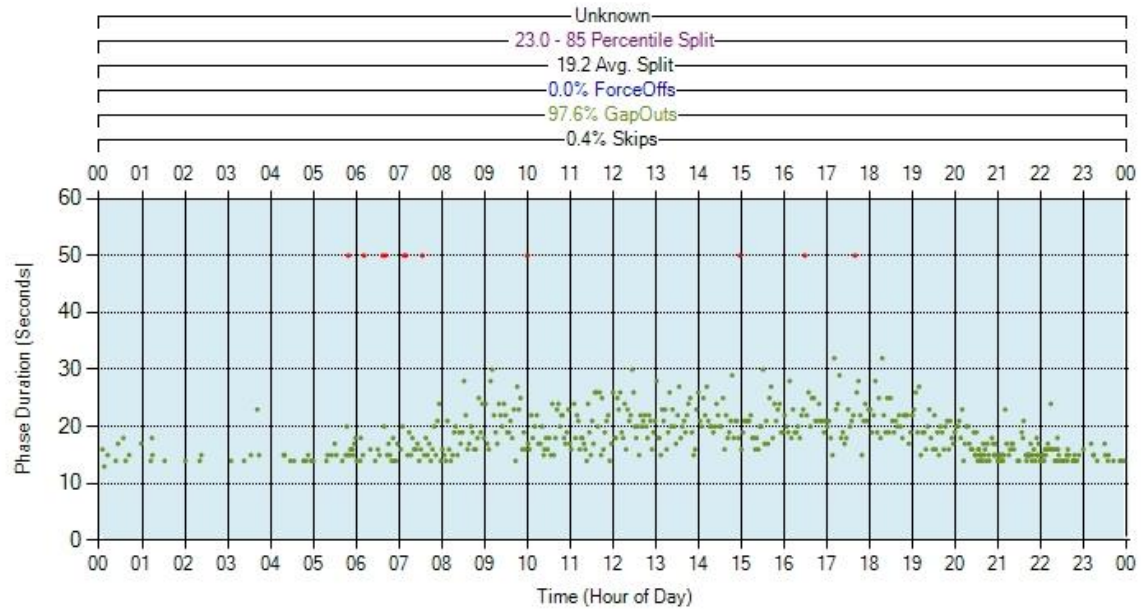
Figure 37 One-week PCDs for Route 18 at Hillsdale Intersection



Split Monitor

ROUTE18_HILLSDALE @ ROUTE18 - SIG#1800
Wednesday, March 13, 2019 12:00 AM - Wednesday, March 13, 2019 11:59 PM

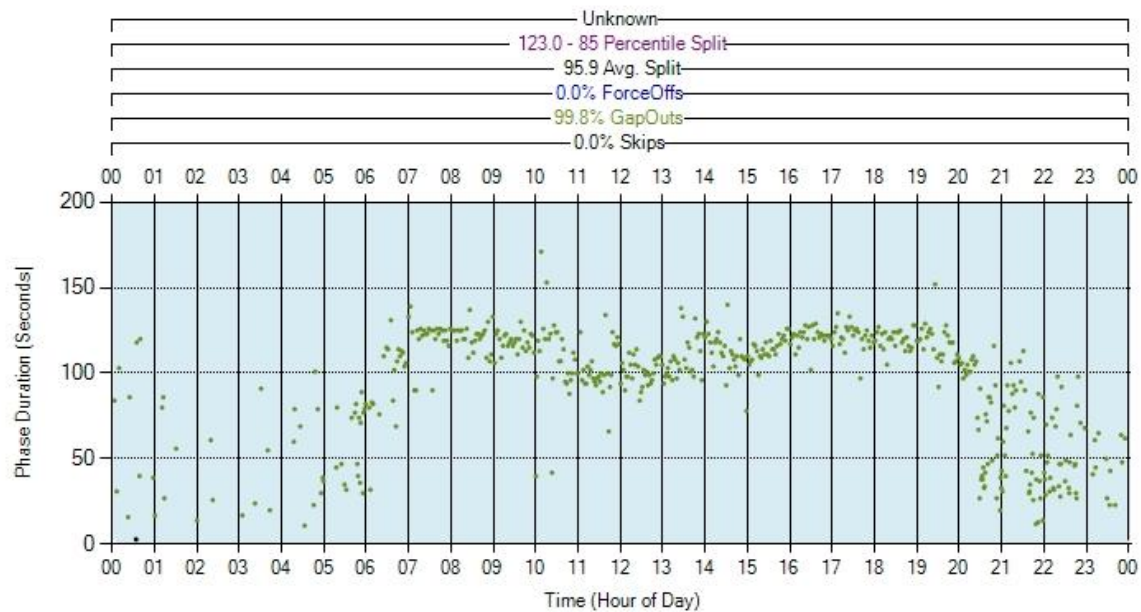
Phase 4



Split Monitor

ROUTE18_HILLSDALE @ ROUTE18 - SIG#1800
Wednesday, March 13, 2019 12:00 AM - Wednesday, March 13, 2019 11:59 PM

