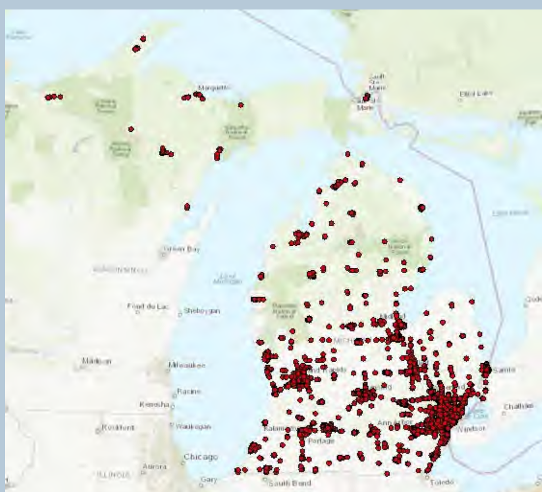
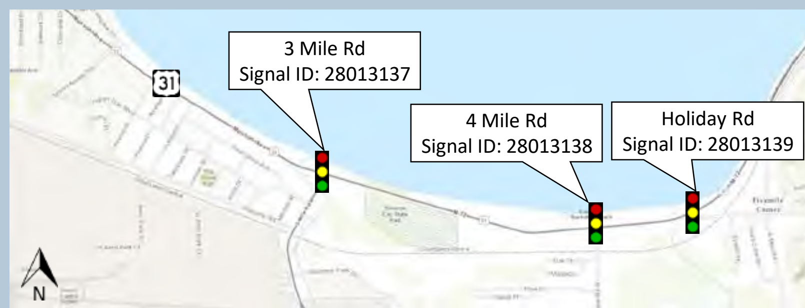
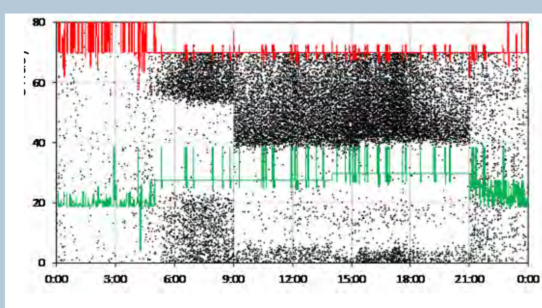
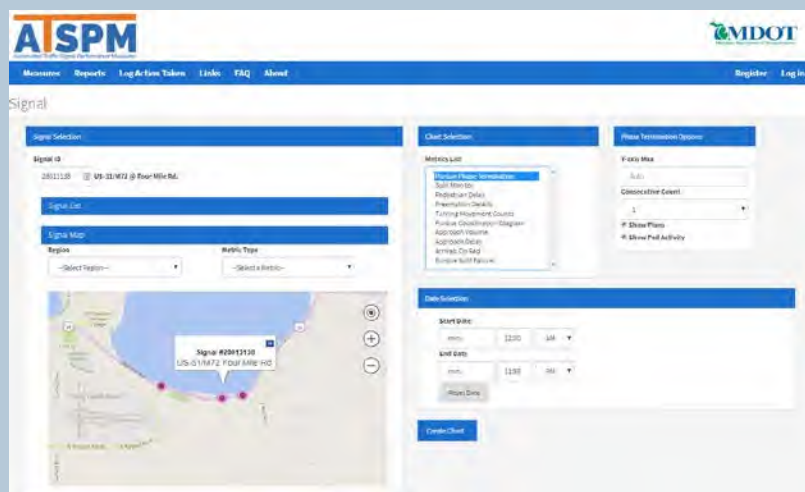
MDOT Signal Performance Measures Pilot Implementation









OR16-002 Final Report

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16. Abstract

The Michigan Department of Transportation (MDOT) is interested in finding a solution to typical traffic signal system concerns using new high-resolution signal controller data and performance measurement techniques. The strategy for this project was to implement two corridors in the state of Michigan with data logging controllers and implement the Automated Traffic Signal Performance Measure (ATSPM) software developed by the Utah Department of Transportation (UDOT). The ATSPM software and data from this platform were used to evaluate and optimize the two corridors and then monitor the performance of the corridors over time. An assessment was then performed to determine the potential cost to deploy such a system on Michigan roadways and to estimate the benefit it may provide to MDOT and roadway users. Recommendations were then made to MDOT on how to proceed with the deployment and development of this technology.

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5 EXECUTIVE SUMMARY

The Michigan Department of Transportation (MDOT) is actively pursuing advanced techniques and technologies to better design, maintain, and operate the roadways in the state. MDOT is interested in finding a solution to typical traffic signal system concerns using new high-resolution signal controller data and performance measurement techniques. These concerns include re-timing schedules, signal timing degradation over time, identification of delay hotspots along a corridor, identification of equipment failures impacting operations and the cost-benefit assessment of improvements. Typically, State DOTs and local agencies lack the time and resources necessary to monitor numerous locations in a pro-active manner and instead are left to work in a reactive manner addressing issues as they arise and come to their attention. Recently, new strategies for performance reporting along signalized corridors have been established and implemented in numerous states nationwide. The objective of this project was to deploy, monitor, and assess the first Automated Traffic Signal Performance Measure (ATSPM) system on an MDOT owned and operated roadway.

This project was both a pilot deployment and a research project to both implement and assess potential costs and benefits associated with deploying signal performance measures (SPM) in the state of Michigan. Two corridors were equipped with additional vehicle detection, communication, and data logging controllers for the purpose of implementing the Utah Department of Transportation's open source ATSPM software. The corridors selected were located in Traverse City, MI and Holland, MI. The two corridors were chosen by MDOT as a result of other planned traffic signal system enhancement projects and the fluctuations in traffic demands each corridor experiences as a result of seasonal tourism travel. A total of 12 intersections were equipped and monitored using the software. A primary deliverable for this project was to assess the costs and potential benefits associated with the deployment of ATSPM's. The additional equipment and labor costs were documented during this project. The primary benefit (reduction in user delay) was estimated comparing probe data before and after timing adjustments were made based on ATSPM data. A survey of region electricians was performed to assess current MDOT maintenance practices, and peer agency meetings and phone calls were conducted with DOT's that are currently using ATSPM systems to monitor traffic signal performance.

This pilot ATSPM research project resulted in significant benefits realized by actual reductions in travel times along the pilot corridors. This project also provided the basis for estimating costs associated with the deployment of ATSPM's, including initial and ongoing operations and maintenance efforts. Peer agency surveys reveal funding, organizational, and staffing adaptations which may be necessary for MDOT to implement ATSPM's on more corridors. The ATSPM system is a tool that can be used to assist traffic engineers to better maintain and operate signalized corridors, but in order to fully maximize the potential benefits a strategy is needed to prioritize deployments, provide adequate monitoring and maintenance staff, and introduce new roles and responsibilities for both MDOT and contracted services. A conceptual deployment and staffing plan are included at the conclusion of this report summarizing proposed deployment phasing, internal and consultant staffing roles, total staffing requirements, and the conceptual location of where new staff services may be provided within existing MDOT Transportation Operation Centers (TOCs). ATSPMs are relatively new and still evolving, but this project indicates significant potential benefits at attractive benefit to cost ratios. An initial step toward statewide deployment is to focus on enhancing communication and detection at traffic signals while integrating

ATSPM utilization into other MDOT initiatives including connected and automated vehicles, adaptive systems, TSMO, and central signal system management systems.

5.1 Key Research Findings

- The annualized user delay benefits realized using the ATSPM data to optimize the offsets on these corridors was $1,048,957.
- Using the annualized user delay benefits ($1,048,957) and actual incurred costs ($370,554), this pilot research project has a BCR of 2.8 to 1.
    - Costs include research contract $218,941.36, equipment costs $132,050, and MDOT labor $19,563)
- Including estimated safety benefits, maintenance benefits, initial optimization benefits, and continuous operational benefits the estimated benefit to cost ratio of a statewide signal performance measure system is approximately 25 to 1.
- A four level system was developed considering both the equipment and staff monitoring levels for traffic signals:
    - Level 0: Consists of a signal installation with communications but no detection and current MDOT monitoring practices
    - Level 1: Includes level 0 equipment plus a data logging traffic signal controller, and incorporates FHWA recommended practice of retiming traffic signals every three to five years
    - Level 2: Includes Level 1 equipment plus side street detection, and incorporates biannual seasonal timing adjustments
    - Level 3: Includes level 2 equipment plus advanced detection on mainline, and incorporates monthly timing adjustments
- The cost to fully equip an existing intersection with side-street and advanced mainline detection, communication, and a data logging controller is approximately $46,125. This is the 10-year estimated cost for an intersection including detection, communication, equipment, and installation. Additionally, there are initial deployment costs, including setting up and verifying the detection in the field. This cost is estimated to be $1,656 per intersection.

6 INTRODUCTION

The Michigan Department of Transportation (MDOT) is interested in finding solutions to typical traffic signal system concerns using new high-resolution signal controller data and performance measurement techniques. These concerns include re-timing schedules, signal timing degradation over time, identification of delay hotspots along a corridor, and the cost-benefit assessment of improvements. Typically, State DOTs and local agencies lack the tools and resources to monitor numerous locations in a proactive manner and instead respond reactively after signal timings degrade enough to trigger a phone call from the public. Recently, new strategies for performance reporting along signalized corridors have been established and implemented in numerous states nationwide. The strategy for this project was to implement two corridors in the state of Michigan with data logging controllers and implement the Automated Traffic Signal Performance Measure (ATSPM) software developed by the Utah Department of Transportation (UDOT). The ATSPM software and data from this platform were used to evaluate and optimize the two corridors and monitor the performance of the corridors over time. A cost-benefit assessment was then performed to determine the potential cost to deploy such a system on Michigan roadways and estimate the benefit it may provide to MDOT and roadway users.

6.1 PROBLEM STATEMENT AND BACKGROUND

There are opportunities to leverage existing vehicle detection at intersections to improve the monitoring of traffic. A robust method for the collection of high-resolution signal controller data has been developed over the last ten years at Purdue University in West Lafayette, IN [1 - 10]. The premise of collecting such signal data is to use advanced traffic controllers to collect and log information at an intersection which can then be used to analyze the signal's performance. This information includes: phase changes, pedestrian events, detector events, barrier/ring events, preemption events, phase control events, overlap events, and coordination events. The information is logged by the controller and can be archived in a database server for future use. Figure 1 illustrates how this high-resolution signal data works. The benefits of a system that automatically logs data is both the scalability over numerous intersections and the ease of collecting data over time.

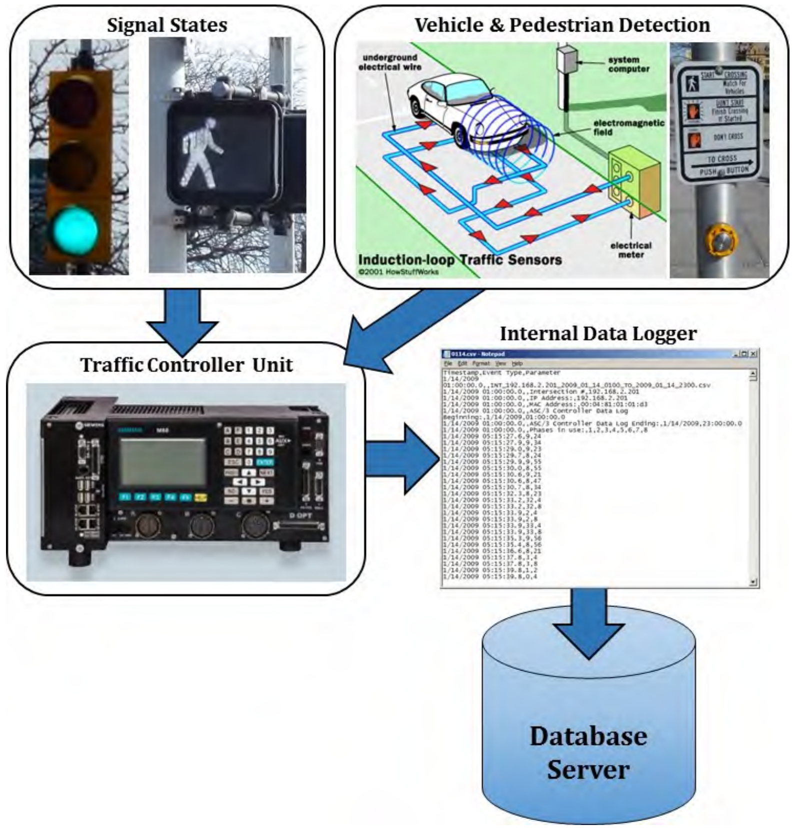


Figure 1. High-resolution signal controller data schematic

The data sets that are collected through the traffic controller were defined by a series of data enumerations developed with the Indiana Department of Transportation, Purdue University, and three major traffic controller vendors in the United States (Siemens, PEEK, and Econolite) [8]. The main benefit of having all three major controller companies agree on these enumerations is a uniform system to create performance measures that are scalable across all intersections with various brands of data-logging controllers. The enumerations provide a specific “Event Code” for each type of data collected at an intersection. Currently there are 256 event codes reserved for use in the data enumerations table. These data enumerations are the foundation for the quickly growing topic of “Signal Performance Measures”, or SPMs. SPMs are quickly being adopted at local, regional, and national levels and have numerous benefits to both the traveling public and operations engineers [3,4,5,6].

There are numerous ATSPMs that have been developed, tested, and implemented. Selected examples are listed and explained in sections below. As these signal performance measures are being implemented, systems are being developed to store, compile, and share this high-resolution signal controller data in real-time, thereby creating a rich data environment to explore the development opportunities of traffic signal performance. Recently featured in the ITE Journal, Automatic Traffic Signal Performance Measures are being implemented and deployed nationwide. The three implementation examples highlighted in the article were Indiana, Las Vegas, and Utah [9]. Utah was introduced to ATSPMs in 2012 by Purdue University and the Indiana Department of Transportation. Since then, UDOT has implemented a state-of-the-art signal performance measures website and publicly shared the source code [11]. This UDOT source code is the basis for this research project; it was used to develop a similar dashboard that may be used on

Michigan roadways. Georgia DOT has similarly adopted this open source framework into their traffic monitoring approach as well.

6.2 Research Objectives

The purpose of this project was to understand and quantify the costs and benefits associated with deploying an Automated Traffic Signal Performance Measures (ATSPM) System in Michigan. ATSPMs are becoming widely adopted nationwide for several reasons including: improved operations, improved maintenance practices, less down time for failed signals, and improved monitoring of agency goals. This project will provide an overview of the costs and benefits associated with the MDOT pilot deployment and discuss other benefits that are seen from around the country. The project objectives of the entire project are highlighted below:

I. Provide to MDOT management an assessment of the cost/benefit of monitoring signal operations using ATSPM's

II. Provide recommendations to MDOT management for staffing and funding levels necessary to monitor signal operations in real time

III. Provide recommendations to MDOT signal operations on equipment and communications infrastructure

IV. Provide a recommended approach utilizing existing equipment/infrastructure where feasible and prioritizing corridors/intersections for monitoring

V. Provide daily trouble reports for signal maintenance and engineering staff using ATSPM's and TACTICS.

6.3 Motivation

The motivation of this study is to improve the current operation of MDOT owned traffic signals. The Federal Highway Administration (FHWA) recommends signals be retimed every three to five years. This pattern of signal retiming is similar to the FHWA practice of pavement rehabilitation. Figure 2 illustrates this practice. After initial construction the pavement degrades until a rehabilitation is performed, this then extends the service life of the pavement to maximize the use of the pavement. Similarly, signal timings can be imagined in the same sense. Figure 3 illustrates two management practices for traffic signal monitoring. The first is the FHWA recommended practice of signal retiming in three to five year increments. The issue with this practice is when detrimental events occur on a corridor such as a sudden increase in volume, a detector failure, or a sudden timing issue they often go unnoticed until the next scheduled retiming or preventative maintenance visit. Signal management with ATSPMs allows an agency to complete a better initial optimization as the data collected at the intersection is more detailed and comprehensive when compared to data used for traditional optimizations. Additionally, when detrimental events occur they are discovered by both continuous and routine monitoring either through use of system reports/alarms, or manual reviews/observations and more promptly addressed. This provides substantial benefit in the form of both user cost reductions and agency costs relative to manually diagnosing and responding to changes in the system. This benefit can be realized when considering five recent signal optimization studies performed by consultants for MDOT. Figure 4 represents a summary of these five projects, all resulted in a substantial cost savings over one year and Benefit Cost Ratios (BCR) of over 15:1.