Phase 6



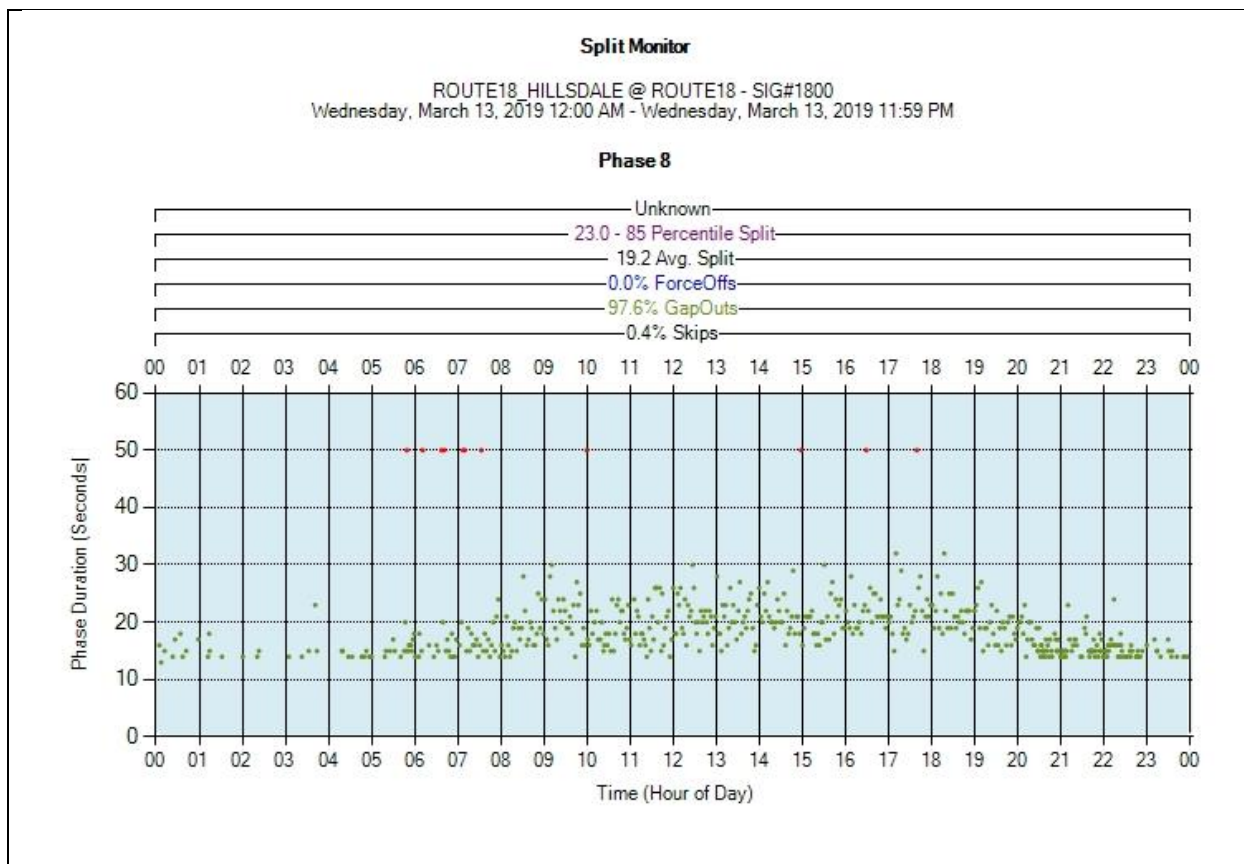


Figure 38 Split Monitor for Route18 at Hillsdale Intersection

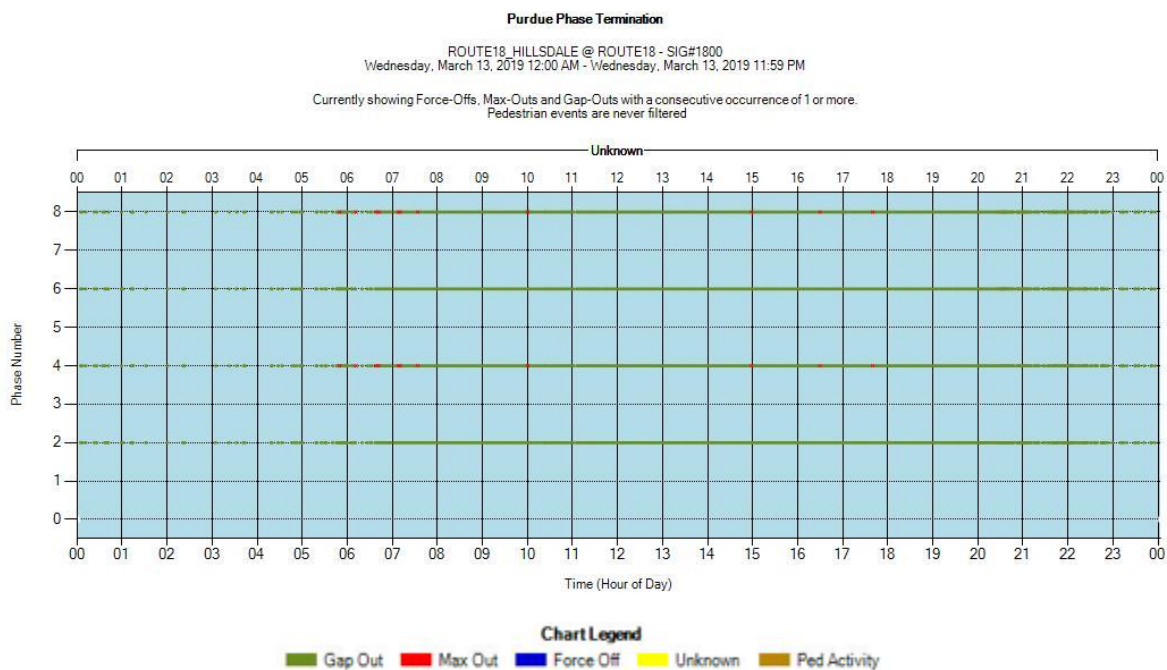


Figure 39 Purdue Phase Termination for Route 18 at Hillsdale Intersection

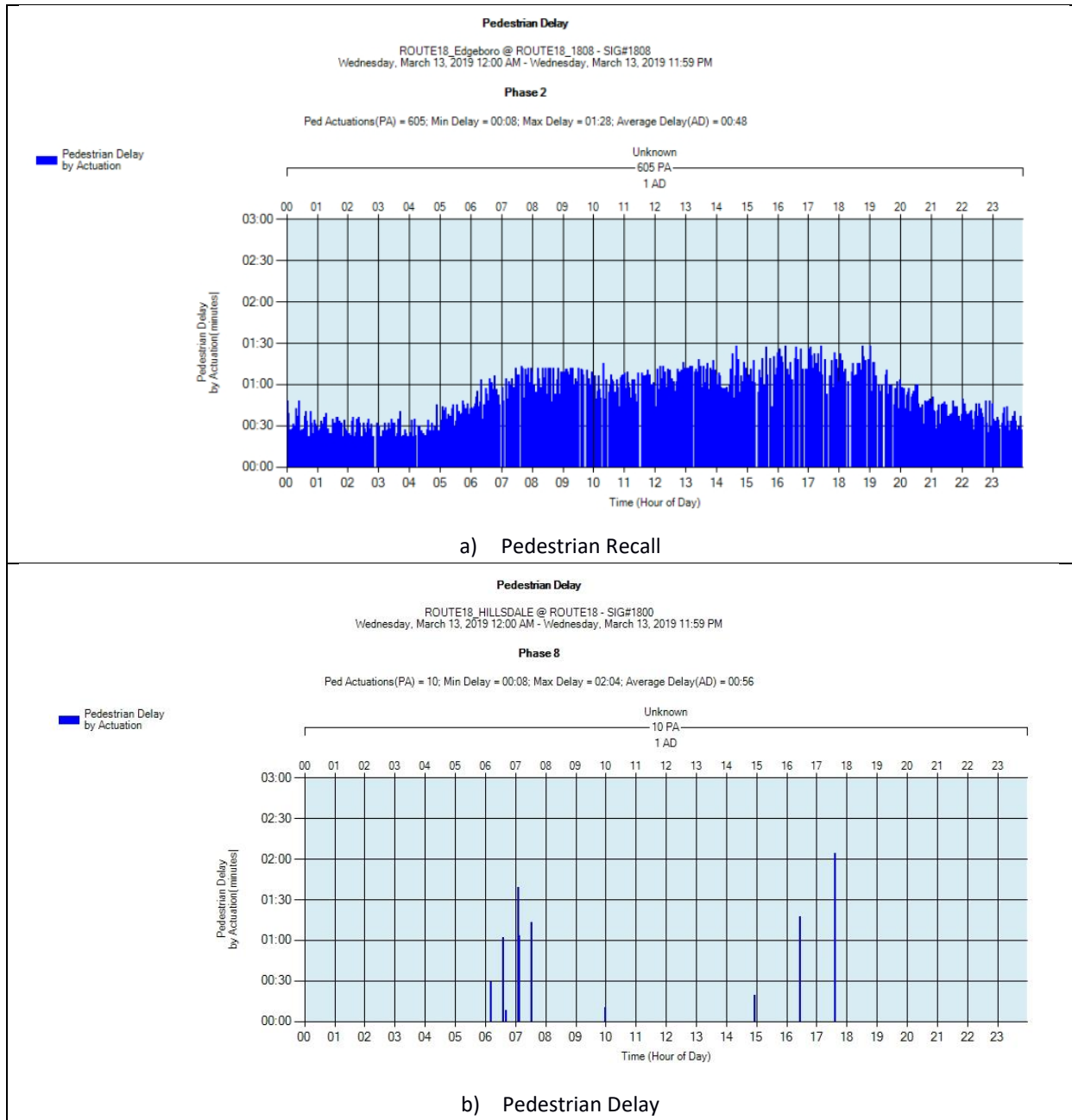
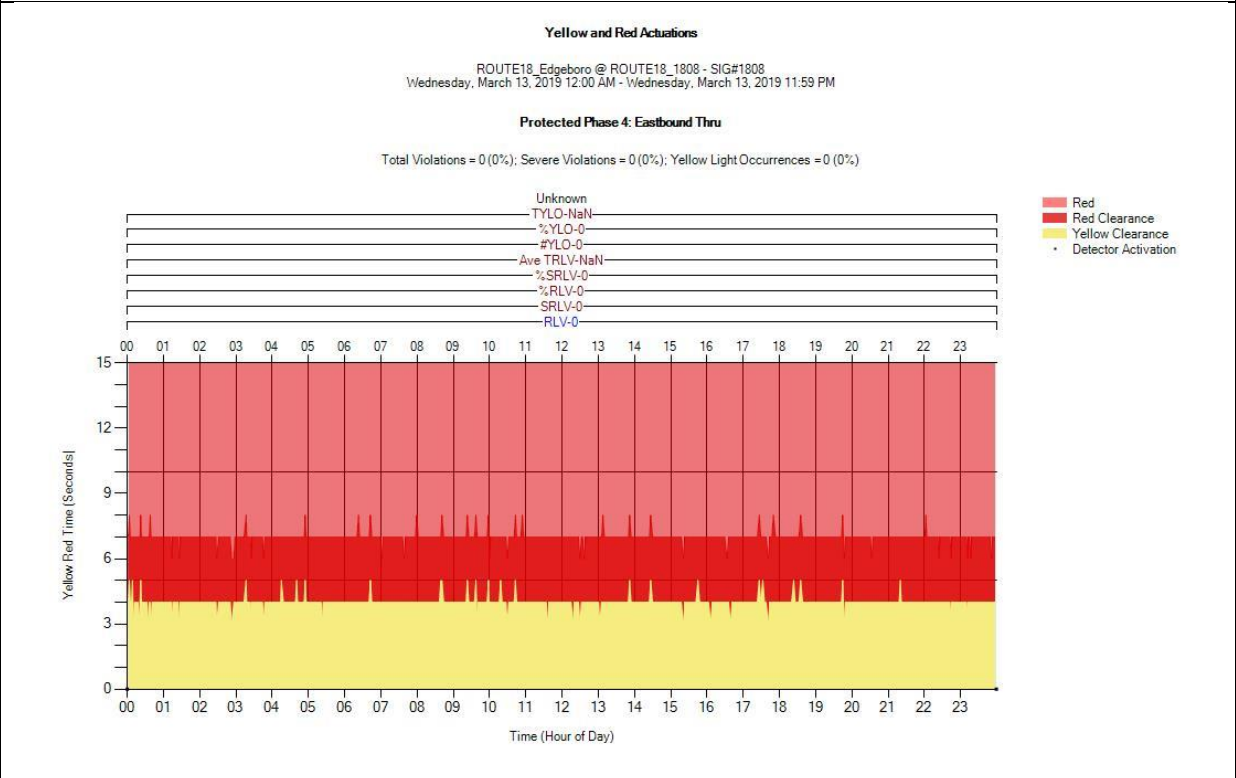
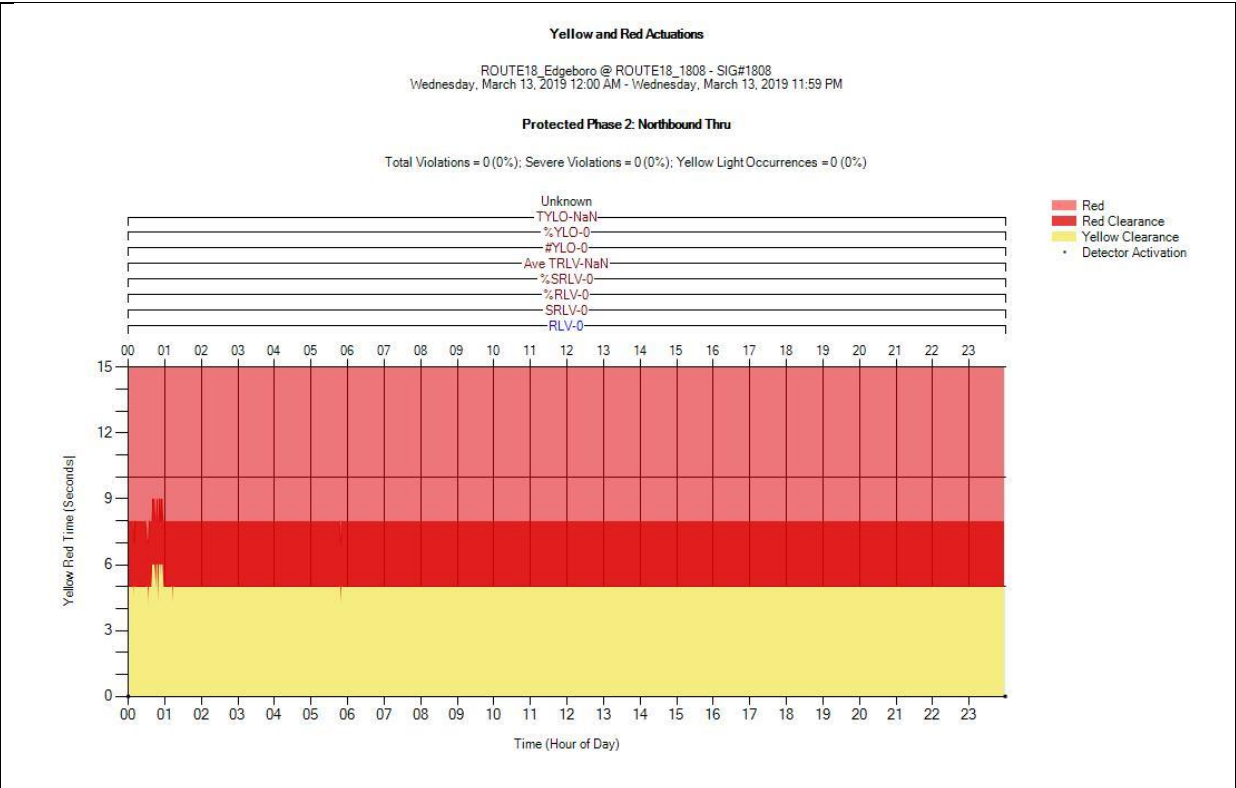


Figure 40 Pedestrian Recall and Pedestrian Delay for Route 18 at Hillsdale Intersection