While these projects can be labeled as a success because of the high BCR, they may actually better represent an opportunity for process improvement as they highlight how inefficient signal timings and changes in traffic patterns went undetected and/or unaddressed.

Properly managing signal timings in the traditional sense would be costly. MDOT currently invests $750,000 per year for signal optimization projects. Considering the amount spent on the five projects below and the 3,143 signals currently owned by the agency, MDOT would need to increase the funding to $3.1 million just to meet the minimum threshold of five year signal retiming set by FHWA (Table 1). This demonstrates a need for additional funding, but does not address the opportunities of continuously monitored signals using ATSPM. The motivation of this project is to investigate what it would truly require from a financial, equipment, and personnel standpoint to deploy such a system and to display and quantify the benefits of deploying such a system.

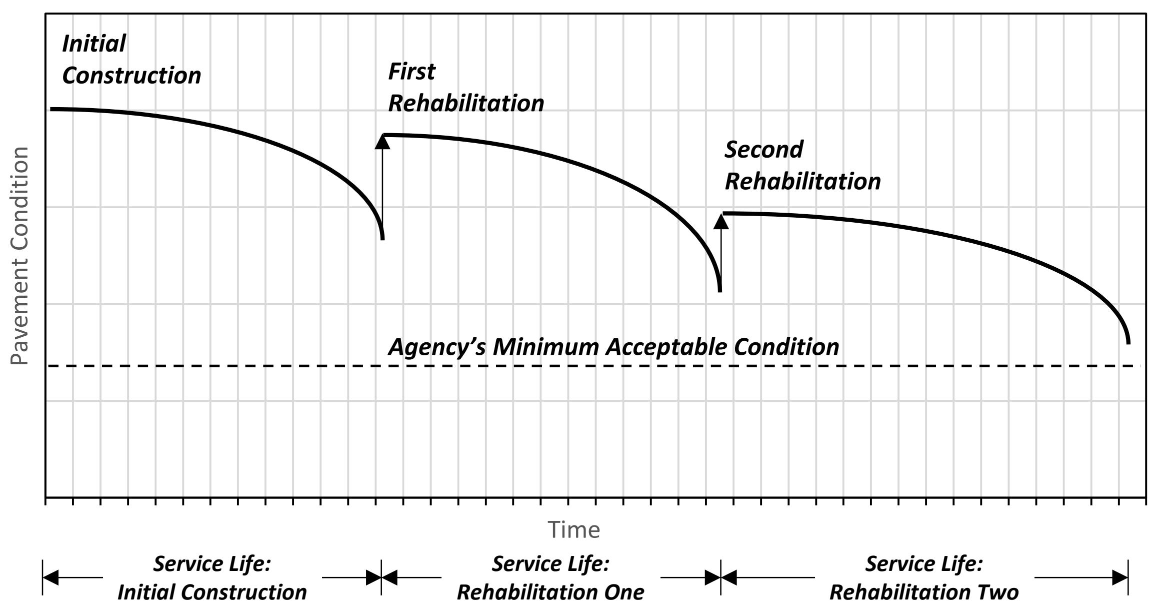


Figure 2. Example lifetime of one pavement design alternative [Adopted from FHWA (1)]

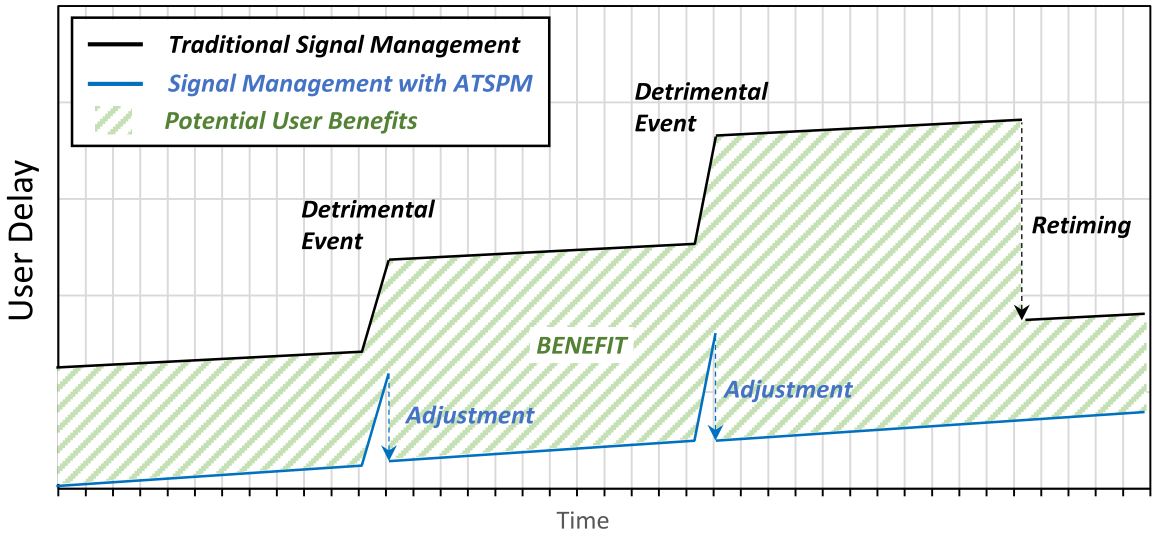


Figure 3. Example of user delay with recommended signal approaches and ATSPMs

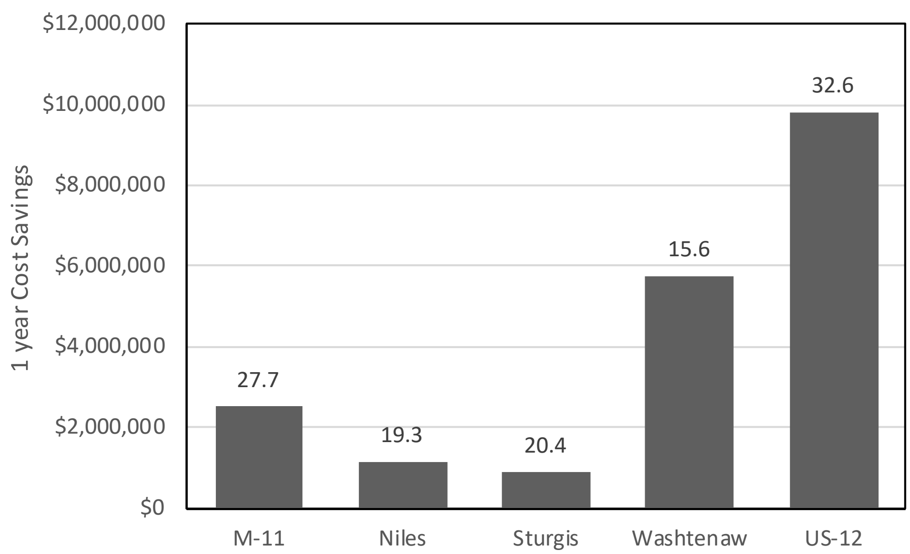


Figure 4. Cost savings of five signal optimization studies in Michigan (benefit cost ratio included)

Table 1. FHWA recommended signal spending applied to MDOT

Current MDOT Retiming Costs	
Number of signals Retimed	174
Total Cost of Retiming Projects	$ 866,700.00
Average Cost Per Signal	$ 4,981.03
5 Year Retiming Cost Per Signal	$ 996.21
Cost to Retime All MDOT Per Year	$ 3,131,078.28

7 LITERATURE & MDOT REVIEW

7.1 OVERVIEW

Automated Traffic Signal Performance Measures are currently being adopted in numerous cities and states across the country. The utilization of detector based data and data logging controllers to create systematic performance measures allows for the monitoring and prompt identification of poorly performing intersections. Producing these measures requires significant physical infrastructure including detection, communication, and data logging signal controllers. The physical infrastructure changes necessary to deploy ATSPM also provide additional functionality to an agency in terms of signal system operations and central system management. Most agencies leverage existing vehicle detection at intersections, however intersections without any detection need to be equipped with infrastructure prior to implementing the full suite of SPMs. ATSPM data are logged at tenth of a second resolution and include any status change that occurs at an intersection. These status changes include detector actuations, phase changes, pedestrian events, preemption events, and coordination events. These data are logged by the controller and sent to a server for storage and processing, allowing for the computation of volumes, turning movement counts, percent arrivals on green (POG), and delay. Using these data to manage arterial signal systems, it is possible to identify and fix offset issues and improve split times, resulting in reduced travel times and delay (1,2,3). One additional benefit of this system is that it provides means to collect data continuously, including weekends and off-peak times when performance is typically not assessed. This continuously collected data can reduce bias caused by models based on limited data from short sample periods which is common with standard engineering practices (4). ATSPMs provide in-depth insight into real-time conditions, but come with substantial infrastructure costs. Installation, maintenance, and operating costs have slowed the pace at which ATSPMs have become commonly adopted. The recurring physical infrastructure costs are perhaps the largest hesitation for widespread adoption of ATSPMs; however through deployment of the infrastructure required to support ATSPMs agencies also obtain a higher functioning and more capable traffic signal system that can deliver increased benefits to both the agency and the roadway users.

7.2 CURRENT ATSPM DEPLOYMENTS

Numerous state DOTs are currently using ATSPMs as part of their day to day operations. The two states with the largest deployments nationwide are Utah and Georgia. These two states were interviewed and a general comparison of funding and staff is provided in Table 2. The most notable differences involve resources specifically dedicated to signal operations and maintenance (O&M). The number of signals per equivalent full-time employee (FTE) dedicated to signal operations (engineer), and the number of signals per equivalent FTE dedicated to signal maintenance (electrician/technician) are critical measures of an agency's capacity to operate and maintain their traffic signals. The central office O&M funding per signal appears to be an indicator of how developed the agency is in implementing a more integrated approach to operating and maintaining their traffic signal system. Both Utah and Georgia indicate that ATSPMs provide enough value for their maintenance management practices alone to substantiate its continued use. Both Utah and Georgia currently have two to three times less signals per engineer/electrician AND they are equipped with ATSPM systems allowing them to more effectively manage their signals.

Table 2. DOT Comparison

	UDOT	GDOT	MDOT
Total Number of Signals Owned by the DOT	**1250**	**6500**	**3143**
Total Number of Signal Maintained by DOT	**1250**	**5445**	**1645**
Total Number of Signals Equipped with ATSPM's	**1710***	**4640***	**12**
Equivalent Engineer FTE's dedicated to Signals O&M (No design or construction)	**9**	**60**	**6**
Equivalent Electrician FTE's dedicated to Signals O&M (No other electrical work)	**25**	**75**	**12**
Signals Maintained by DOT per (Equivalent Engineer FTE's dedicated to Signals O&M)	**146**	**91**	**275**
Signals Maintained by DOT per (Equivalent Electrician FTE's dedicated to Signals O&M)	**50**	**73**	**143**
Central Office Funding for O&M Signals	**$5,000,000**	**$45,500,000**	**$1,000,000**
Other Funding for Signals (Non O&M)	**$9,400,000**	**$20,000,000**	**$23,600,000**
Total Funding for Signals	**$14,400,000**	**$65,500,000**	**$24,600,000**
Total Funding per Total Signals	**$11,520**	**$10,077**	**$7,827**
Central Office O&M Funding per Total Signals	**$4,000**	**$7,000**	**$318**

*includes signals not owned/operated by DOT

7.3 MDOT

7.3.1 Signal Inventory

MDOT currently owns 3,143 signals throughout the state of Michigan (Figure 5). Table 3 shows the breakdown of signals owned and operated per region. The MDOT signal inventory also includes communication type, detection type, controller type, and other statistics regarding the age of certain equipment. These numbers can be used to estimate the total cost of deploying an ATSPM system. The inventory serves a very valuable purpose and does need to be maintained and updated for proper management practices. Additionally, it would be beneficial to include a thorough documentation of both the current timing plans, the plan drawings of the intersection, and the detector channel setup of the intersection. This will improve the speed and accuracy to deploy a statewide ATSPM system. It can also assist in the management and monitoring practices of state signal engineers. A summary of the statewide signal inventory can be found in Appendix A.

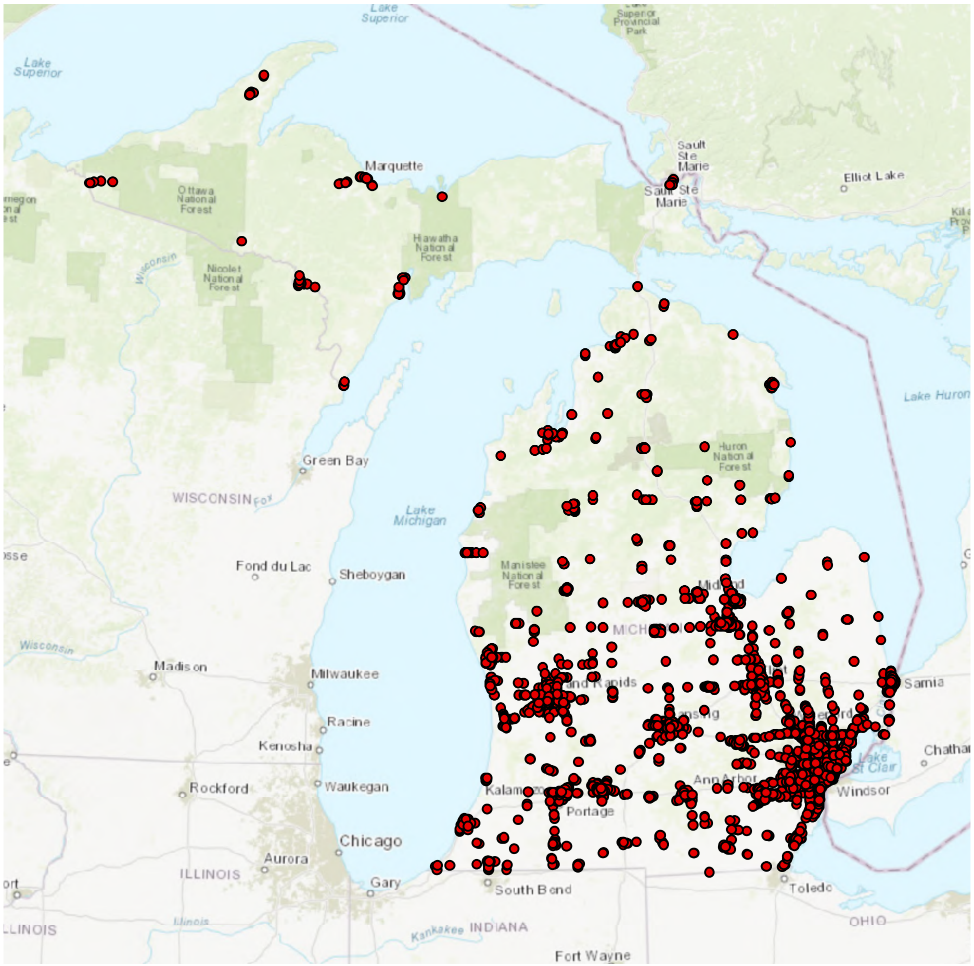


Figure 5. MDOT owned signals

Table 3. MDOT owned signal inventory

Region	# Signals	MDOT Maintained	Other Agency Maintain	# Signals
Bay	488	355	**Genesee County**	133
Grand	378	209	**City of Grand Rapids**	169
Metro	1307	400	**Oakland County**	347
			Macomb County	258
			Wayne County	302
North	134	134		
Southwest	274	198	**City of Battle Creek**	76
Superior	79	79		
University	483	270	**Washtenaw Co. or City of Ann Arbor**	96
			Lansing Board of Water and Light	117
TOTAL	*3143*	*1645*		*1498*

7.3.2 Maintenance Survey

The current maintenance practices of MDOT were investigated through a survey of electricians statewide. This survey consisted of opinions from regional staff and is not information that is actively recorded by MDOT. Currently, the maintenance and monitoring of signals in the state relies mostly on calls from the public, or other system stakeholders, to alert MDOT about issues as observed based upon traffic, or signal system, operations in the field. The purpose of this survey was to understand the potential benefits that could be realized with an ATSPM system. Table 4 shows rough estimates of trouble calls that each region receives in a given year broken into signal timing issues and equipment issues. The survey also asked about "false calls" or calls from the public that eventually were determined to be a non-issue. These calls could have been eliminated with an ATSPM system that could verify either equipment issues or signal timing issues using the platform and avoid the time and costs associated with dispatching MDOT staff and equipment to investigate. An example of the survey and additional survey results are included in Appendix B.

Table 4. Maintenance Survey Estimates on Trouble Calls and False Calls

Region	Trouble Calls (ST)	% False (ST)	Trouble Calls (EI)	% False (EI)	Total Savings (hrs.)
Metro	12	10%	200	5%	11
Superior	15	6%	50	5%	5
University	30	50%	6	50%	36
Bay	400	20%	300	5%	315
North	100	50%	50	50%	325
Grand	140	85%	325	20%	617
Southwest	150	20%	300	10%	210
Total	***847***	***35%***	***1231***	***12%***	***1519***

**EI = Equipment Issues ST = Signal Timing Issues

8 Setup and Implementation

8.1 Corridors

The US-31 corridor in Holland, MI is a 4.2-mile north-south corridor with an average AADT between 30,000 and 40,000 vehicles (Figure 6). The corridor currently operates in mostly fixed time with 7 signals in the southbound direction and 6 signals in the northbound direction. The corridor is located just east of Holland, MI, a 30,000-resident town near Lake Michigan on the west side of the state

The US-31 corridor in Traverse City, MI is a 1.5-mile east west corridor with an AADT between 30,000 and 35,000 vehicles (Figure 7). The corridor varies in volume seasonally and there are two distinct timing plans for the summer season and the winter season along the corridor. The corridor consists of three signals and is located just east of Traverse City, MI.

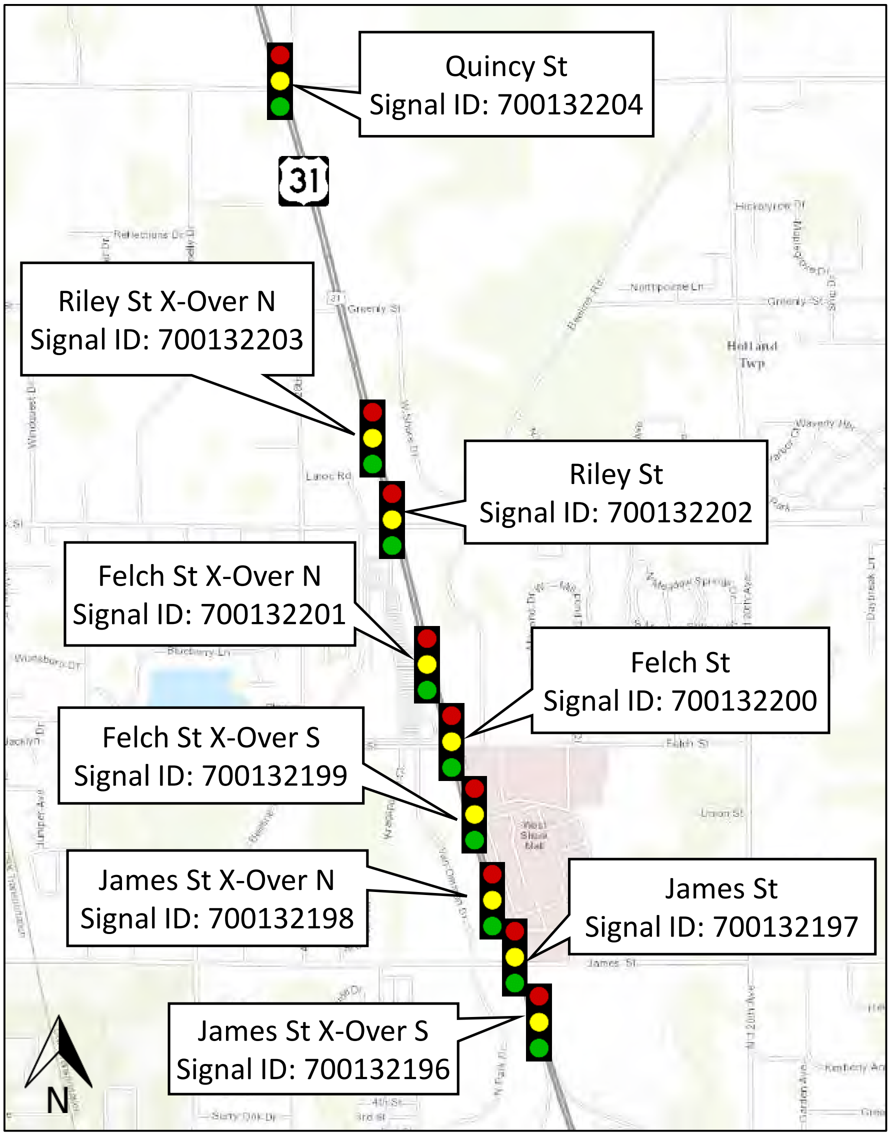


Figure 6. US-31 corridor in Holland, MI

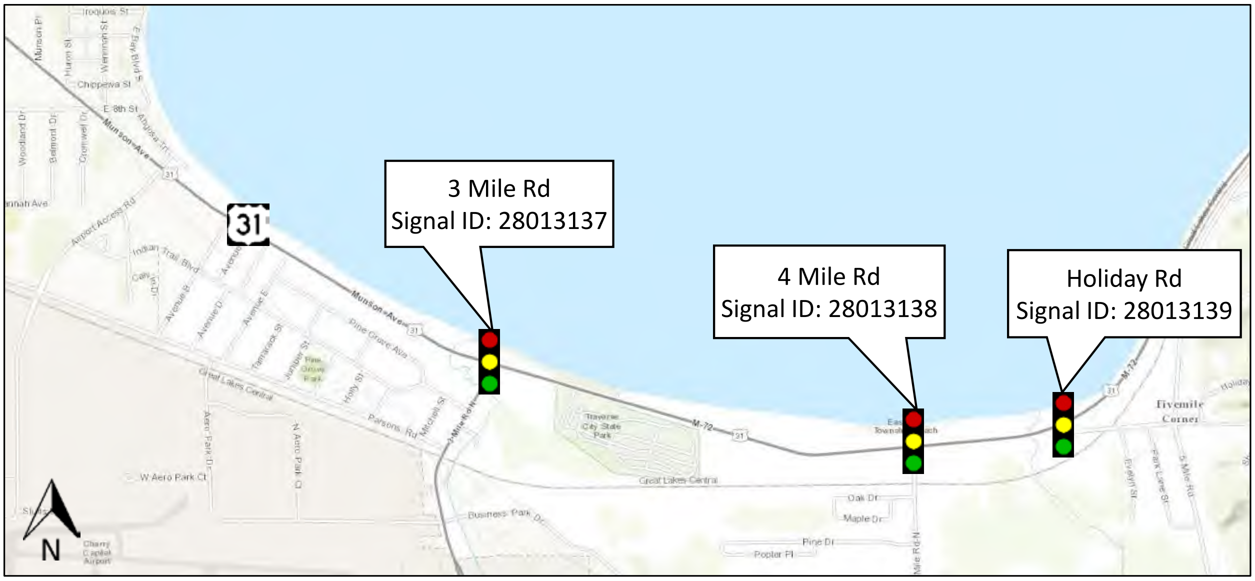


Figure 7. US-31 corridor in Traverse City, MI

8.2 EQUIPMENT

8.2.1 Detection

Signal performance measures rely heavily on detection. INDOT typically uses in-pavement loops, while Utah and others use a hybrid approach combining loops, magnetometers, cameras, and radar. Monitoring counts from these detectors allows engineers to determine any detector issues or significant changes in corridor volumes. This project relied on Sensys magnetometers deployed at the intersections. The configuration of a sample intersection (US-31 & Riley in Holland) is shown in Figure 8.

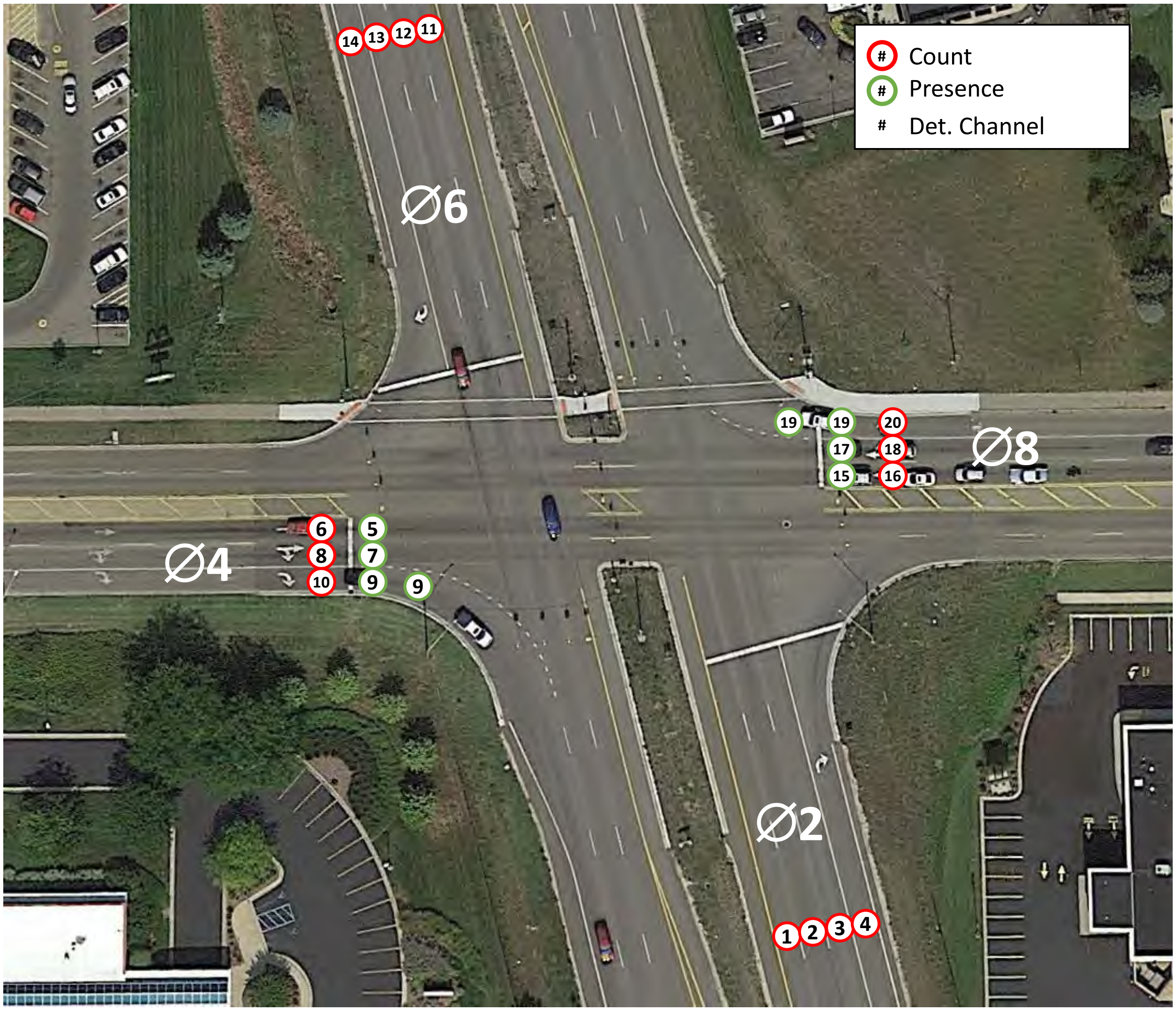


Figure 8. Detector channels at US 31 and Riley Street.

8.2.2 Controller

A data logging controller is required to gather the raw data from each of the intersections. The data includes detector activations, phase changes, and other changes that occur at an intersection. This project used Siemens Mod 60 controllers at all of the intersections.

8.2.3 Communication

Network connectivity between the MDOT intersection and the server hosting the ATSPMAT dashboard is critical for SPMs, both in the short term and long term. The amount of data and frequency of collection requires consistent communication to each of the intersections. This project used cellular and wireless communications which required a few unique alterations and considerations beyond the standard UDOT ATSPM software. An overview of the communication setup can be seen in Figure 9.

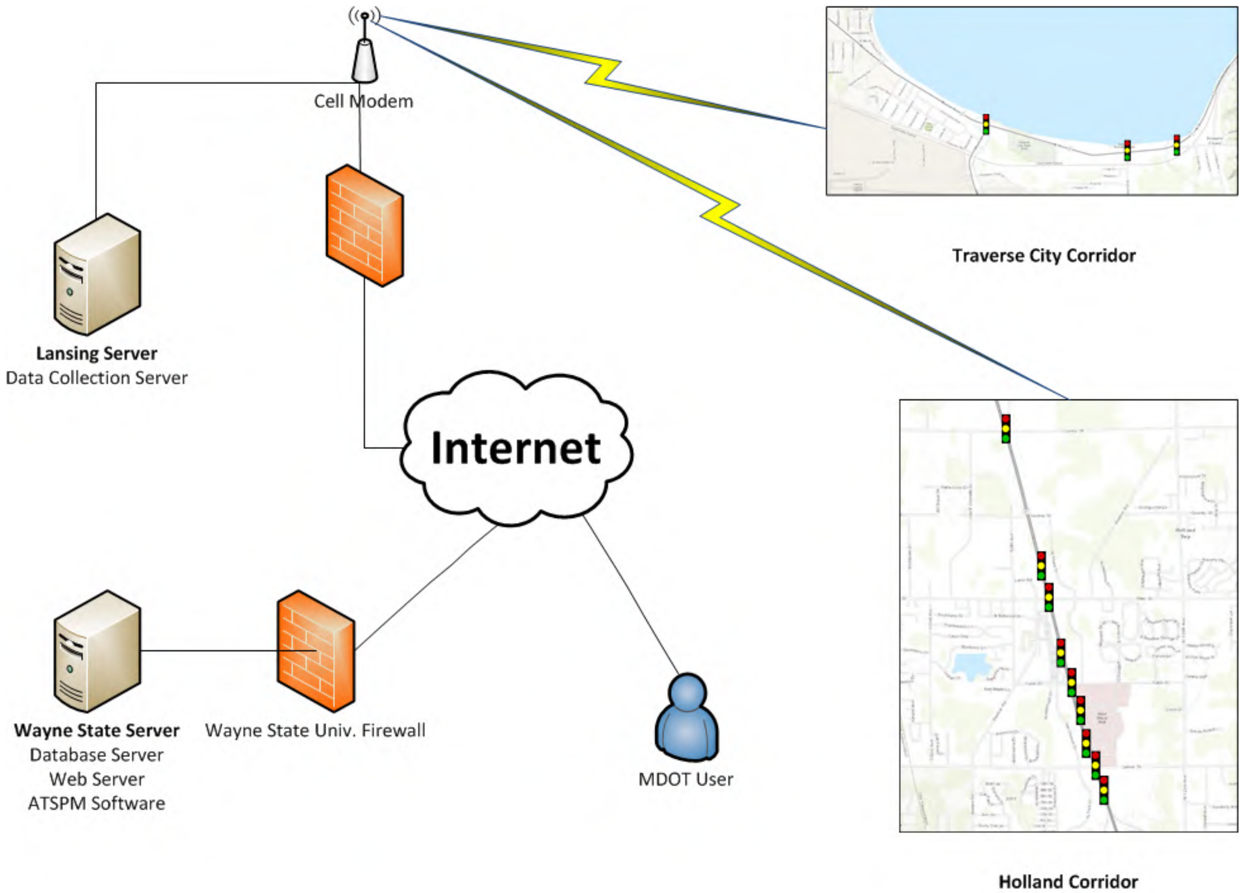


Figure 9. MDOT ATSPM communication setup

8.2.3.1 Network Connections

To support near real-time collection of traffic signal controller log data the network connections for this project had:

- IP based networks between the ATSPM central (or communication) server and the field traffic signal controllers, and
- FTP services enabled allowing access to the mini-FTP server that is embedded within each traffic signal controller

8.2.4 Software Customization

The UDOT open source ATSPM software package was developed and maintained based upon the specific needs and requirements for their traffic signal and communications infrastructure. As such it was necessary to develop some unique customizations for this project to account for the following project requirements.