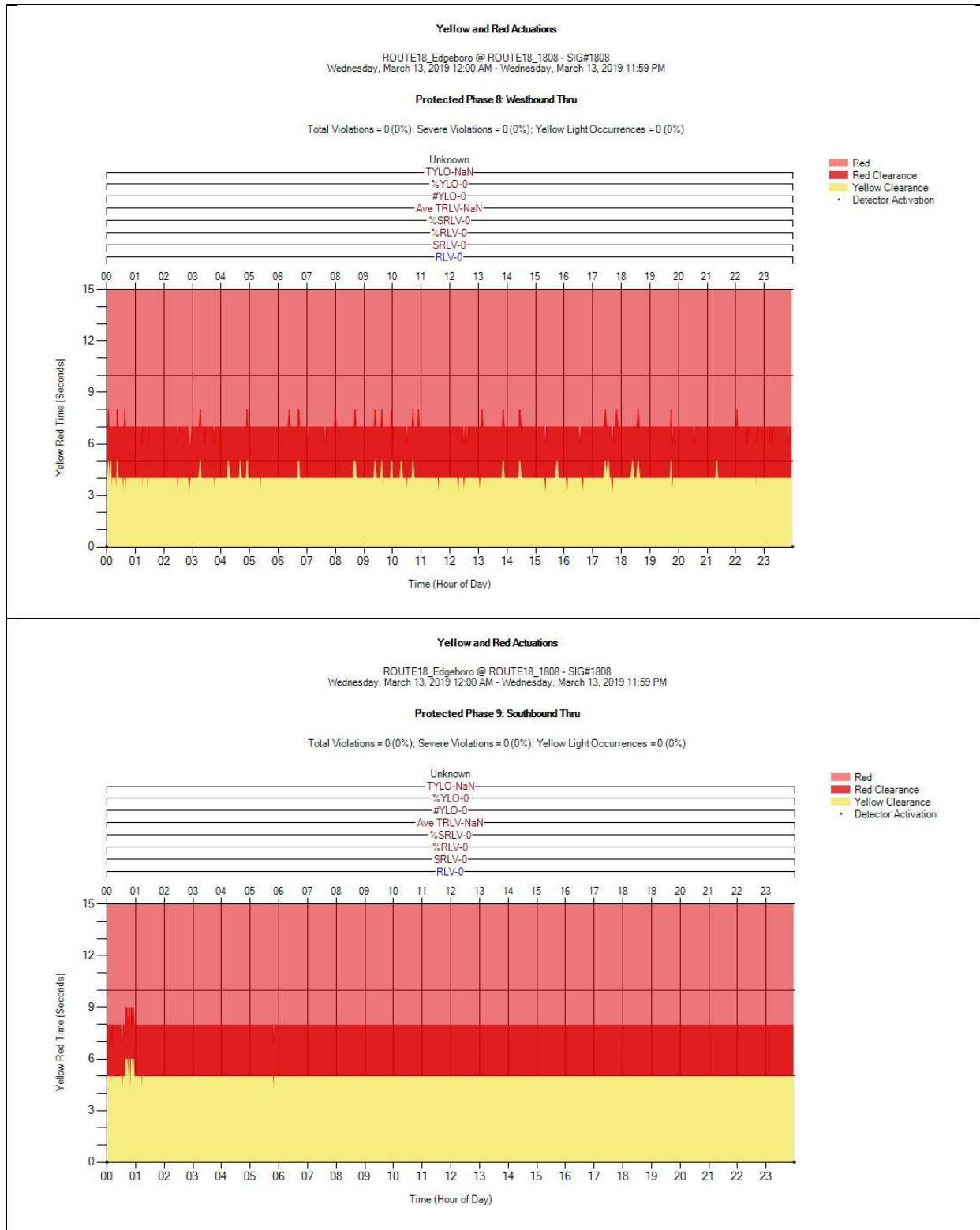


Figure 41 Yellow and Red Actuations

Discussion

One issue happened when trying to translate original ATSC InSync history data into ATSPM event code is the skipped phases. As can be seen from the following Figure 42, Phase 4 has an excessively long cycle length than the other three phases during free time.

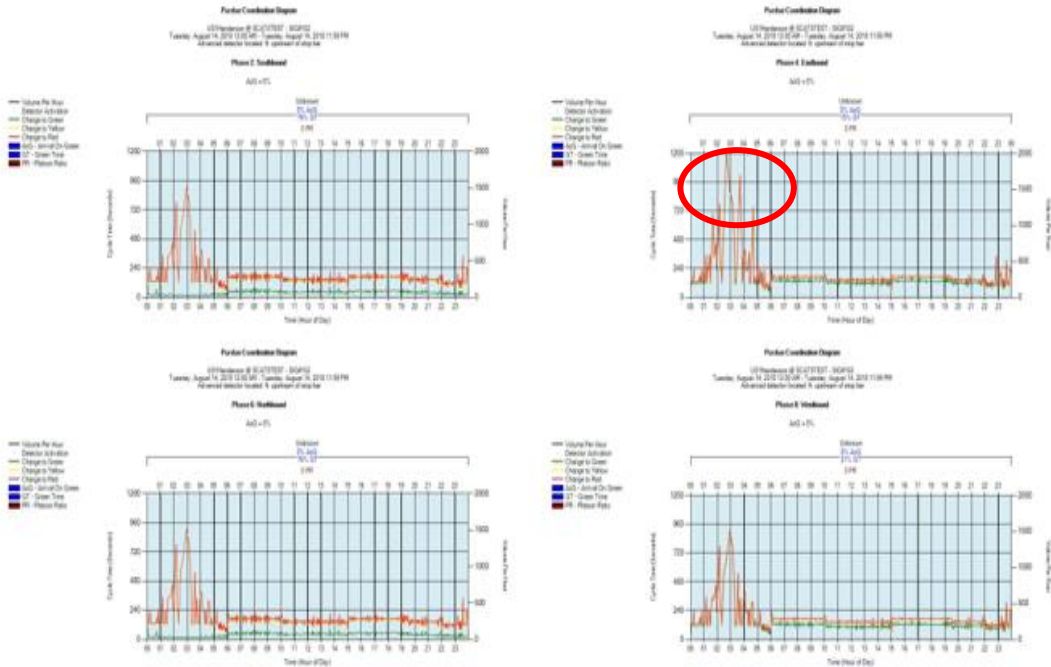
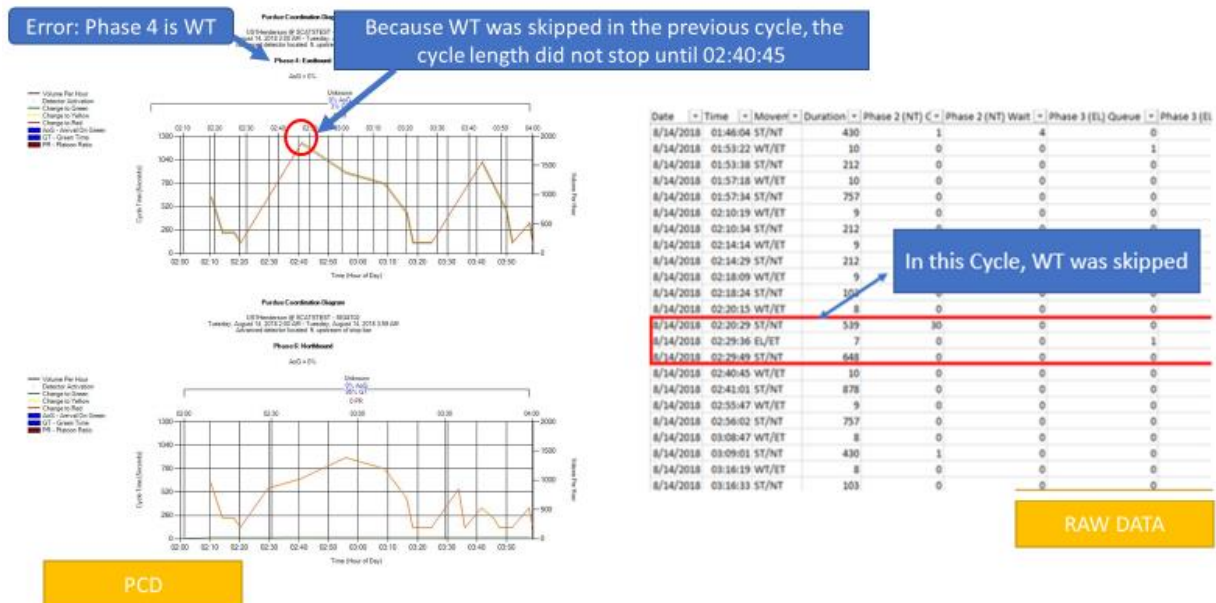


Figure 42 Skipped Phases Result in Abnormal Cycle Length

The next Figure 43 provides inspection through looking at both the raw data and PCD to explain why the extreme cycle length occurs.



In the next Figure 44, it shows how we fix the logic flaws that brings extreme cycle length for skipped phases.



Summary and Conclusion

ATSPM has many advantages over traditional traffic signal monitoring and management processes. ATSPM system uses high-resolution (0.1 sec) traffic signal controller data to support data-driven decision-making process instead of complaining driven process. The ATSPM is flexible enough to accept their sources of traffic controller data that are not necessarily defined at high-resolution. ATSPM also allow consistent and dynamic monitoring of signal-controlled intersection rather than project-based method of traffic survey. In contrast to reactive operation and maintenance, ATSPM enables proactive solution to quicker problem solving and depict better picture about signal system. The research team recognizes that the incorporation of various adaptive traffic control systems such as InSync and SCATS systems on major NJ corridors and networks have created a foundation for building real-time performance measures. To implement a RT-SPM system successfully in NJ, the research team has accomplished the prototype for the first phase. The following key research problems have been investigated.

Key Findings

Task 1. Review Literature, Systems, and Practices

The literature review part includes the following sections: The State of Practice on Real-Time Signal Performance Measurement, Data Needs and Measurement Methods for SPM Systems, Existing Signal Performance Measurement Systems, and detailed review of related reports, synthesis, and academic papers. The team also conducted intensive review on Utah ATSPM system and installation manual and identified ways of migrating the system to NJ.

Task 2. Organize and Facilitate Targeted Stakeholder Meetings

The meetings with the Stakeholder Committee has revealed that there is information from a number of separate data sources. A lot of post-processing of the data is not happening in real-time and requires an exhaustive post-process analysis of the data. This stakeholder meeting provided ideas about what type of performance measurements are feasible and what can be done with the collected information. They indicated that in the near future the number of adaptive signal intersections will be more than double than what they are at the time of this report. The big question is how to leverage these adaptive systems to best evaluate and manage future corridors.

Task 3. Create Inventory of Existing NJDOT Arterial Management System

The team visited Arterial Management Center and learned about several signal performance systems including InSync, SCATS, and TRANSCOM fusion application interfaces. A detailed summary of the system reviewed has been developed as one deliverable for this project.

Task 4. Identify Performance Metrics and Measurement Methods for NJDOT RT-SPM System

The team has conducted comprehensive review of SPMs that is built in ATSPM system. The team has also investigated customized SPMs that can be generated by NJDOT detector and travel time data.

Task 5. Develop System Architecture and Concept of Operations for NJDOT RT-SPM System

The team has established a bench test of the Utah's signal performance system based on data collected from a high-resolution traffic signal controller located on TCNJ's campus (atspm.lions.tcnj.edu/atspm), which is currently accessible through a VPN. To leverage the existing ATCS system, the team has developed signal event conversion program to translate SCATS and InSync history record to event code based on Indiana Traffic Signal Hi Resolution Data Logger Enumerations (2012).

Task 6. Real-Time Traffic Signal Data Management Guidelines

The team created a data management manual for adaptive traffic signal data processing. The team established meta data table for the test signal controllers; validated the algorithm results through a comprehensive debugging process. The team also completed the test to automatically connect to database using VPN and MSSQL database management system.

Task 7. Develop Deployment Strategies Considering Existing, Planned, and Future Systems

Deployment strategy is decomposed as the following steps:

1. ATSPM configuration;
2. Data export module;
3. Event Conversion Module;
4. Data Management Module;
5. Visualization Module.

Task 8. Conduct Case Studies of System Deployment

The team has started implement the process of pulling one-month data into the TCNJ ATSPM platform. The research team has worked with NJDOT to get access to the traffic signal from different intersections along selected testing corridors.