- MDOT cellular vs. UDOT fiber optic backhaul communications
- MDOT wireless corridor communications vs. UDOT fiber optic communications

Due to the increased latency in communication transmissions it was necessary to customize the default settings for timing out of FTP transmissions to avoid loss of data packages due to the slower and less reliable transmissions from the MDOT cellular and wireless communications. UDOT defaults in the configuration parameters for the "Import Controller Logs" component are as follows:

- FTPTimeout (default setup is 50 ms)

To resolve the above issues, the ATSPM software was customized to accomplish the following:

- Controller logs polling cycle reduced to 5 minutes, instead of default setup of 15-minutes
    - Reduced potential to obtain data from field should a momentary drop in backhaul communications occur;
- Each "Import Controller Logs" task is set to run 3 times in sequence, instead of using the default setup of one time
    - Improved the success rate of the importing tasks avoiding the loss of data due to a singularly unsuccessful import attempt
- Extending the FTP timeout setting for "FTPTimeout" configuration setup of the "Import Controller Logs" component; increased from 50 ms to 500 ms
    - Improved the latency tolerance associated with the cellular communications and tolerances of the FTP connections.

8.3 Data and Data Evaluation

There are three data sets that were used for the evaluation of the corridors:

1. **Signal Performance Measures from the dashboard**
   Throughout the duration of the project the ATSPM dashboard was used for measuring traffic and signal system conditions along the two corridors. This allowed the research team to understand current conditions and record performance details such as: approach delay, arrivals on green, and # of split failures. These conditions and performance details are highlighted below.

2. **Using probe vehicle data from third party vendors**
   In addition to observing the ATSPM dashboard, the second method to understand operational performance utilized probe vehicle data.

3. **Using portable Bluetooth sensors along the corridor.**
   The final approach to evaluate baseline conditions was the use of portable Bluetooth sensors. These sensors allowed for a validation process to take place comparing the probe vehicle data and Bluetooth sensors. In addition, when major timing changes take place, the Bluetooth sensors were used to measure the impact before and after the implementation of the change. For example, if a split at an intersection was modified four Bluetooth cases could be deployed at the intersection to monitor the day prior, the day of, and the day after the change.

9 SIGNAL PERFORMANCE MEASURES

The UDOT ATSPM dashboard provides the ability to monitor and measure the performance of signalized intersections remotely. Figure 10 shows the dashboard that has been created by this project team and adopted by MDOT. The dashboard allows for the immediate creation of Signal Performance Measures over time. These performance measures are highlighted and explained below using the intersection of US-31 and Riley Ave. in Holland, MI on September 19, 2018.

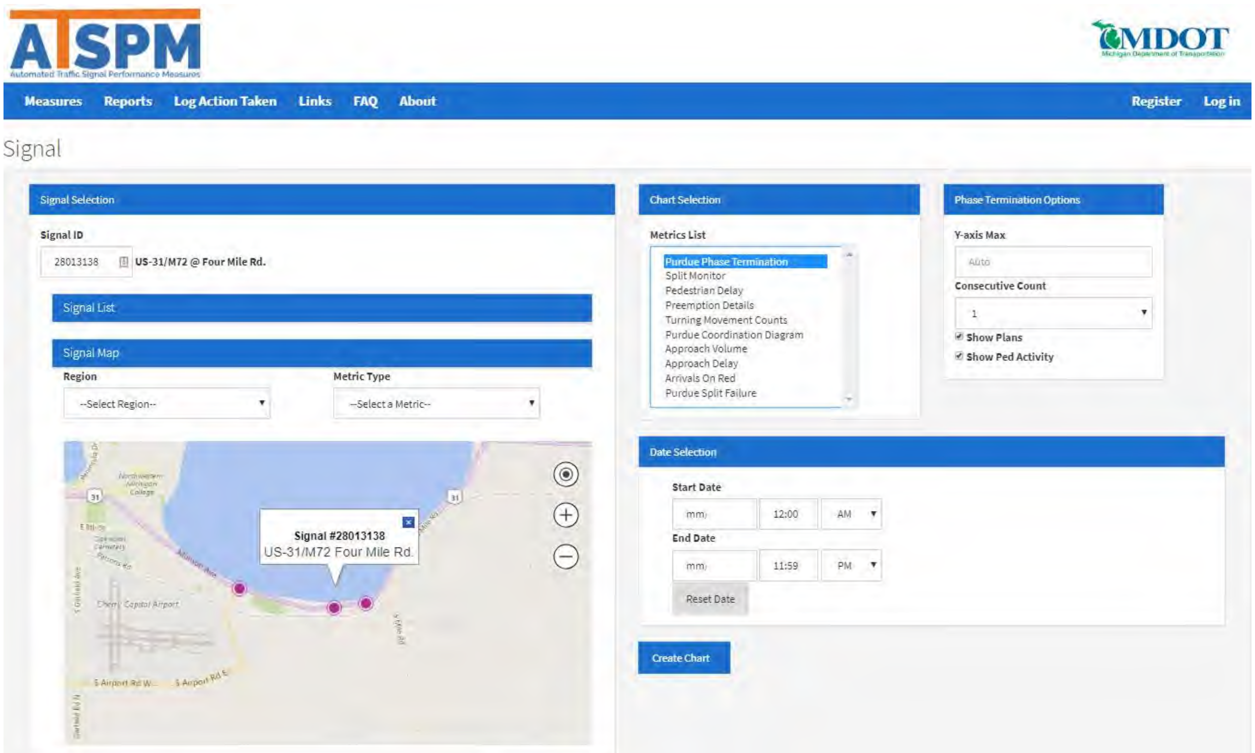


Figure 10. MDOT ATSPM dashboard (http://atspm.eng.wayne.edu/MDOT)

9.1 OVERVIEW AND EXAMPLES

- Purdue Phase Termination Diagram (Figure 11) – A graphic that allows a user to visualize how the phases at an intersection are ending. The main advantage of this performance measure is it allows the user to see if all phases are being utilized, or if there are opportunities to take time from one phase and give it to another.
- Split Monitor Diagram (Figure 12) – This graphic allows a user to see the split time a given phase is getting throughout the day. This allows users to verify the split times that were programmed into the controller.

- Pedestrian Delay Diagram (Figure 13) – Using the pedestrian buttons at an intersection, this graphic allows a user to visualize the pedestrian activity at an intersection. It also quantifies the delay that those pedestrians are seeing at an intersection.
- Preempt Service Request Diagram (Figure 14) – If a corridor utilizes preemption for emergency vehicles, this graphic would allow a user to see how often the preemption is being utilized. Both corridors in this study do not use preemption.
- Turning Movement Counts (Figure 15) – This graphic allows users to see the turning movement counts at an intersection. This graphic utilizes the detectors at an intersection to provide the turning movement counts at each intersection. One note is the turning movement counts are not accurate for shared through/right or through/left lanes.
- Purdue Coordination Diagram (Figure 16) – This is one of the most valuable performance metrics. Utilizing the advanced detectors on the main line, the graphic visualizes when vehicles are arriving in the cycle. The goal is for a majority of vehicles to arrive when the signal is green. This graphic allows users to assess how the progression of the corridor is performing.
- Approach Volume Diagram (Figure 17) – Similar to the turning movement count graphic, the approach volume aggregates all of the volume information collected from the detectors at the intersection and visualizes them over the selected time period.
- Approach Delay Diagram (Figure 18) – This graphic is valuable for understanding the delay along the mainline of each of the intersections. Using the advanced detection along the corridors, delay is estimated for each vehicle and averaged. One important note for this approach is the delay is underestimated because deceleration and acceleration are not included in the assumptions.
- Arrivals on Red Diagram (Figure 19) – This graphic allows users to see the percent arrivals on red over time. The Arrivals on Red diagram shows similar information as the Purdue Coordination Diagram.
- Purdue Split Failure Diagram (Figure 20) – The Purdue Split Failure Diagram is useful for determining split failures on the side street. Split failures are defined where vehicles would have to wait through an entire cycle before passing through the intersection. In the Purdue Split Failure Diagram this is predicted by looking at the occupancy of the detectors during green and the occupancy of the detectors during the first 5 seconds of the red phase. If the detector is occupied throughout the green and the first five seconds of red, there is a strong possibility there was a split failure. This is represented with a vertical yellow line in the graphic.

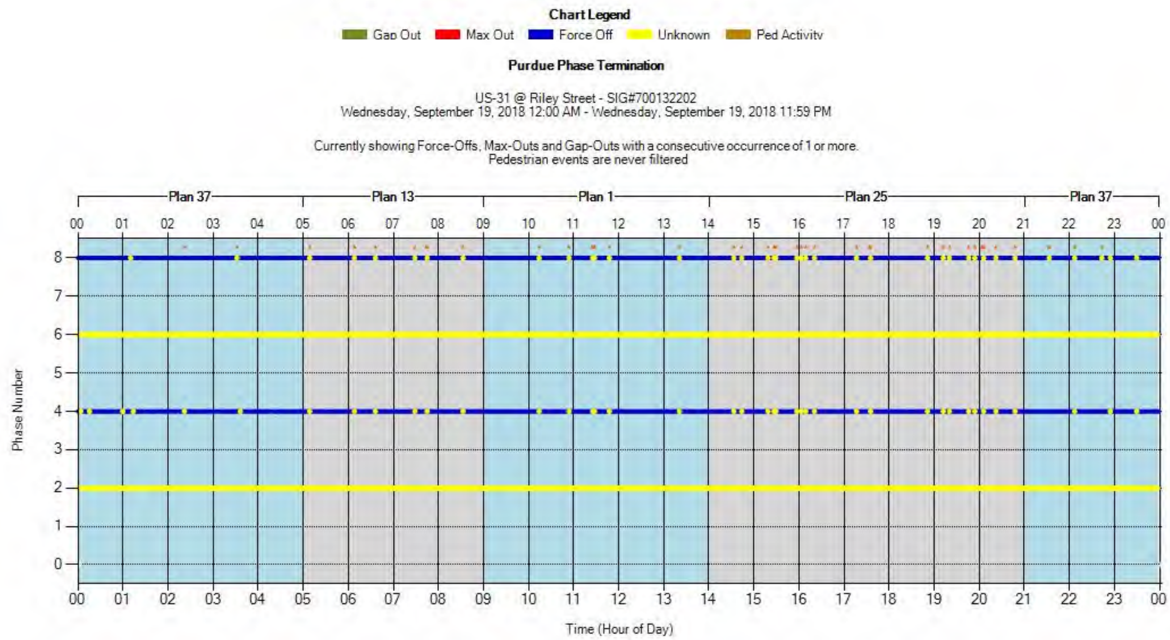


Figure 11. Purdue phase termination diagram

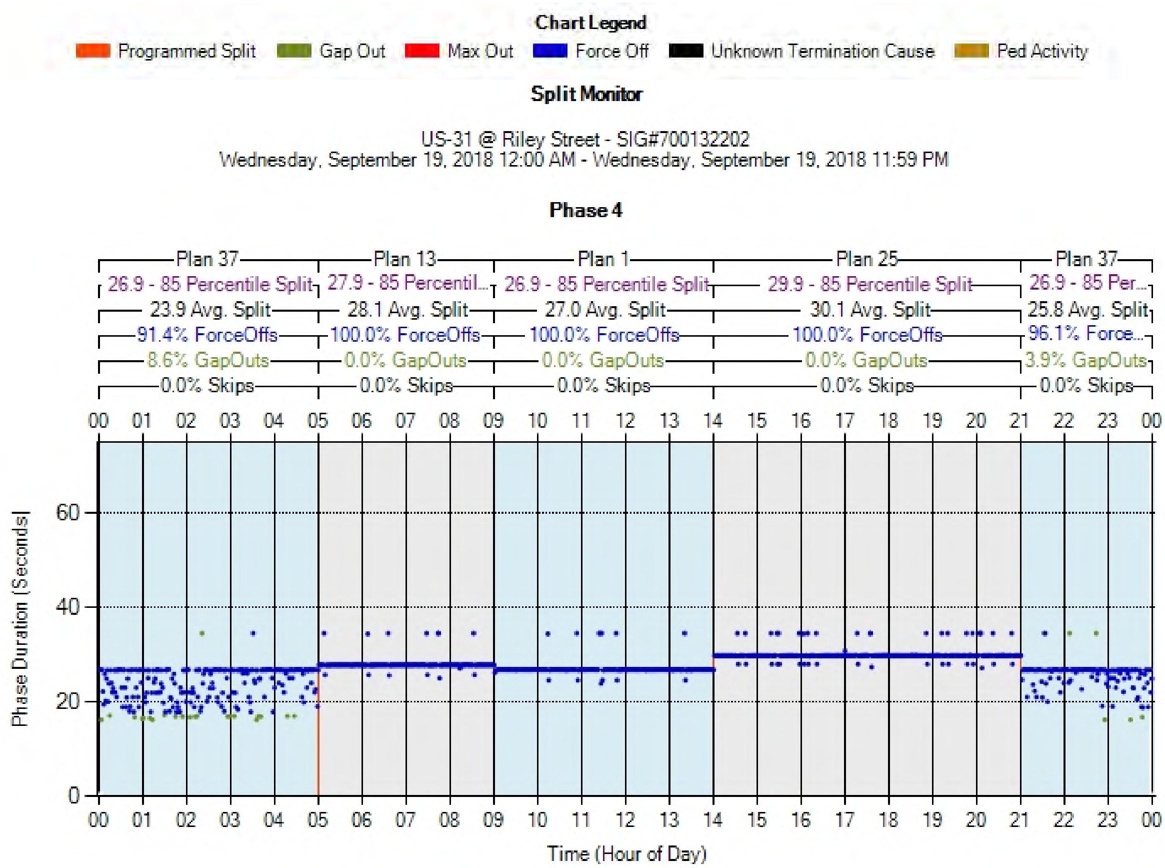


Figure 12. Split monitor diagram

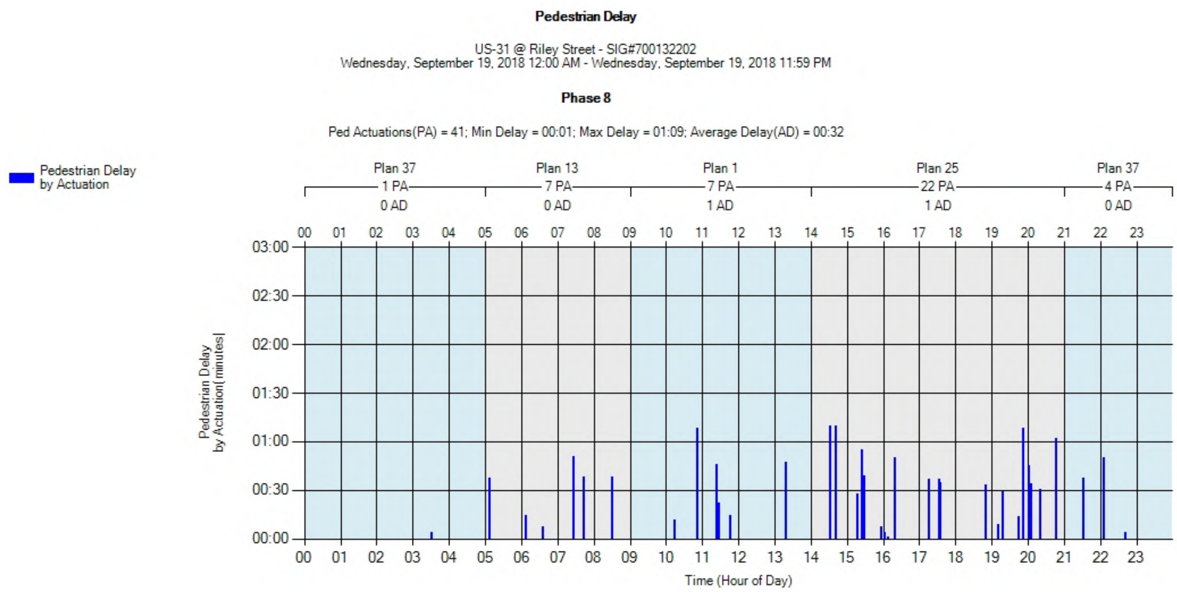


Figure 13. Pedestrian delay diagram

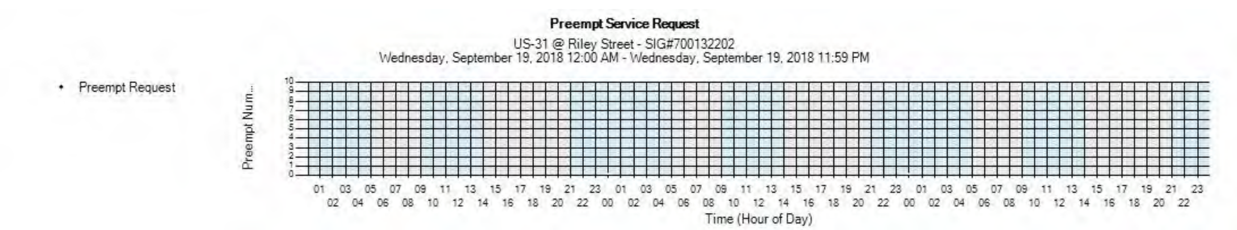


Figure 14. Preempt service request diagram

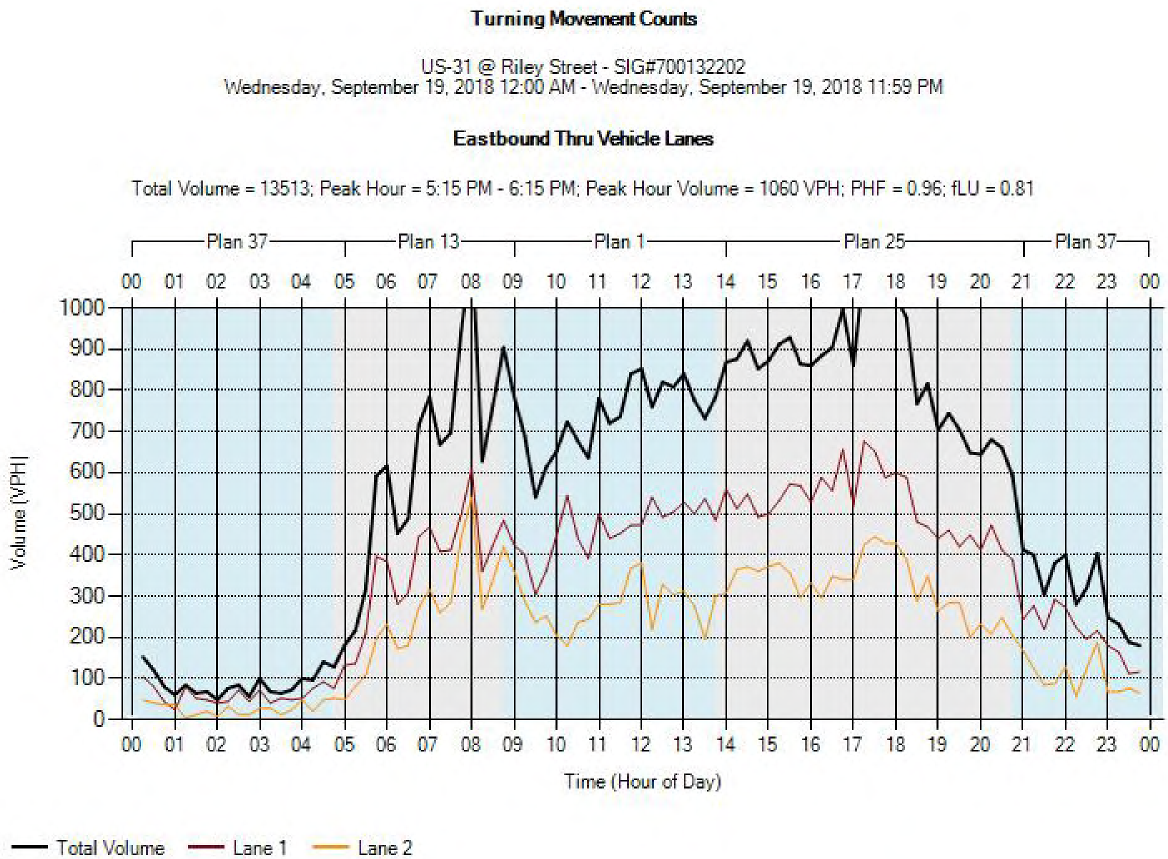


Figure 15. Turning movement counts

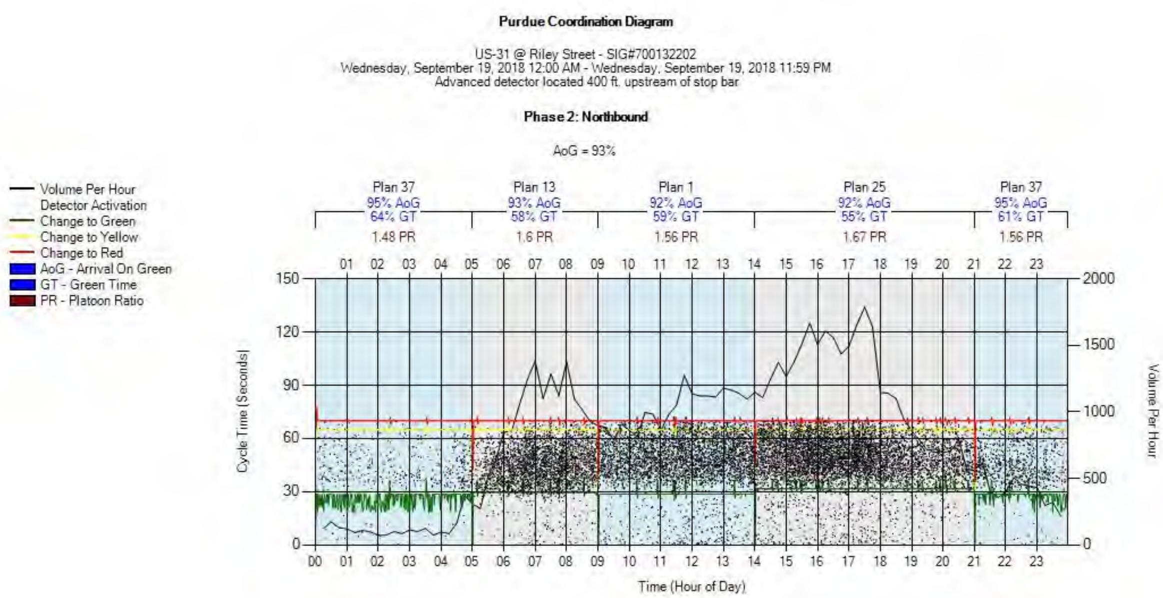


Figure 16. Purdue coordination diagram

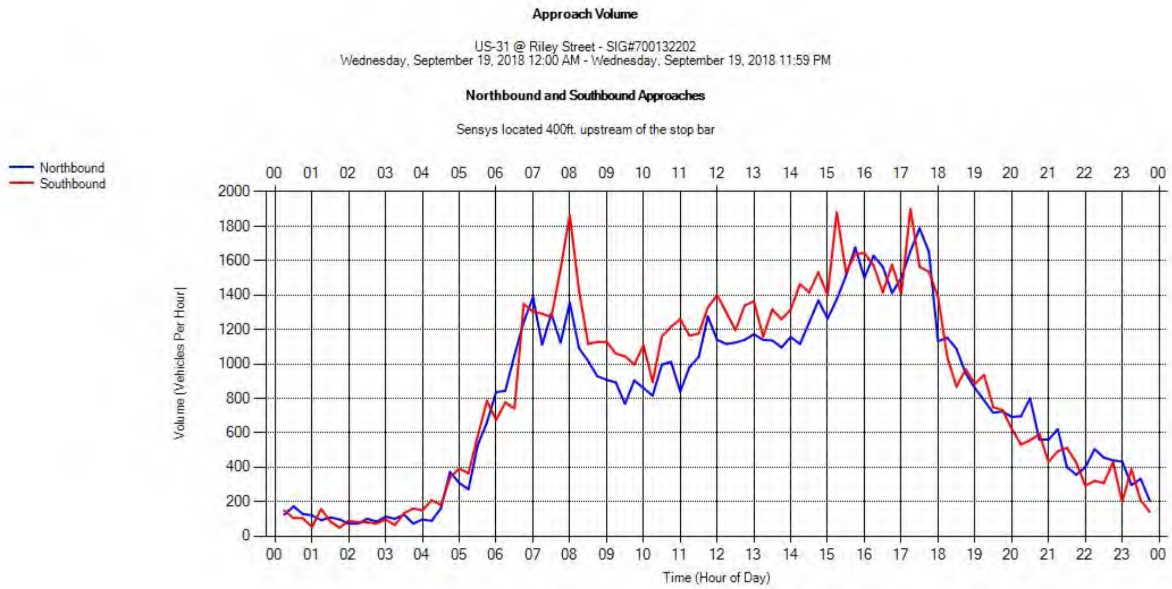


Figure 17. Approach volume diagram

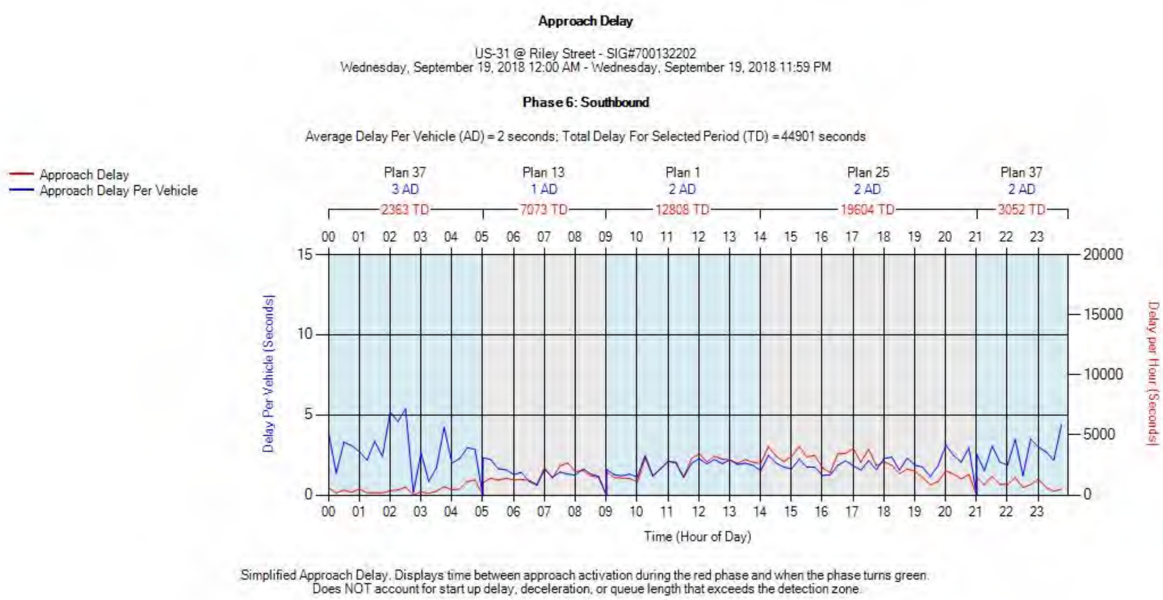


Figure 18. Approach delay diagram

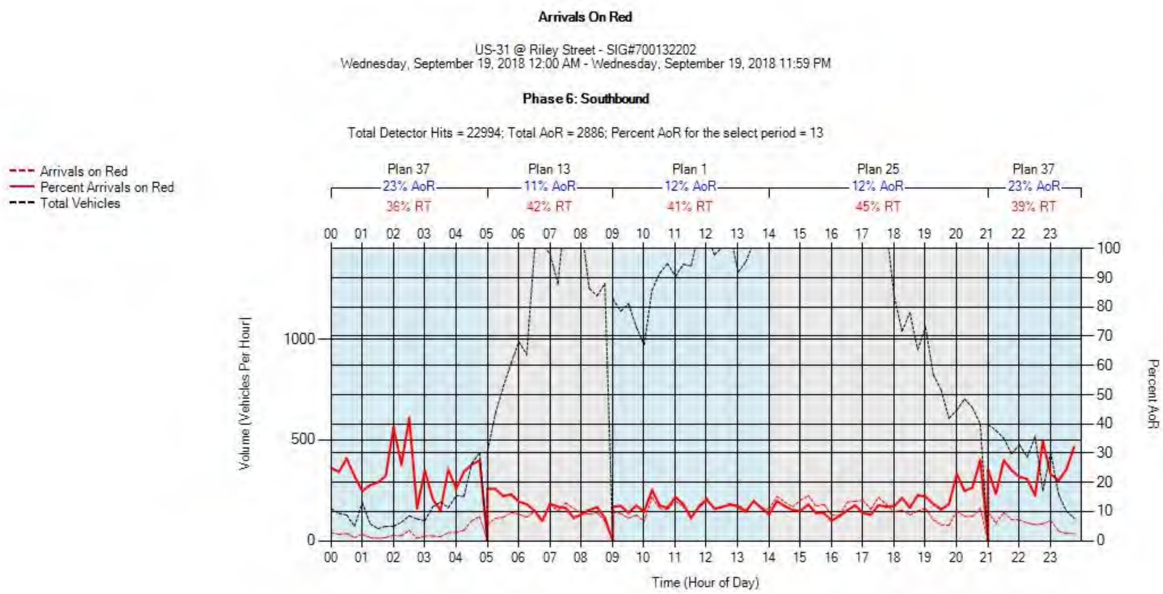


Figure 19. Arrivals on red diagram

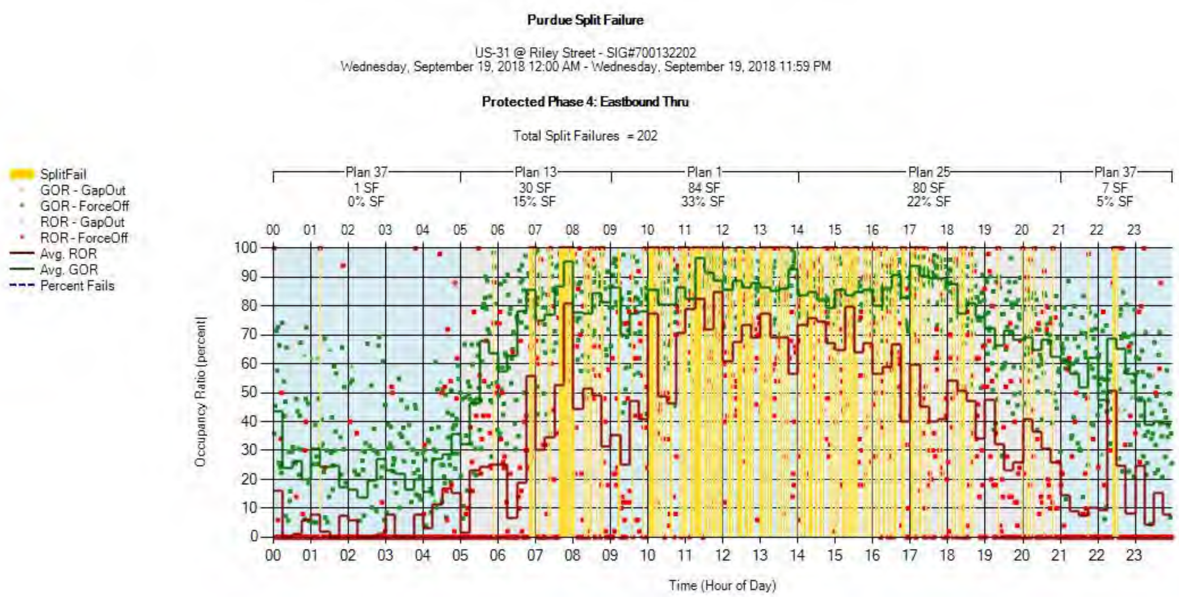


Figure 20. Purdue Split Failure diagram

These performance measures, specifically the Purdue Coordination Diagram, allow for an assessment of the baseline conditions along the corridors. Figure 21 shows the original PCDs for the Holland corridor. The issues on the corridor include:

Northbound US 31:

- Figure 21i –Random arrivals at the S. James crossover
- Figure 21ii – Obvious offset issue during the 0500-0900 timing plan at James Street.
- Figure 21iii – Offset issue at the S. Felch crossover during the 0500-0900 timing plan
- Figure 21iv – Offset issue at the S. Felch crossover in the 1400 – 2100 timing plan
- Figure 21v – Offset issue at the Felch intersection in the 1400 – 2100 timing plan
- Figure 21vi – Platoon getting clipped at Riley St.
- Figure 21vii – Platoon dispersion at Quincy St.

Southbound US 31:

- Figure 21viii –Random arrivals at the Quincy intersection
- Figure 21ix – Numerous turning vehicles from Riley arriving on red.
- Figure 21x – Slight offset issue in the 1400-2100 timing plan

Using these graphics, it is clear that the southbound direction appears to be better coordinated during all of the timing plans throughout the day. The percent arrivals on green were calculated for each of the intersections in each direction. The corresponding callout from Figure 21 was placed in Table 5. Over the entire day, a majority of the intersections seem to be performing well. The worst performing non-random arrival approach is northbound at Quincy, with arrivals of 65.8% over the course of the day. These issues identified by the detector data will help determine the ability of other data sets to also identify such issues.

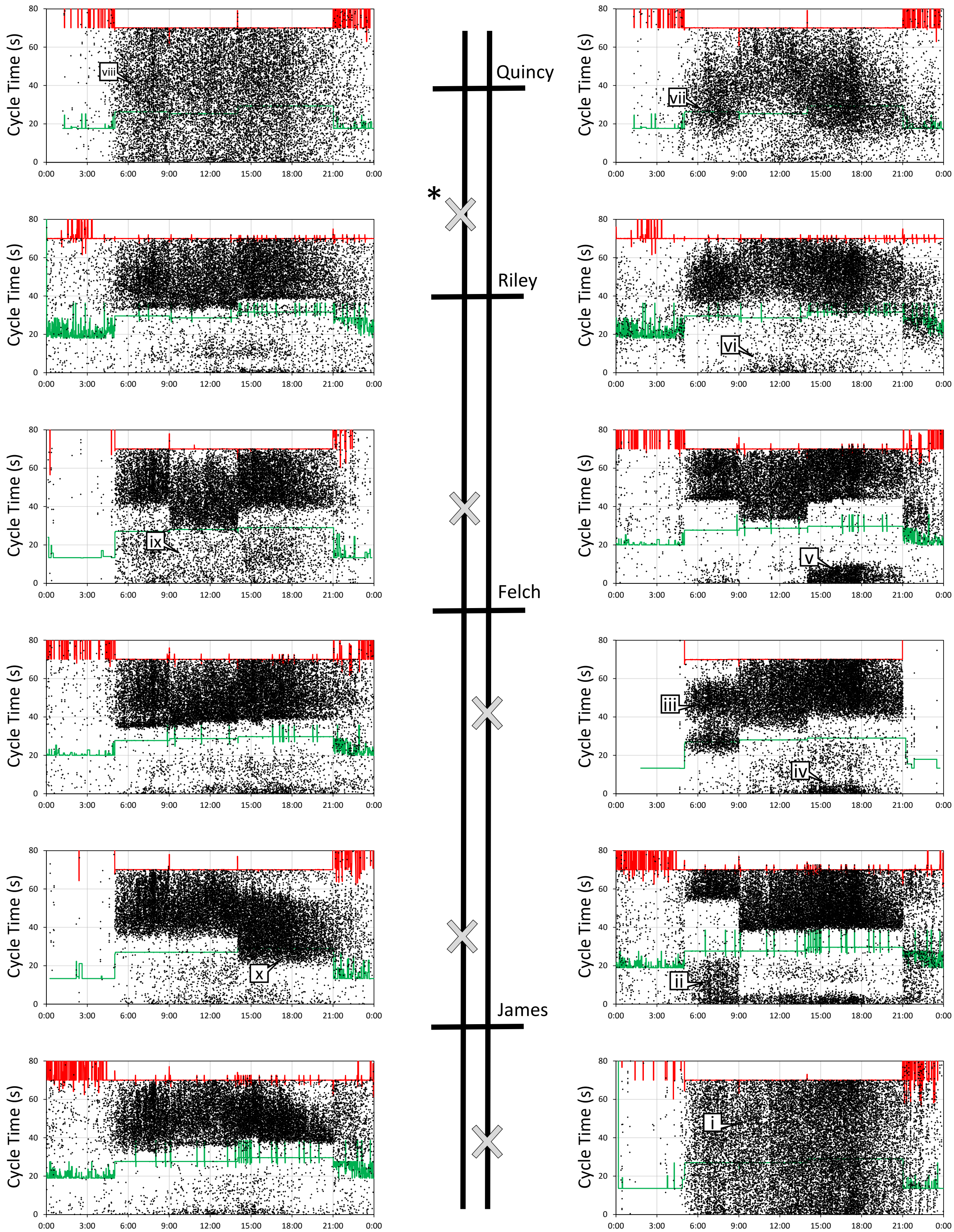


Figure 21. Purdue Coordination Diagrams for the US-31 Holland corridor (7/12/17)

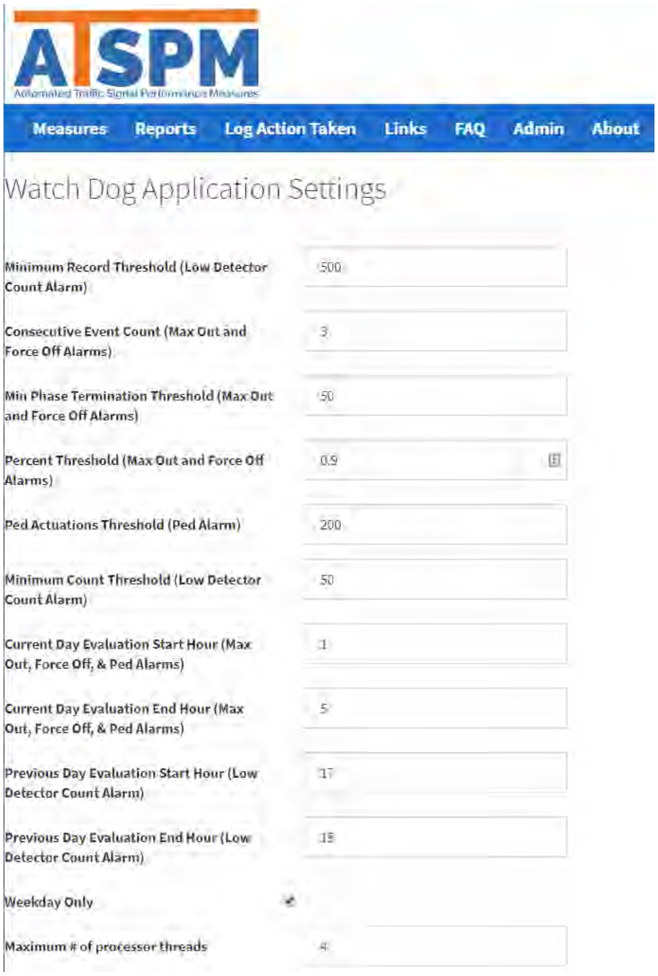
*The N. Riley crossover is not included in this image

Table 5. Arrivals on Green using Signal Performance Measures

Order	Direction	Intersection	Arrivals On Green			
			0500-0900	***0900-1400***	***1400-2100***	***All Day***
1	NB	S. James X Over	64.1% (i)	63.3% (i)	61.7% (i)	64.8%
2	NB	James St.	67.3% (ii)	92.1%	89.4%	82.4%
3	NB	S. Felch X. Over	86.5% (iii)	89.4% (iv)	86.2% (iv)	87.7%
4	NB	Felch St.	95.2%	93.6%	77.7% (v)	87.2%