Task 9. Synthesize and Communicate Research Outcome (Technology Transfer)

Task 10. Prepare Quarterly, Draft, and Final Report

Future Work

During Phase 2, the team will create automated environment adaptive to ATSPM Data. Specific goals for future work are listed:

- 1) For phase two, the team will work with ATSC (Automated Traffic Signal Control) vendors/contractors more directly to make this project as standard ATSPM solutions.
- 2) During phase two, the research team will expand the performance metric by considering detector data. We will make this project more integrated with existing adaptive signal control systems. The second phase will make this project be more readily available for other agencies.
- 3) The project enables ATSC to generate ATSPM-like data, but the team can incorporate proprietary data from Vendor, such as queue/wait time, degree of saturation, predicted volumes, etc., into the ATSPM software.

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26. Zheng, J., Liu, H., Misgen, S., & Yu, G. (2013). Performance Diagnosis Tool for Arterial Traffic Signals. *Transportation Research Record: Journal of the Transportation Research Board*, (2356), 109-116.
27. Smaglik, E., Sharma, A., Bullock, D., Sturdevant, J. and Duncan, G. (2007). Event-Based Data Collection for Generating Actuated Controller Performance Measures. *Transportation Research Record: Journal of the Transportation Research Board*, 2035, pp.97-106.

Appendix

Appendix I. System Architecture

System Components

Entire system contains five major components: 1) Configuration Module, 2) Controller Log Export Module, 3) Event Translation Module, 4) Data Management Module, 5) Visualization Module. In configuration module, this system needs to conduct ATSPM Configuration, Software and Database Configuration, Programming Language and Packages Installation and System Setup. Controller log export module connect servers in ATSPM and database to retrieve historical controller log file. Event translator module convert SCATS/InSync high-resolution controller file to event code based on Indiana Traffic Signal Hi Resolution Data Logger Enumerations (2012). Data management module communicates with ATSPM database. For signal performance visualization module, this system provides on-demand analysis and on-line system monitoring. As shown in Figure 45.

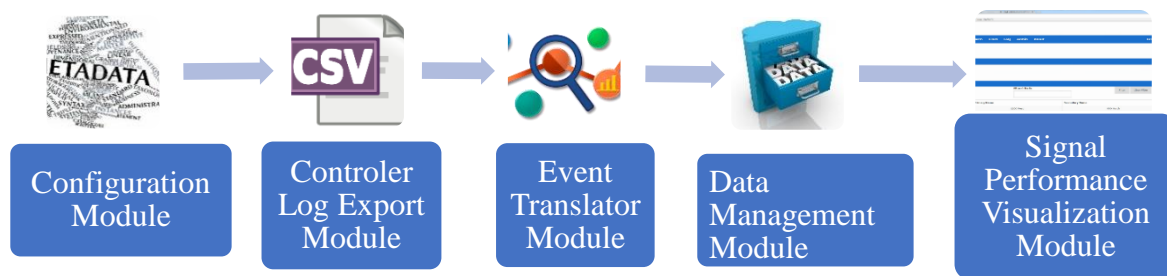


Figure 45 System Components

System Functionality

Figure 46 describes graphically the equipment, communication, and networks used by the system. System inputs includes Controller event log, signal plan, volume, speed detectors, adaptive system event files. The output includes various signal performance metrics. Those metrics can be used by arterial management center, travelers' information system and so on.

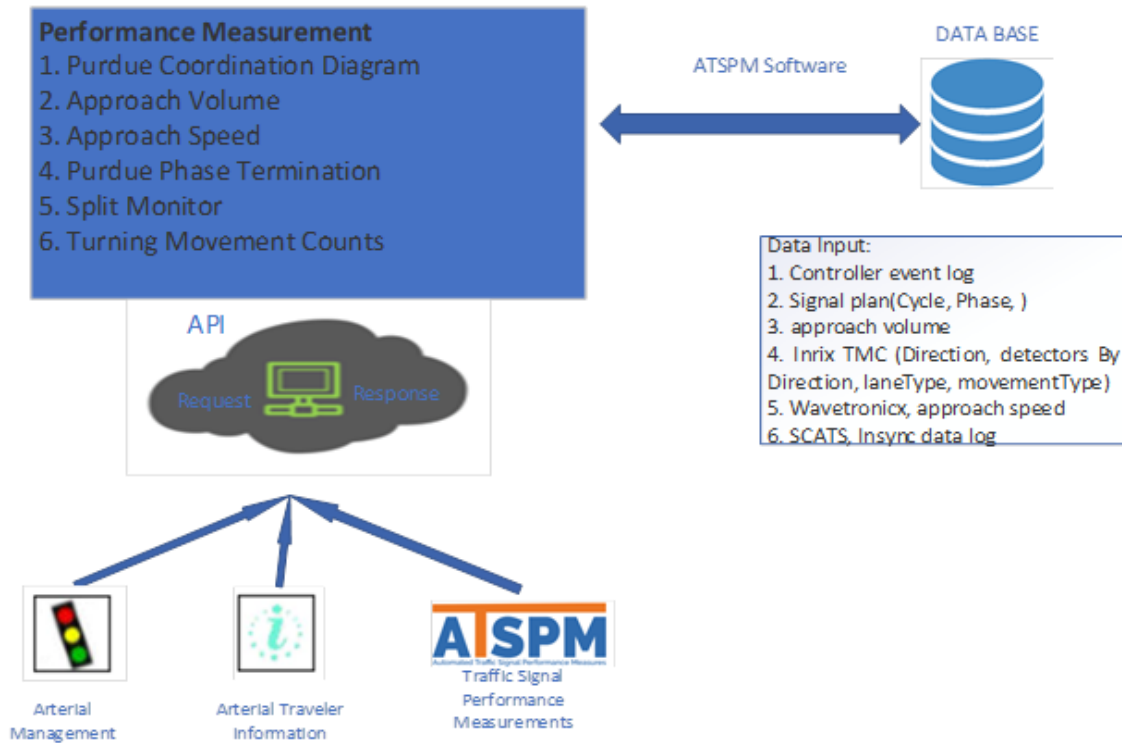


Figure 46 System Functionality

Required Hardware

The ATSPM system consists of four major hardware components: High-resolution controller, Server, Communications Equipment, and Detection.

- a. **High-resolution controller:** In this study, we select several potential testing corridors. Route 1 is controlled by InSync, while Route 18 is controlled by SCATS. InSync controller can provide queue length estimation through Samsung camera detector, estimate waiting time through stop bar detector, anticipate the rate of vehicles, estimated arrival rates. Intersections equipped with SCATS system responds automatically to changes in traffic flow based on real-time information regarding degree of saturation, arrival on green, offset/cycle provided by vehicle detectors. Web interfaces, historical files for InSync and SCATS are shown in the Figure 47.

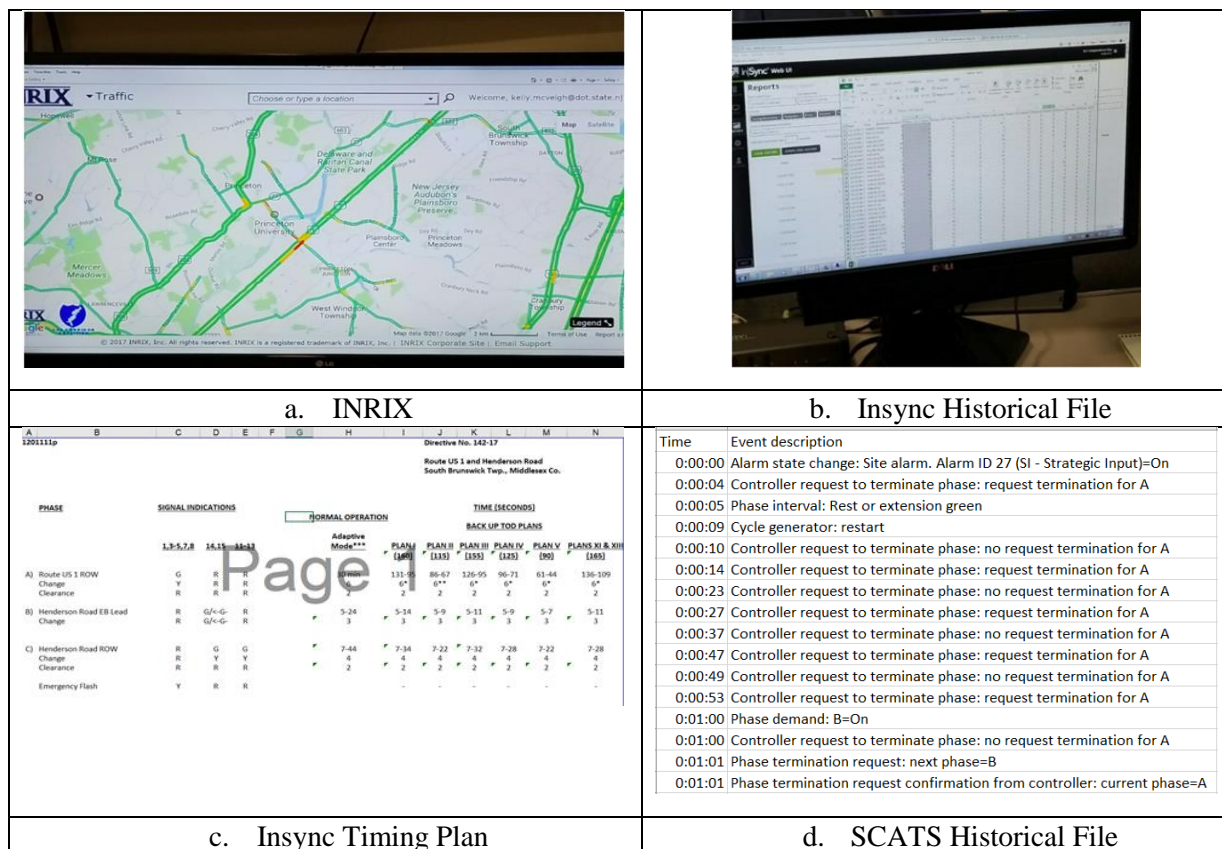


Figure 47 High-Resolution Controller: (a) INRIX Web UI (b) Insync Historical File in Traffic Management Center (c) Insync Timing Plan (d) SCATS Log File

- b. Servers:** This equipment can store the unprocessed high-resolution data, database software, and ATSPM software. Traffic management center provides server, where all programs are running. Three types servers are needed in this system, including application server, database server, and web server. Application server imports and decodes all log files; database server with the appropriate processing power, memory, interacts with all components of this system for data storage and retrieval. Web server provides chart image and display chart image to traffic engineers.
- c. Communications:** Communication equipment includes wireless router, GPS, Raspberry Pi, etc. The communication equipment connects signal controllers with ATSPM data base server and connects database with application server. The Figure 48 shows examples of communication setting-up using FTP and routers between different applications.