5	NB	Riley St.	94.9%	88.0% (vi)	87.0%(vi)	86.7%
6	NB	Quincy St.	71.8% (vii)	78.7% (vii)	50.3% (vii)	65.8%
1	SB	Quincy St.	64.0% (viii)	65.1% (viii)	59.3% (viii)	64.4%
2	SB	Riley St.	93.3%	87.6%	85.0%	87.3%
3	SB	N. Felch X. Over	82.7% (ix)	84.6% (ix)	83.4% (ix)	84.6%
4	SB	Felch St.	95.0%	91.8%	87.8%	90.6%
5	SB	N. James X Over	95.6%	89.0%	80.9% (x)	88.0%
6	SB	James St.	96.9%	93.7%	94.0%	94.2%

9.2 WATCHDOG EXAMPLES

The current performance measure system of the ATSPM relies on users to identify and track performance issues at intersections using the tool. The Utah software also includes a continuous monitoring feature that focuses on communication and detection issues. The Watch Dog application is set up to send emails to select individuals daily to alert the agency of potential maintenance issues based on the previous 24 hours. These emails include alerts if detector didn’t meet certain volume thresholds, if there were errors in force off or max out errors, or if there were high pedestrian activation errors. Figure 22a shows the settings that can be adjusted for alerts. Figure 22b shows an example of a watchdog email. These emails allow for automated and continuous monitoring of equipment at all intersections equipped with ATSPMs.



a) *Watch Dog Settings* b) *Watch Dog Email*

Figure 22. Watch Dog application

9.3 Commercial Examples

The UDOT open source software was used for the purposes of this study. There are other commercial products that also provide ATSPMs. Two were also deployed on the corridors used for this study. Miovision was deployed on the Traverse City Corridor and EDI was deployed on the Holland Corridor. Table 6 shows a comparison of the features of all three providers. It should be noted that all of these products are continuously evolving and additional features are being added regularly. The biggest addition from the third party providers relative to the open source Utah software was real time images of the current state of the signal. This can be useful in traffic operations centers for the monitoring of signal performance.

Table 6. Comparison of features from commercially available products

ATSPM	**UTAH**	**Miovision**	**EDI**
Purdue Phase Termination	X		
Split Monitor	X		
Pedestrian Delay	X	X	
Preemption Details	X		
Turning Movement Count	X		
Purdue Coordination Diagram	X	X	X
Approach Volume	X	X	
Approach Delay	X	X	X
Arrivals on Red	X	X	X
Purdue Split Failure	X	X	
Green Allocation		X	
Occupancy Ratio		X	
Phase Interval (PCD without arrivals)		X	
Arrival and Departure delay			X
Cabinet Tools			
Current State		X	X
Counts by Phase			X
Cabinet Health			X
RYG Channels			X

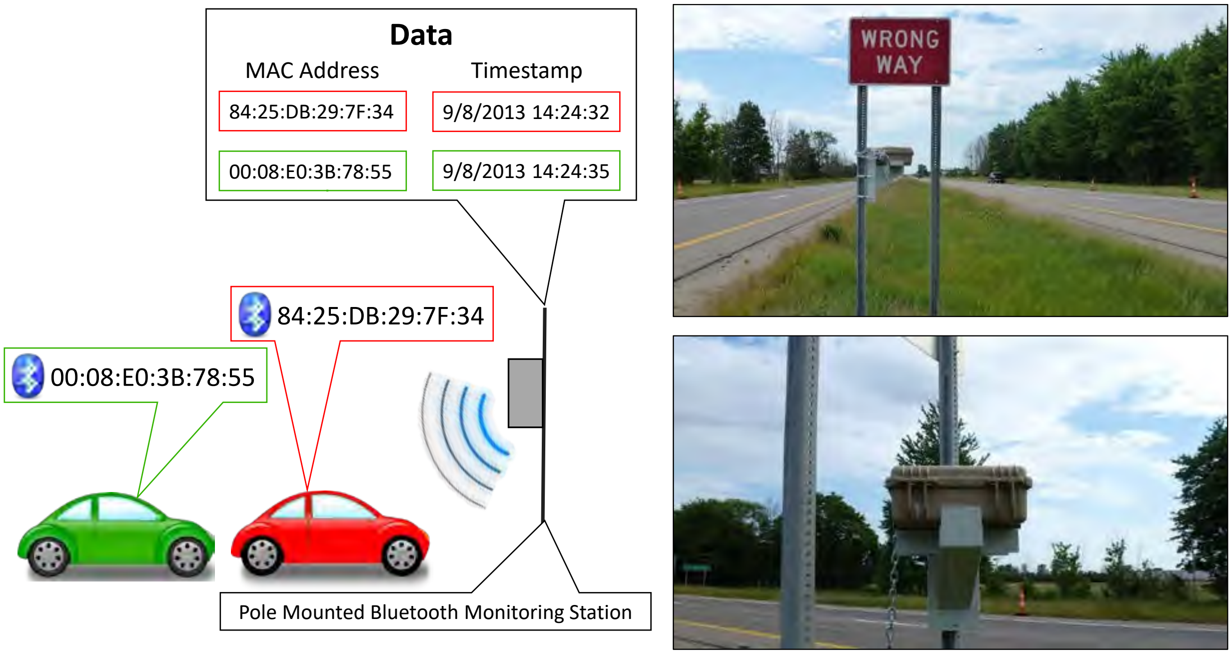
10 PROBE VEHICLE DATA

10.1 OVERVIEW

The purpose of this study is to evaluate the impact of the ATSPM system and quantify the benefits. As previously discussed, quantifying the benefits requires a third party source of data to evaluate the impact of signal timing changes. For these purposes Bluetooth/WIFI matching and crowd sourced probe vehicle data were used to evaluate the corridors.