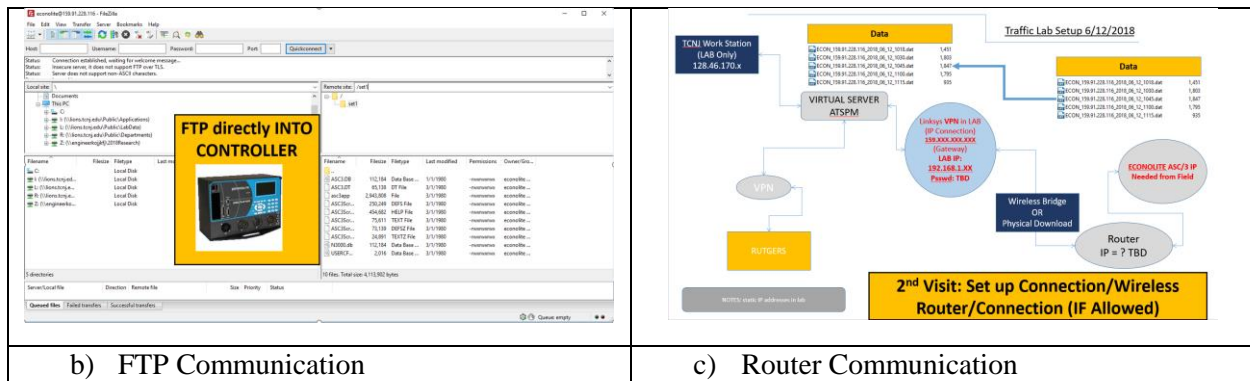


Figure 48 Communication: (a) FTP Connection (b) Wireless Router Connection

- d. **Detection (option):** Detection has three main different categories, such as lane group detector, lane-by-lane stop bar detector and advanced count. Automated Traffic Signal Performance Measures will work with any type of detector that is capable of counting vehicles (i.e. loops, video, pucks, radar). Please note that Purdue Phase Termination and Split Monitor do not use detection and are extremely useful measures.

In the Table 14, it presents performance measurements and required detectors.

Table 14 Performance Measurements and Required Detection

| MEASURE | DETECTION NEEDED |
|-----------------------------|---|
| Purdue Coordination Diagram | Setback count (350 ft – 400 ft) |
| Approach Volume | Setback count (350 ft – 400 ft) |
| Approach Speed | Setback count (350 ft – 400 ft) using radar |
| Purdue Phase Termination | No detection needed or used |
| Split Monitor | No detection needed or used |
| Turning Movement Counts | Stop bar (lane-by-lane) count |
| Approach Delay | Setback count (350 ft – 400 ft) |
| Arrivals on Red | Setback count (350 ft – 400 ft) |
| Travel Time | Historical INRIX Data |

Commonly used detector in New Jersey includes the followings:

- Wavetronics: Many controllers equipped with Wavetronics only for one or two approaches rather than the entire intersection.
- Stopbar: Stopbar detectors are available for route 130 and route 32, which is controlled by SCATS system.
- Advance Detector: Advance detectors are available on several intersections on Route 1 and Route 130.
- Autoscope Video Detector: Route 1 and Route 30 have very good camera coverage.
- 511 Cameras: 511 cameras have been deployed at only a few intersections of Route 1 and Route 130.

Required Software

The software components of ATSPM for accident site reconstruction functionality include 1) ATSPM Software 2) Event Translator Script, 3) MS SQL Software. As shown in Table 15.

- 1) ATSPM Software: The open-source ATSPM (Version 4.0.1) Software is used to calculate signal performance metrics and generate visual charts for traffic managers and public consumptions.
- 2) Event Translator Script: A python-based program is developed to translate Insync and SCATS historical log file into ATSPM recognized event file. Several Python libraries needs to be installed, including *numpy*, *pandas*, *pyodbc*, etc.
- 3) MS SQL Software: Among several types of database software, SQL Server is widely used with the open source code. Microsoft provide a free version of SQL database software, but it has size constraint of 10 GB.

Table 15 Servers and Applications

| Server | Applications |
|--|---|
| Windows Server 2008 (or newer) | <ol style="list-style-type: none">1. .NET 4.5.2 Framework is required. Newer and older versions are not supported.2. Microsoft Visual Studio (Free Community License is enough). This is for debugging and recoding the ATSPM C# code.3. Python. This is for debugging and running data retrieving and archiving code. This was written by Rutgers University. The Python Code will be searching for the SCATS and InSync folders (see item f below).4. Python Libraries (Beautiful Soup, Selenium, Requests, Shutil, os, sqlite3, etc.). This will need access to Port 3128.5. Firewall exceptions to connect to traffic signal controllers.6. Mapped Network Drives to SCATS and InSync folders.7. Access to an SMTP Server (for Watchdog/e-mail alerts). |
| IIS 7 or later. This could be on a separate Web Server or run on the application server. | <ol style="list-style-type: none">1. ASP.NET 4.0 (or newer). |
| SQL Server or SQL Server Express 2012 (or newer) | <ol style="list-style-type: none">1. Management Studio installation |

Appendix II ATSPM Installation and Data Input Instructions

(This Appendix is adapted from Georgia DOT ATSPM installation Manual:

https://traffic.dot.ga.gov/ATSPM/Images/ATSPM_Installation_Manual.pdf)

The Procedure Following these steps (Figure 49) will install the Utah Department of Transportation (UDOT) ATSPM software on a server with no previous SPM installation. Typically, all components are installed in the same server, but individual components may be housed in different locations on the network. There must be one folder on the server or network that is shared to both the website and the location of the web services.

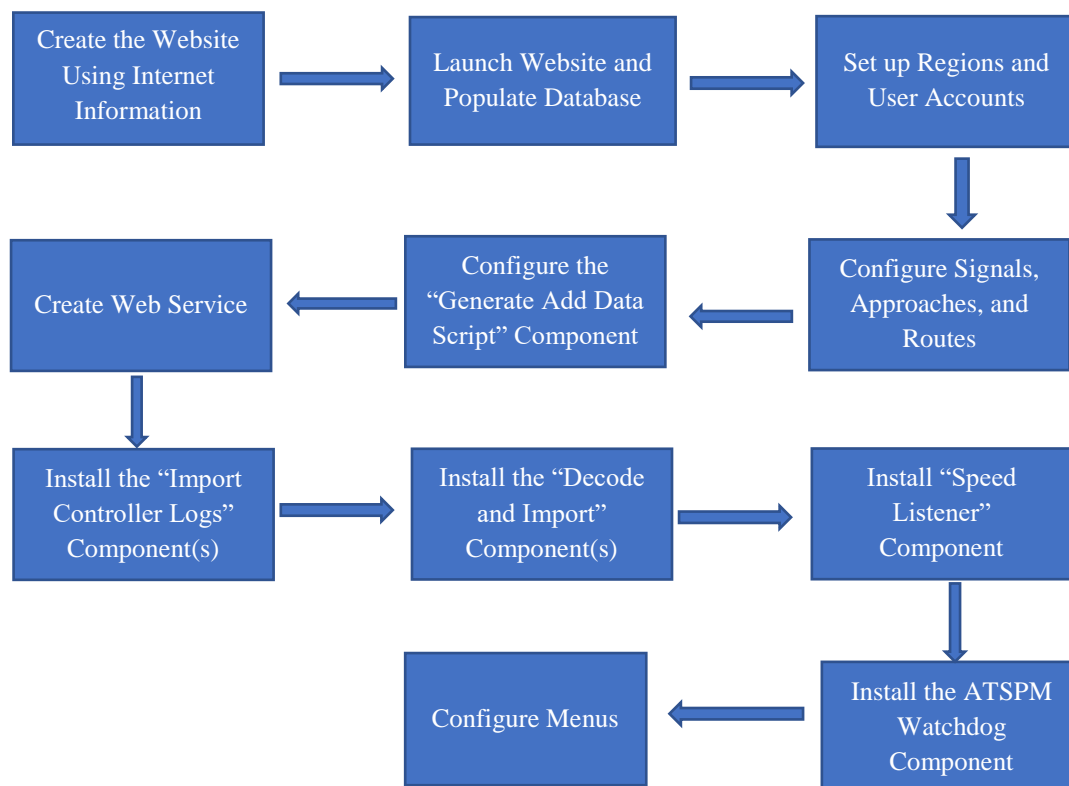


Figure 49 ATSPM Installation Flowchart

SQL Connection

The Figure 50 demonstrates how to remotely transport signal event data into database server through VPN connection. The program and database server can be in different computers. If so, we need to establish VPN connection to access the database. Python package “pyodbc” is used to connect and insert converted records into database through executing. Next step, you need to obtain server name, database name, user name and password and build connection between event convertor program with SQL database. After translating the ATSC event code into ATSPM event code, executing SQL command through python to insert the events into destination database.

MS SQL Connection and Data Loading

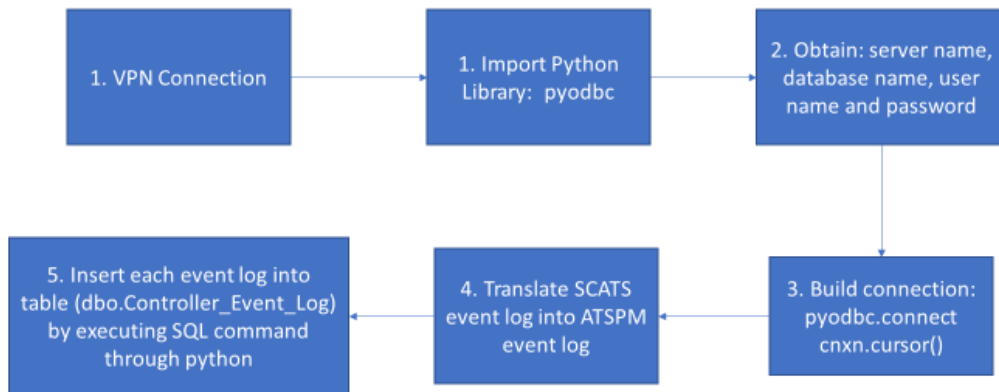


Figure 50 MS SQL Connection

Database Event Log

Table 16 Controller_Event_Log Table Field

| Field Name | Field Type | Explanation |
|------------|------------|---|
| Signal ID | int | Signal id |
| Timestamp | Datetime | Time stamp |
| Code Event | int | detector activation |
| Param | int | Event parameter, including phase start and end, actuation, etc. |

SQL:

```
CREATE TABLE [dbo].[Controller_Event_Log](
    [SignalID] [nvarchar](10) NOT NULL,
    [Timestamp] [datetime] NOT NULL,
    [EventCode] [int] NOT NULL,
    [EventParam] [int] NOT NULL
) ON [PRIMARY]
```


Appendix III Meta File Conversion Instructions

InSync Meta Data

Figure 51 illustrates how to build a metadata file for an adaptive signal intersection controlled by InSync.

Instructions to prepare Meta-data for InSync:

1. Step 1: to identify all used phases for this intersection by opening a historical InSync file.
2. Step 2: Create table containing, intersection ID, plan ID, phase Number, minimum green, maximum green, day of time, day of week, change interval and red interval, and plan type.
3. Step3: look for the original meta data file in InSync system to fill the created table in step two.

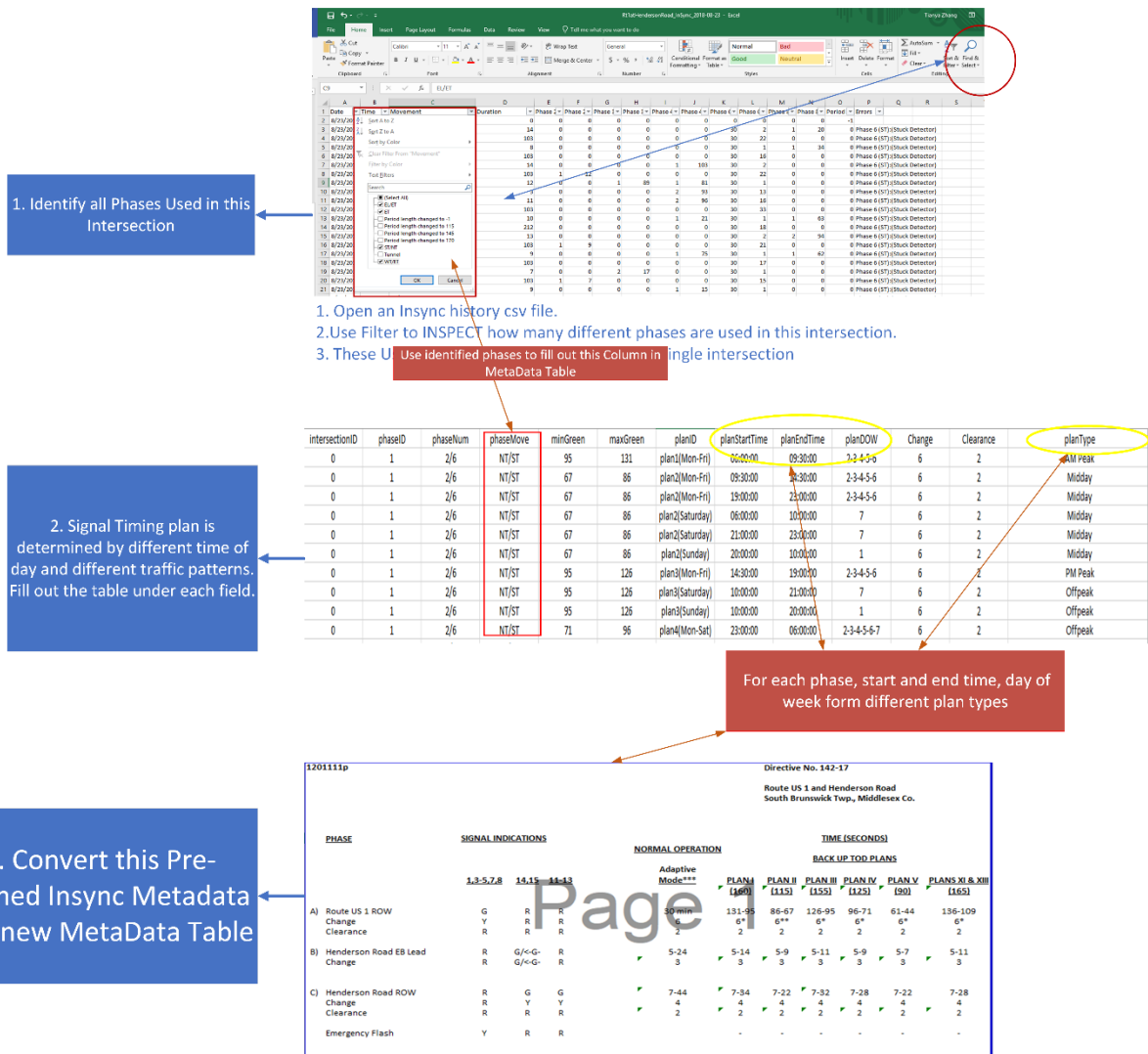


Figure 51 InSync MetaData Preparation

SCATS MetaData

Figure 52 demonstrates the interface for a SCATS controlled unconventional intersection of Route 18 at

Edgeboro, which is a complicated intersection with early-cut green, jug-handle, pedestrian signal and overlaps. Table 17 shows metadata file for this intersection. Note that SCATS can use different phase number rather than NEMA phase number. The name of fields in the excel table can be either lower case or upper-case.

Table 17 Meta Data Table for Route 18 at Turnpike-Edgeboro

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|----------------|---------|-------------|-------------------|----------|----------|--------|---------------|-------------|---------------|--------|-----------|----------|
| IntersectionID | phaseID | phaseLetter | Movements_Phase | minGreen | maxGreen | planID | planStartTime | planEndTime | PlanDOW | Change | Clearance | PlanType |
| 1808 | 1 | B | WBT, WBL (8,3,10) | 5 | 22 | None | None | None | 1-2-3-4-5-6-7 | 4 | 0 | |
| 1808 | 2 | C | EBT, WBT (4,8,10) | 15 | 32 | None | None | None | 1-2-3-4-5-6-7 | 4 | 3 | |
| 1808 | 3 | D | NBT, SBT(2,9) | 18 | 18 | None | None | None | 1-2-3-4-5-6-7 | 3 | 0 | |
| 1808 | 4 | A | NBT, SBT(2,9,6) | 7 | None | None | None | None | 1-2-3-4-5-6-7 | 5 | 3 | |

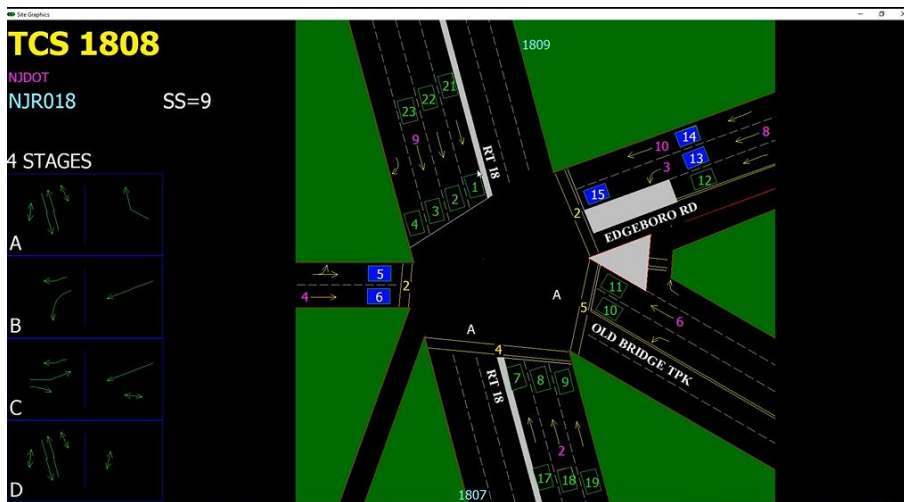


Figure 52 SCATS Phase Number and Approaches from Route 18 at Turnpike-Edgeboro

Instructions to prepare Meta-data for SCATS:

1. Step 1: To identify all used phases and associated approaches for this intersection by looking at SCATS interface.
2. Step 2: Create table containing, intersection ID, plan ID, phase Number, minimum green, maximum green, day of time, day of week, change interval and red interval, and plan type.
3. Step3: look for the SCATS historical file and meta data file to fill the created table in step two.

Meta Data Loading

The next figure shows how the metadata file was used to generate different types of signal actuation events. Firstly, we find the corresponding phase, day of time and time of data based on timestamp of current record. Secondly, we extract maximum green, minimum green, change interval and red interval from metadata table. Then, the signal phase duration was compared to minimum and maximum green time to determine signal actuation.

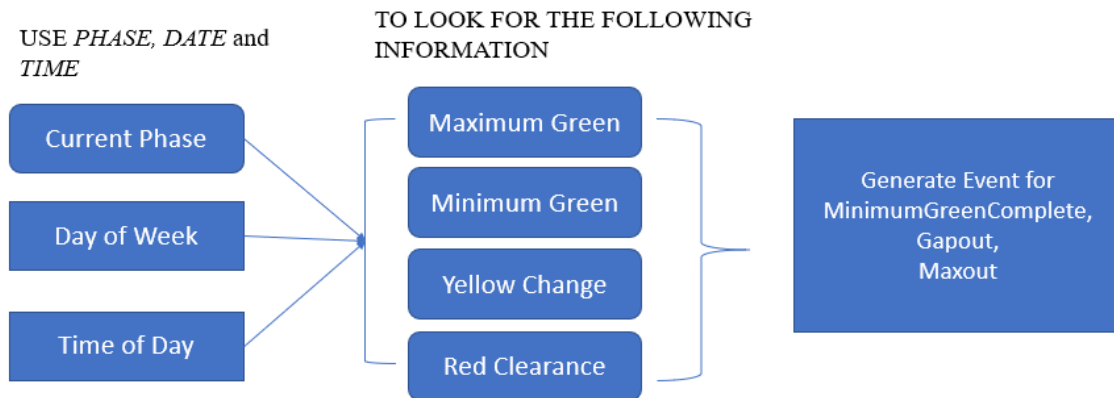
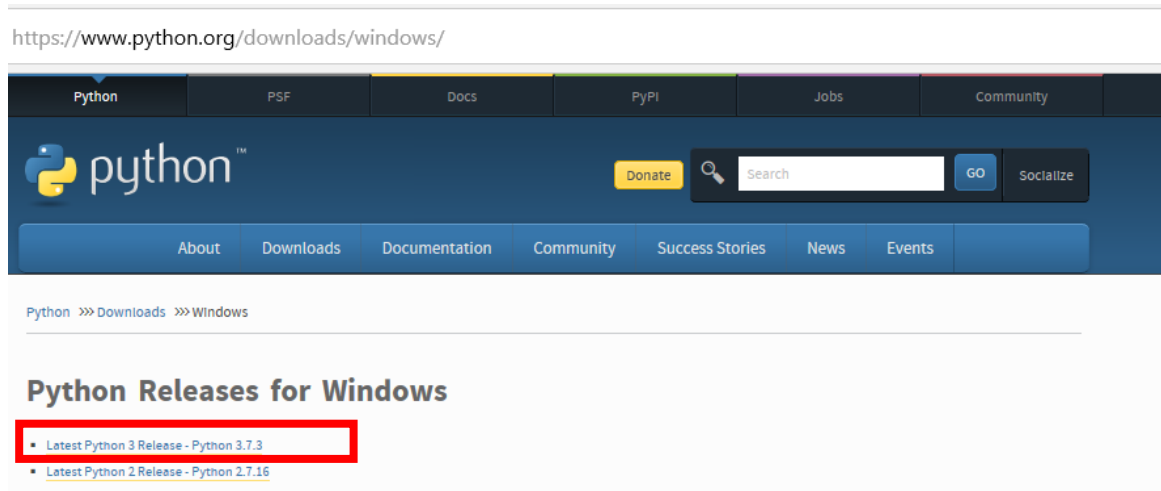


Figure 53 Meta-Data Processing

Appendix IV: Event Translator Installation and User Guide

Step 1: Download the Python 3 Installer

1. Open a browser window and navigate to the [Download page for Windows](https://www.python.org/downloads/windows/) at [python.org](https://www.python.org/).



2. Underneath the heading at the top that says **Python Releases for Windows**, click on the link for the **Latest Python 3 Release - Python 3.x.x**. (As of this writing, the latest is Python 3.6.5.)
3. Scroll to the bottom and select either **Windows x86-64 executable installer** for 64-bit or **Windows x86 executable installer** for 32-bit. (See below.)

SideNotes: 32-bit or 64-bit Python?