10.2 BLUETOOTH DATA

Bluetooth/WIFI matching Bluetooth and WIFI sensors have become a prominent method of detecting congestion issues on various roadways. These sensors read Media Access Control (MAC) addresses from vehicles passing the roadside devices. These MAC addresses are then matched between different sensor locations and a travel time is derived. Historically, these sensors have been used to monitor overall travel time of corridors, but they have also been used to monitor signal performance [6]. Figure 23a illustrates the MAC address concept. Five sensors were used on the US-31 corridor in Holland and five sensors were also used on the Traverse City corridor to measure baseline conditions. An example of these monitoring stations can be seen in Figure 23b.



a) Bluetooth/WIFI Concept b) Bluetooth/WIFI Deployment

Figure 23. Bluetooth/WIFI sensors on Holland corridor

10.3 Segmented Probe Vehicle Data

Commercially available probe vehicle data is rapidly becoming one of the most widely used sources for mobility and travel time data [12,13,14]. The probe data is made up of vehicle speeds from GPS devices, cell phones, and in vehicle telematics. These speeds are then aggregated by third party vendors into representative speeds of predefined segments of roadway every minute. This data set provides near ubiquitous coverage of the road network both spatially and temporally. The state of Michigan has been using this data source for annual evaluation of the interstate system and in traffic operations centers for the identification and analysis of crashes, weather events, and negative impacts on roadway operations. This project used probe vehicle data along the corridors to evaluate the improvements made in progression along the mainline.

10.4 Comparison

The Bluetooth data was used to validate the segmented probe vehicle data for both Holland and Traverse City. Figure 24 shows the segments and Bluetooth monitoring stations for the US-31 corridor in Holland. Figure 25 shows the comparison of a week of data from the Holland corridor for Bluetooth and Probe Vehicle Data. Overall, the probe travel data and Bluetooth data show similar trends in the travel time throughout the week. The Bluetooth data does have some issues as the MAC address matching does not guarantee the device is taking the most direct approach to the next sensor or that the device is in a vehicle (potentially a pedestrian or bike). The Bluetooth sensors do have the advantage of being mobile therefore the segments can be customized for each corridor. Figure 25 shows a comparison of the two technologies over a week in June 2017.

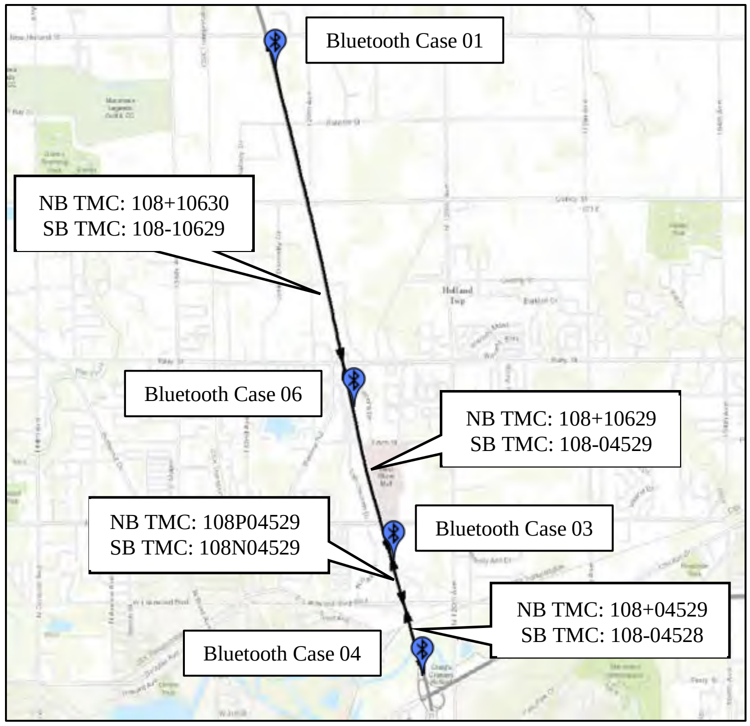


Figure 24. Bluetooth locations and probe vehicle data segments

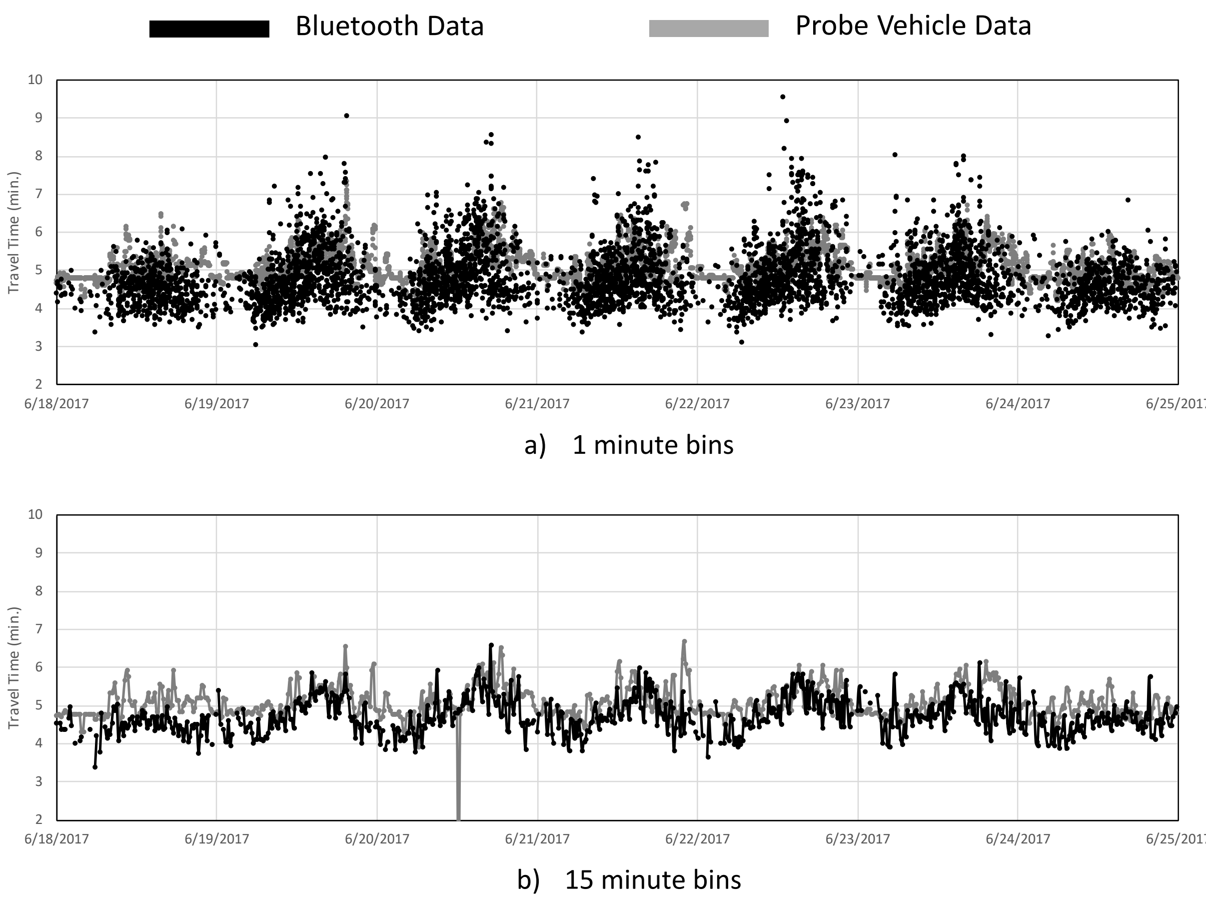


Figure 25. Bluetooth and probe vehicle data comparison

11 CORRIDOR OPTIMIZATION

The ATSPM website link-pivot feature was not applicable or functioning throughout the duration of this project. This is a result of the open source software and compatibility issues with the Michigan corridors. The link-pivot feature within the ATSPM source code does not work with Median U-turn corridors. Instead four optimization techniques were developed, employed, and compared to improve coordination and progression for the US-31 corridor in Holland. These techniques include the traditional link pivot, signal clustering algorithms, and a traditional hill climbing technique.

Four different optimization techniques were developed and tested on the US-31 corridor. The first method tested was the traditional Link-Pivot, which optimizes signal offsets in order along a corridor, ensuring optimal outcomes for each link between signals. The traditional Link-Pivot method proved to be ineffective because median U-turn signals only control traffic in one direction. Next two different signal clustering algorithms were tested. The first attempt was to prioritize the main intersections along the corridor and lock the relative offsets between the main intersections and their corresponding crossovers. These locked offsets were then linked together to develop corridor wide offsets. Next the Clustered Link-Pivot which optimized subsystems of signals, main intersections and their corresponding U-turn, and then linked them together using the traditional Link-Pivot optimization between the clustered blocks. Finally, a common optimization technique known as ‘hill climbing’ was used in combination with adaptive step sizes. A hill climbing method is an iterative technique used to find a solution to a problem, then makes incremental changes to find a better solution, and continues until no improvement can be discovered.

Each technique was applied to the AM, off-peak, and PM timing plans on the Holland Corridor, and the results were compared using both computational efficiency and total change in AOG. Figure 26 displays the results of the test. Despite not being the most computationally efficient algorithm, the results showed that the most effective method was the 'hill climbing’ optimization. The additional computation resources required to reach superior results using this method were negligible.

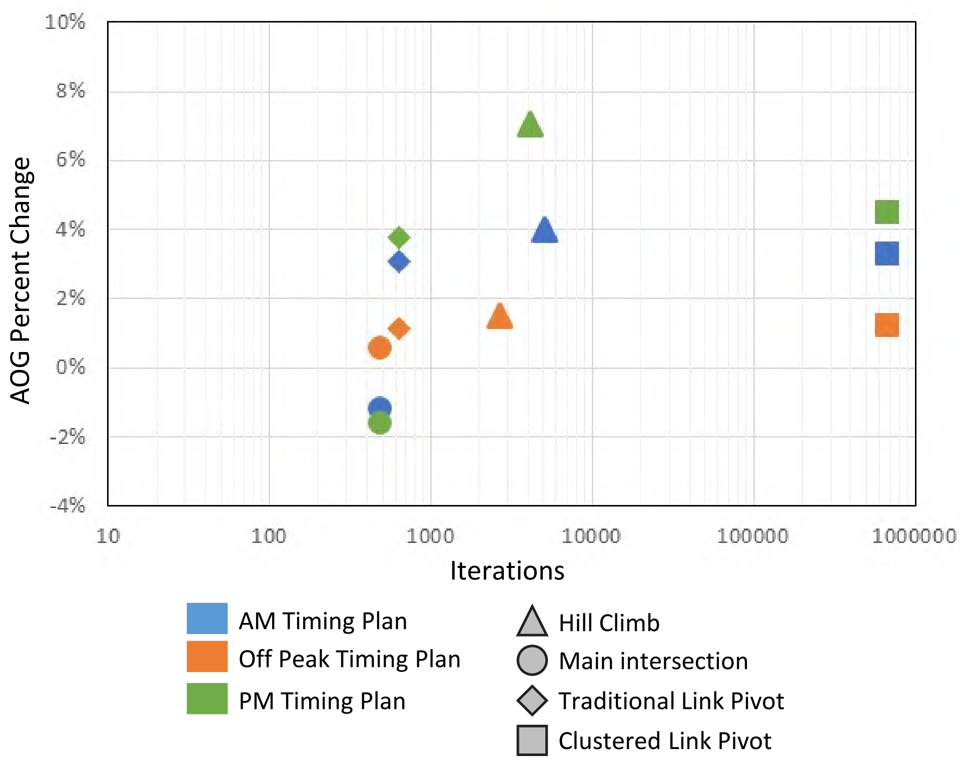


Figure 26. Optimization methodology

After developing the computational tools necessary to optimize the corridors, numerous adjustments were implemented along both the Traverse City and Holland corridors. Table 7 lists the adjustments that were made to the two corridors using ATSPMs and the optimization algorithms developed by WSU. The benefits of these adjustments were quantified using both user cost savings and emissions.

Table 7. Adjustments made on the Holland and Traverse corridors

Adjustment	Nature of Change	Date of Change
Holland Link-Pivot	Offset	6-28-2018
Holland Riley Misstep	Input Error	7-11-2018
Holland Overnight Timing	Actuation/Offset	8-29-2018
Traverse Link-Pivot (Summer)	Offset	8-20-2018
Traverse Link-Pivot (Winter)	Offset	9-17-2018
Traverse Wrong Cycle	Programming Error	4-27-2018

11.1.1 Holland –James Offset Adjustment

The first adjustment made to the Holland corridor was at the James intersection. The offset between the S. of James Xover and the James intersection was causing vehicles to arrive to late in the cycle during the AM timing plan. Thus, many vehicles were arriving on red (Figure 27 callout 'i'). Using the PCD, it was determined that a 17 second decrease in the amount of time between offsets would improve progression between these two signals. The change was implemented on September 12th 2017. Figure 28 callout 'i' shows how the vehicle arrivals were no longer arriving during the red phase of the NB approach after the change was made. Arrival on Green (AOG) improved from 61% to 92%.

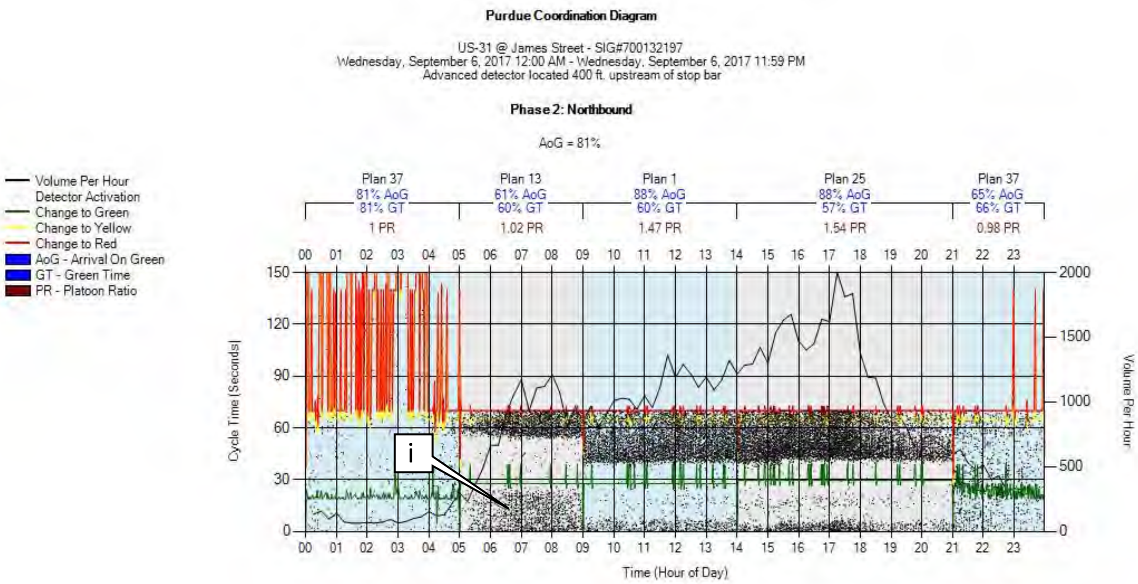


Figure 27. PCD for NB James in Holland before initial offset adjustment

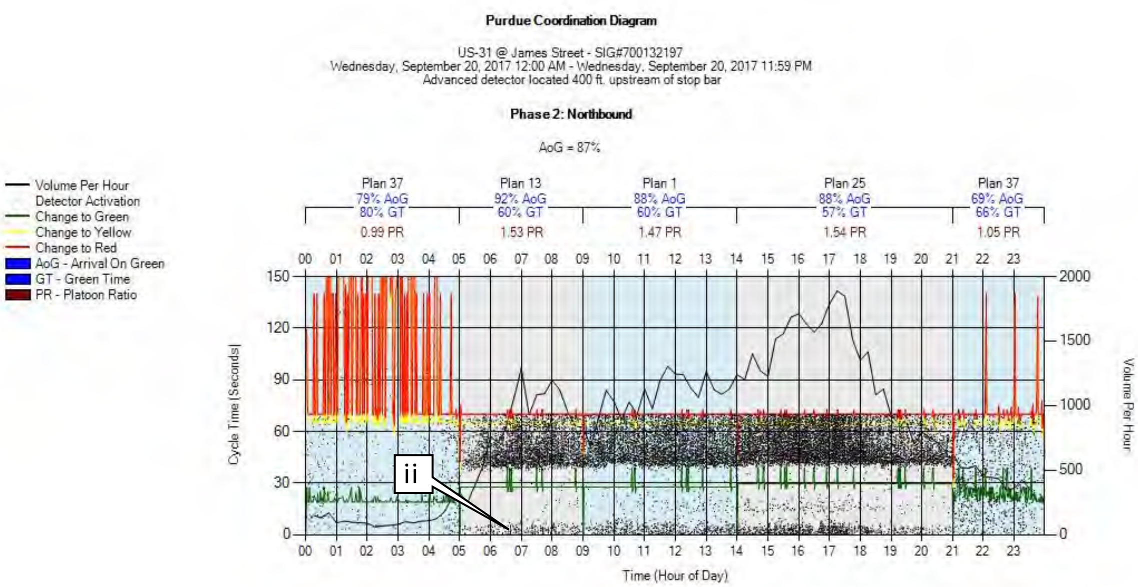


Figure 28. PCD for NB James in Holland after initial offset adjustment

In order to quantify the user impact of the S. James Xover offset adjustment, probe vehicle data was used to calculate travel times. Figure 29 shows a cumulative distribution function with the distribution of travel times before and after the adjustment. Using the 50th percentile travel times and volumes collected from the ATSPMs, it was determined that delay was reduced. In addition to the cost savings created by this signal timing change, the problem was relatively easy to both identify and mitigate using ATSPMs and required relatively few engineering hours to solve.