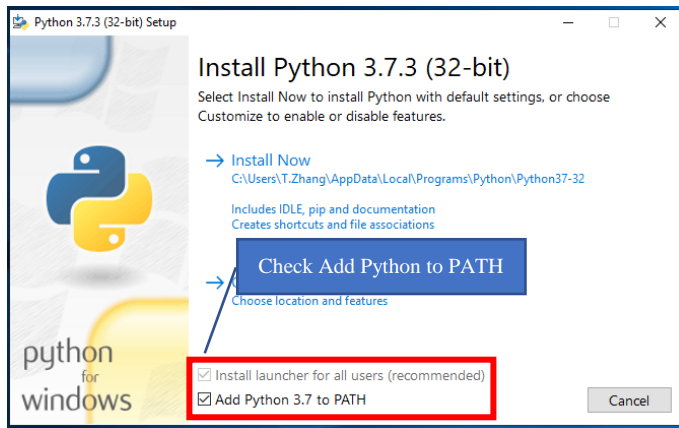
For Windows, you can choose either the 32-bit or 64-bit installer. Here's what the difference between the two comes down to:

- If your system has a 32-bit processor, then you should choose the 32-bit installer.
- On a 64-bit system, either installer will actually work for most purposes. The 32-bit version will generally use less memory, but the 64-bit version performs better for applications with intensive computation.
- If you're unsure which version to pick, go with the 64-bit version.

Note: Remember that if you get this choice “wrong” and would like to switch to another version of Python, you can just uninstall Python and then re-install it by downloading another installer from [python.org](https://www.python.org/).

Step 2: Run the Installer

Once you have chosen and downloaded an installer, simply run it by double-clicking on the downloaded file. A dialog should appear that looks something like this:



Important: You want to be sure to check the box that says **Add Python 3.x to PATH** as shown to ensure that the interpreter will be placed in your execution path.

Then just click **Install Now**. The installation will start.

Step 3: Install the packages using PIP

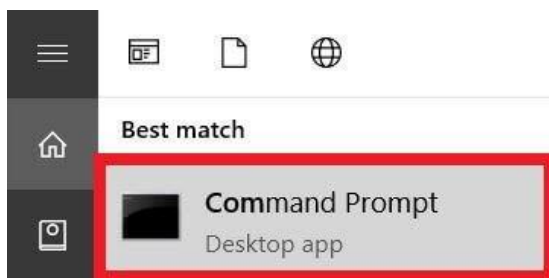
If you're using Windows, you'll be able to install a Python package by opening the Windows *Command Prompt*, and then typing this command. Follow the same steps to install packages: “numpy” , “pandas” and “pyodbc”

```
pip install package name
```

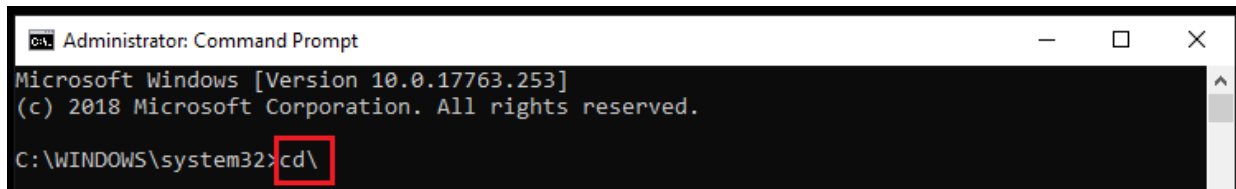
1. First, type **Command Prompt** in the Windows search box:



2. *Right click* on the Windows Command Prompt. Then, select **Run as administrator** (by running the Command Prompt as an administrator, you'll avoid any permission issues):

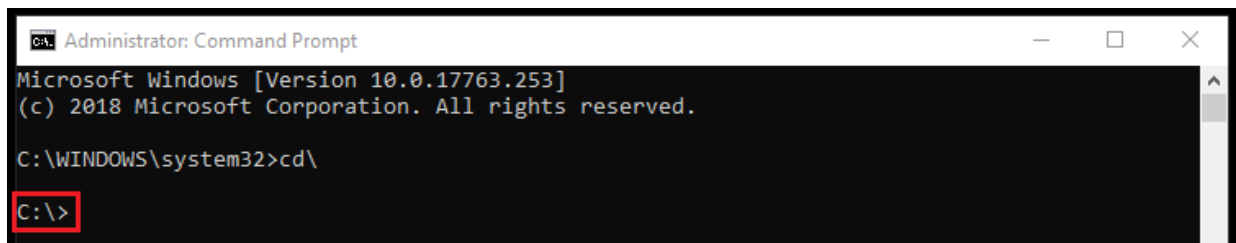


3. In the Command Prompt, type “cd\” as this command will ensure that your starting point has only the drive name:



```
Administrator: Command Prompt
Microsoft Windows [Version 10.0.17763.253]
(c) 2018 Microsoft Corporation. All rights reserved.
C:\WINDOWS\system32>cd\
```

4. Press **Enter**. Now you'll see the drive name of C:\>

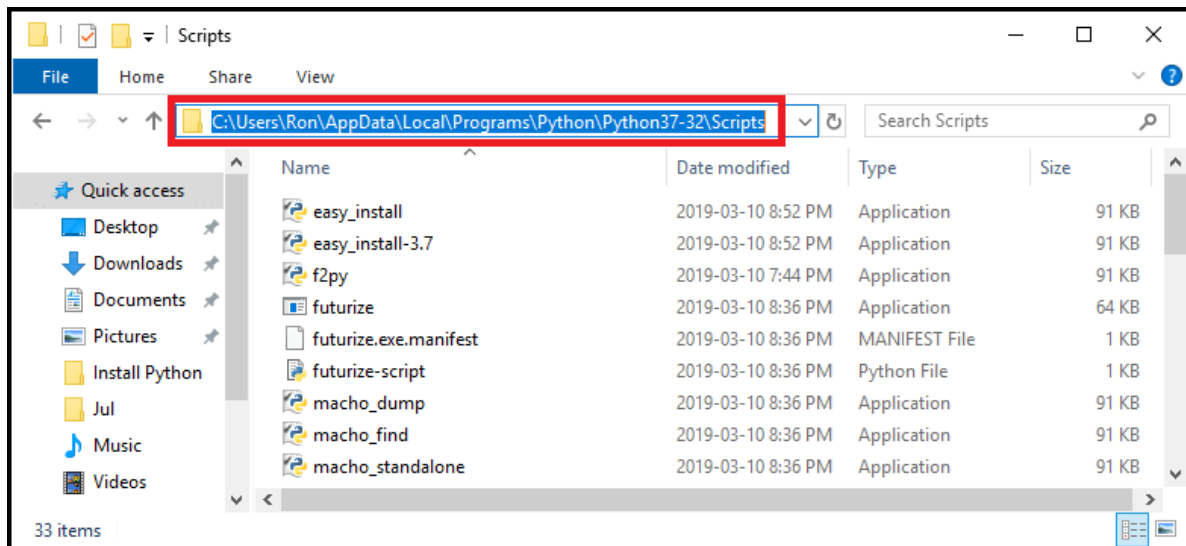


```
Administrator: Command Prompt
Microsoft Windows [Version 10.0.17763.253]
(c) 2018 Microsoft Corporation. All rights reserved.
C:\WINDOWS\system32>cd\
C:\>
```

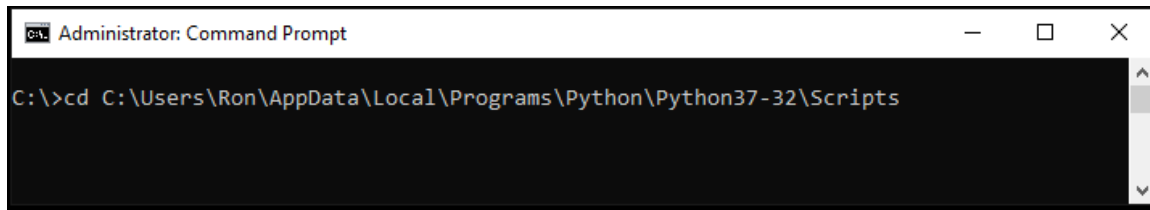
5. Locate your Python **Scripts** path. The Scripts folder can be found within the Python application folder, where you originally installed Python.

In my case, the Python Scripts path is:

C:\Users\Ron\AppData\Local\Programs\Python\Python37-32\Scripts

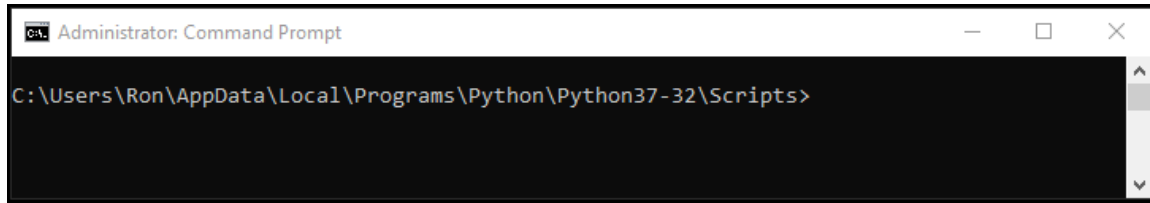


In the Command Prompt, type **cd** followed by your Python **Scripts** path:



```
C:\>cd C:\Users\Ron\AppData\Local\Programs\Python\Python37-32\Scripts
```

(6) Press **Enter**, and you'll see something similar to the following:



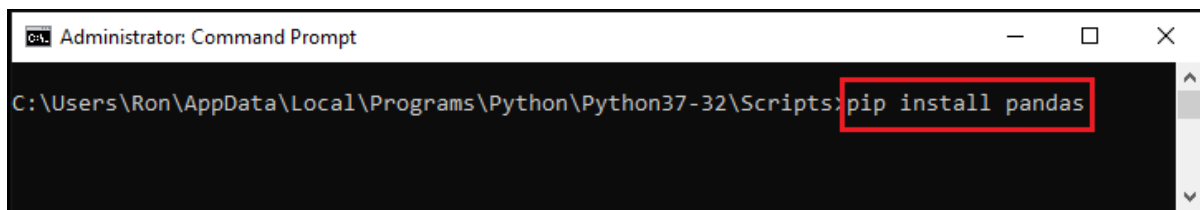
```
C:\Users\Ron\AppData\Local\Programs\Python\Python37-32\Scripts>
```

(7) Now, type the pip install command to install your Python package. The pip install command has the following structure.

```
pip install package name
```

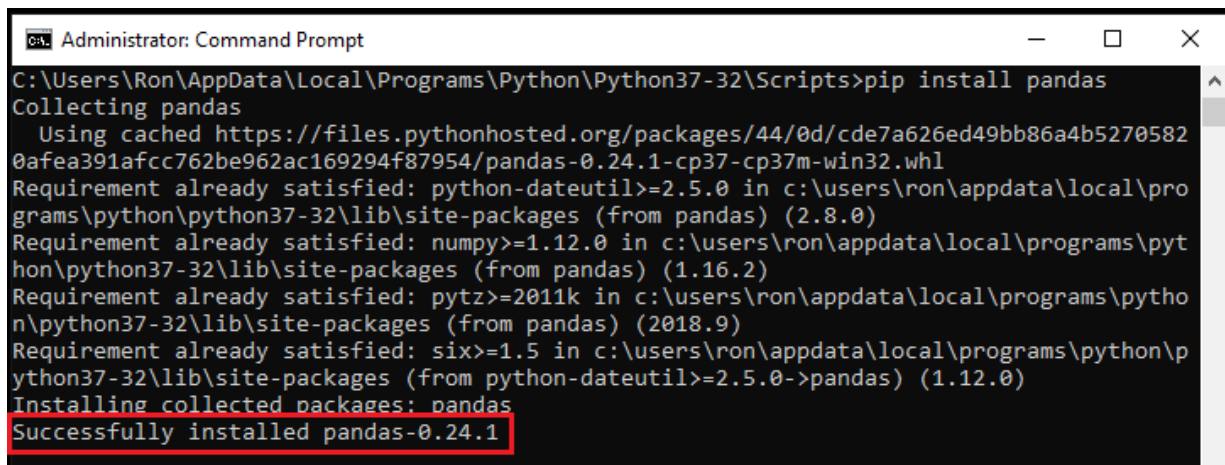
Since in our case, we would like to install the *pandas* package, then type the following command in the Command Prompt:

pip install pandas



```
C:\Users\Ron\AppData\Local\Programs\Python\Python37-32\Scripts>pip install pandas
```

(8) Finally, press **Enter**, and you'll notice that the package (here it's pandas) will be installed:



```
C:\Users\Ron\AppData\Local\Programs\Python\Python37-32\Scripts>pip install pandas
Collecting pandas
  Using cached https://files.pythonhosted.org/packages/44/0d/cde7a626ed49bb86a4b52705820afea391afcc762be962ac169294f87954/pandas-0.24.1-cp37-cp37m-win32.whl
Requirement already satisfied: python-dateutil>=2.5.0 in c:\users\ron\appdata\local\programs\python\python37-32\lib\site-packages (from pandas) (2.8.0)
Requirement already satisfied: numpy>=1.12.0 in c:\users\ron\appdata\local\programs\python\python37-32\lib\site-packages (from pandas) (1.16.2)
Requirement already satisfied: pytz>=2011k in c:\users\ron\appdata\local\programs\python\python37-32\lib\site-packages (from pandas) (2018.9)
Requirement already satisfied: six>=1.5 in c:\users\ron\appdata\local\programs\python\python37-32\lib\site-packages (from python-dateutil>=2.5.0->pandas) (1.12.0)
Installing collected packages: pandas
Successfully installed pandas-0.24.1
```

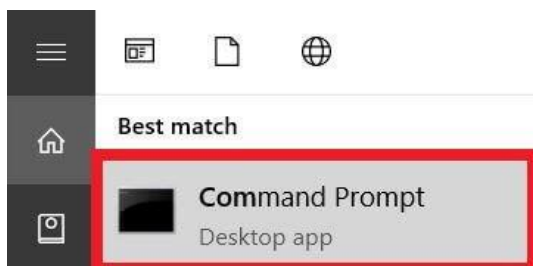
Figure 54 Install package through command line window

Step 4: Run the event convertor program

1. First, type **Command Prompt** in the Windows search box:

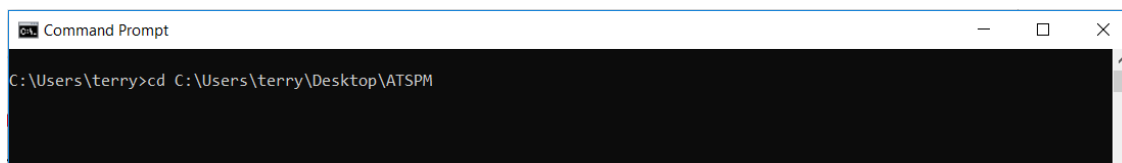


2. Click on the Windows Command Prompt.



3. Type **cd** followed by your working folder path, we will show the folder architecture in the next session. For example, the working folder path is “C:\Users\terry\Desktop\ATSPM”.

Input: cd C:\Users\terry\Desktop\ATSPM



You will see the following:

```
Command Prompt
C:\Users\terry>cd C:\Users\terry\Desktop\ATSPM
C:\Users\terry\Desktop\ATSPM>
```

4. Run the Program

1) Type in the following commands

a. InSync run:

“python Insync_convertor.py InSync_file_folder meta_file_folder ”

b. SCATS run:

“python SCATS_convertor.py SCATS_file_folder meta_file_folder ”

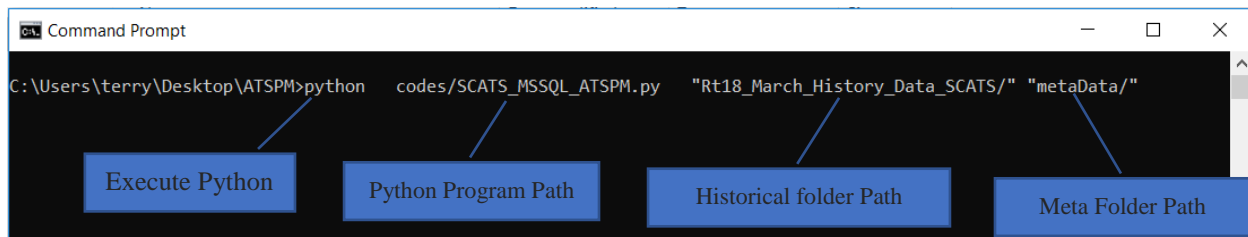


Figure 55 command line example of running the converter python program

```
python codes/SCATS_MSSQL_ATSPM.py "Rt18_March_History_Data_SCATS/" "metaData/"
```

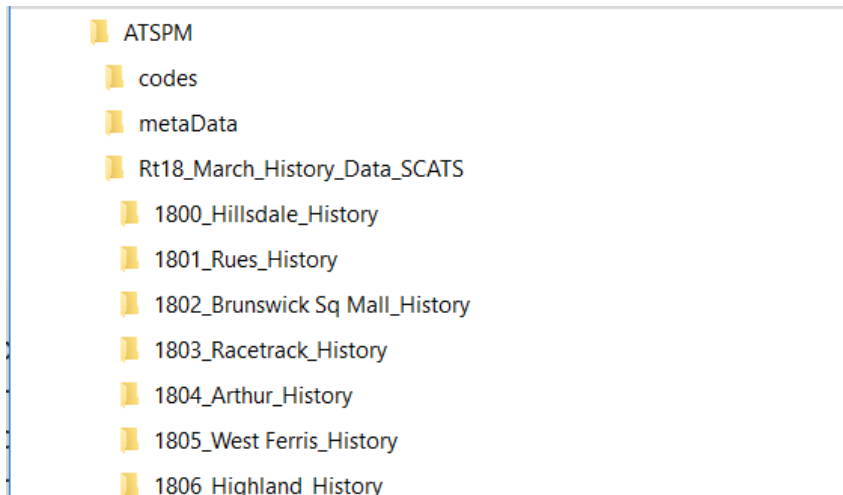
There are four parts in the commands:

1. **python:** to call the python program
2. **codes/SCATS_MSSQL_ATSPM.py:** python code path
3. **"Rt18_March_History_Data_SCATS/":** historical file folder path
4. **"metafiles/":** meta file folder path

Folder Structure and Configuration

1. Folder Structure

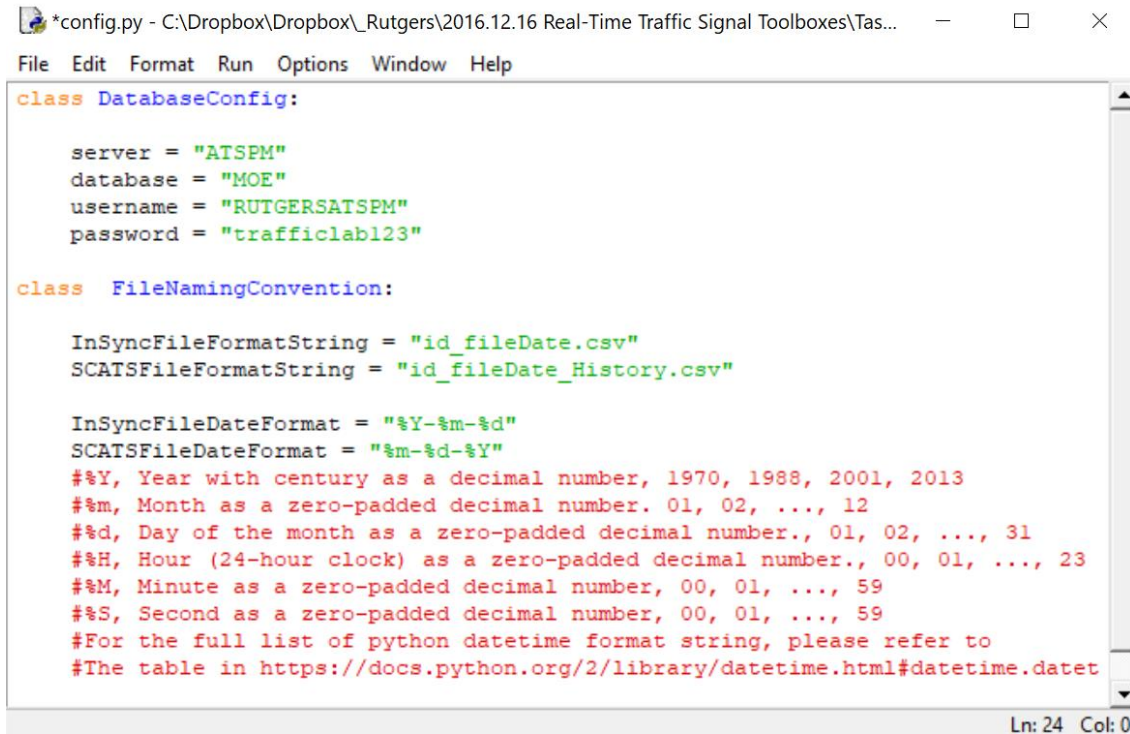
An example of Folder Structure is shown as following. The working folder is named as ATSPM/. There are three sub folders in the main folder, codes/, metadata/, and historical file folder



2. Python Code Configuration

The configuration of the Python Code parameters is done through modifying config.py file, which is under the folder of codes. There are two classes, DatabaseConfig and FileNamingConvention. DatabaseConfig is used to store the database information, including server, database name, user name and password, etc.

FileNamingConvention is used to setting the historical file name. As the *signal ID* and *date* information is read through file name, user has to make sure the historical file name is consistent to the configuration.



```
*config.py - C:\Dropbox\Dropbox\Rutgers\2016.12.16 Real-Time Traffic Signal Toolboxes\Tas...
File Edit Format Run Options Window Help

class DatabaseConfig:

    server = "ATSPM"
    database = "MOE"
    username = "RUTGERSATSPM"
    password = "trafficlab123"

class FileNamingConvention:

    InSyncFileFormatString = "id_fileDate.csv"
    SCATSFileFormatString = "id_fileDate_History.csv"

    InSyncFileDateFormat = "%Y-%m-%d"
    SCATSFileDateFormat = "%m-%d-%Y"
    #%Y, Year with century as a decimal number, 1970, 1988, 2001, 2013
    #%m, Month as a zero-padded decimal number. 01, 02, ..., 12
    #%d, Day of the month as a zero-padded decimal number., 01, 02, ..., 31
    #%H, Hour (24-hour clock) as a zero-padded decimal number., 00, 01, ..., 23
    #%M, Minute as a zero-padded decimal number, 00, 01, ..., 59
    #%S, Second as a zero-padded decimal number, 00, 01, ..., 59
    #For the full list of python datetime format string, please refer to
    #The table in https://docs.python.org/2/library/datetime.html#datetime.datet

Ln: 24 Col: 0
```

File Date Format string. The python code uses the date format string to recognize the data string in the file name. The format of the date strings are specified in InsyncFileDateFormat and SCATSFileDateFormat. The detailed meaning of the format string can be found in the above code. The format string is currently compatible with the filenames as specified in the 1. Folder structure.