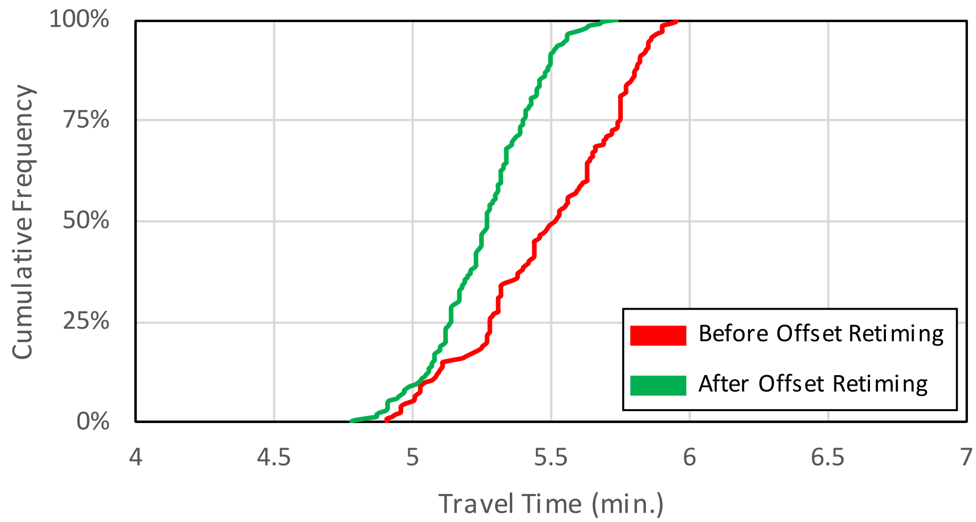


Figure 29. Probe vehicle data before and after offset adjustment

The next step in improving mobility in Holland was to perform a corridor wide offset adjustment. It was apparent from the PCDs along the corridor that multiple signals had suboptimal arrival patterns (Figure 30). After identifying potential areas of improvement, optimal offsets were identified using WSU's 'hill climbing' algorithm, as discussed above. On April 30th, 2018 the new offsets were implemented on the Holland corridor. However, after the initial offset adjustment, a new optimization algorithm showed additional corridor improvements were possible and on June 28th revised offsets were implement across the entire corridor. Shortly after implementing these changes some issues in the installation of these new timing plans occurred. These issues involved the wrong offsets being programmed into two locations. These will be discussed in more detail in the following section. However, once these issues were identified and fixed, the impact of this adjustment was quantified.

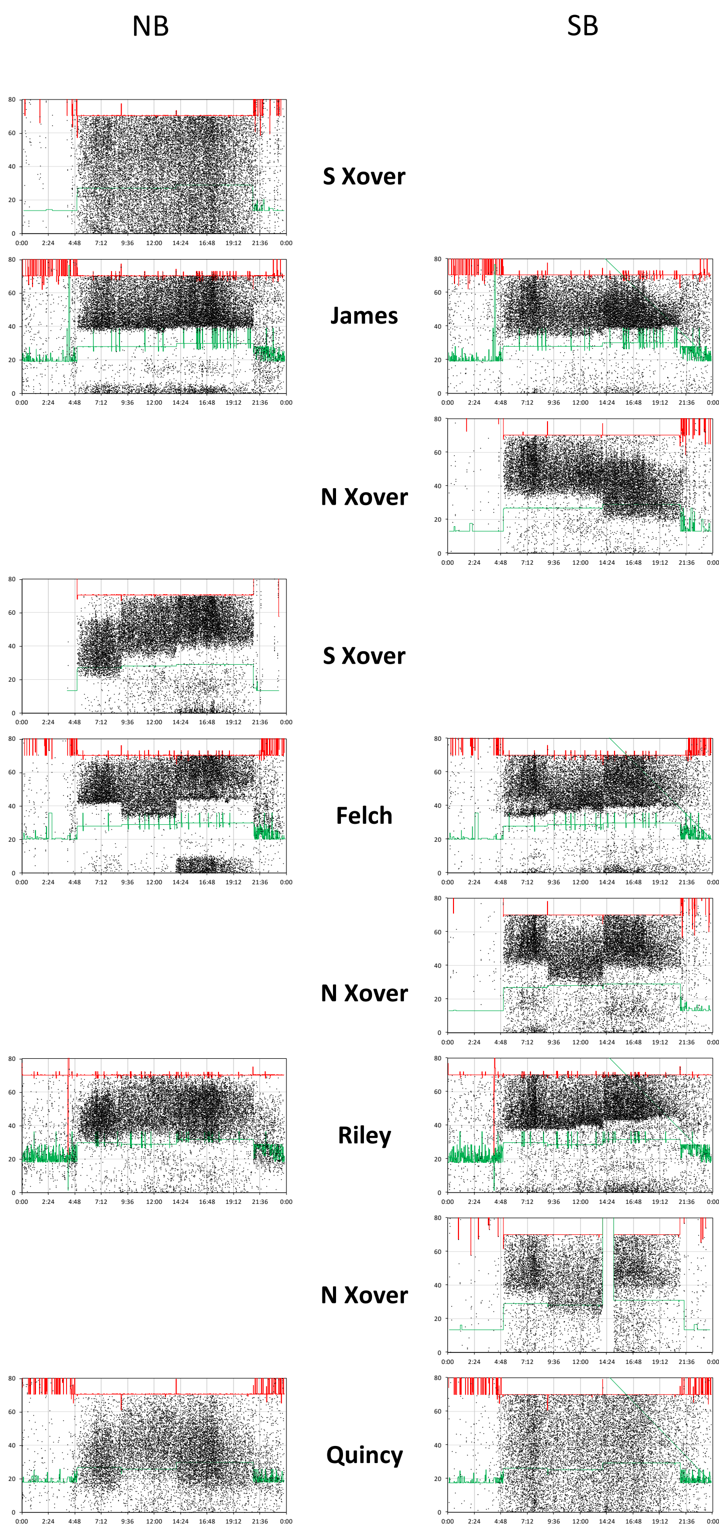


Figure 30. US 31 in Holland original PCDs

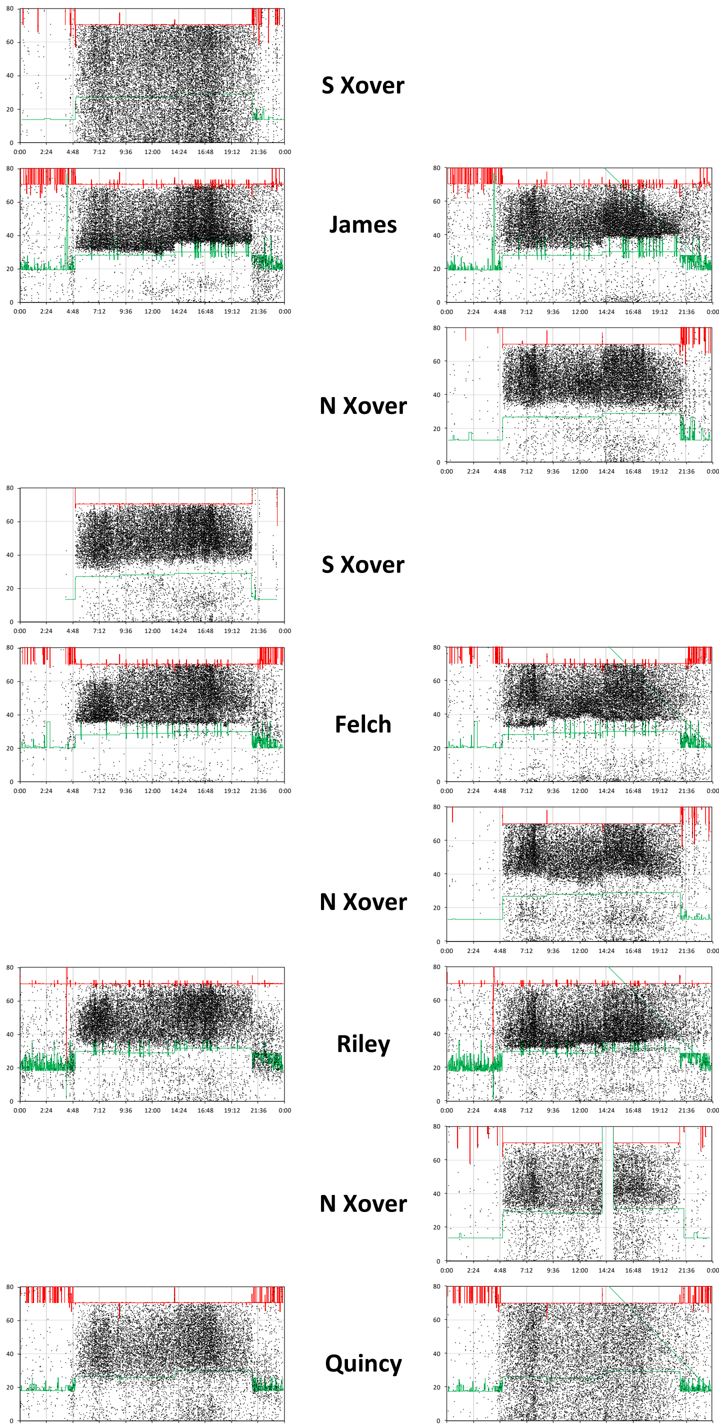


Figure 31. US 31 in Holland updated PCDs

Probe vehicle data sets were used to quantify the benefits realized on the corridor. Because the AM, off-peak, and PM timing plans were adjusted, before and after travel times were computed for these times using probe vehicle data. A week of data from Monday through Friday was selected to show the impact. The impact in the NB direction is displayed in Figure 32, and the SB direction is displayed in Figure 33. In both directions travel times were reduced. This can be visualized by a tighter cluster of travel time points in the scatter plots and lower overall travel time.

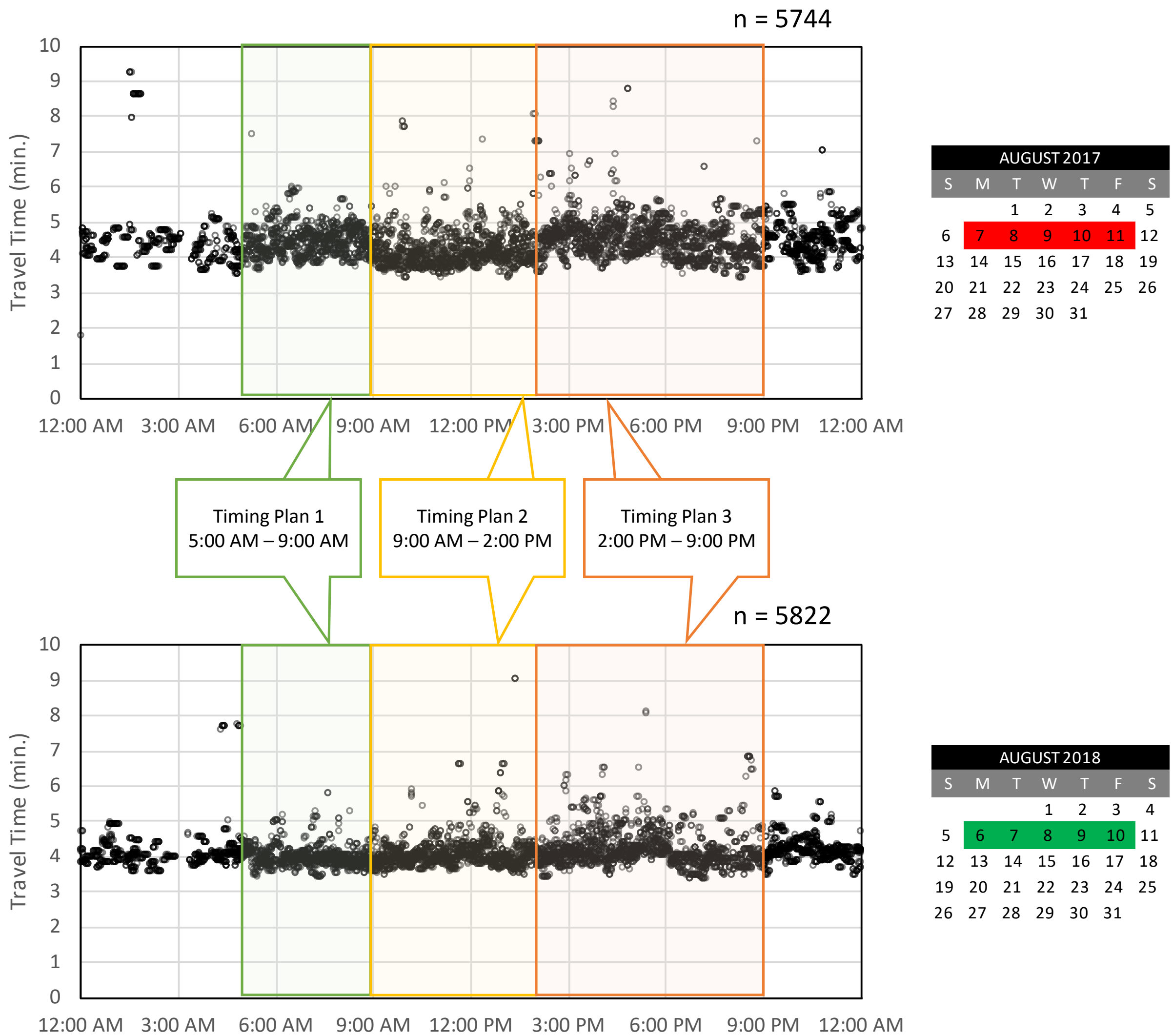


Figure 32. Northbound US-31 in Holland original vs. updated offset travel times

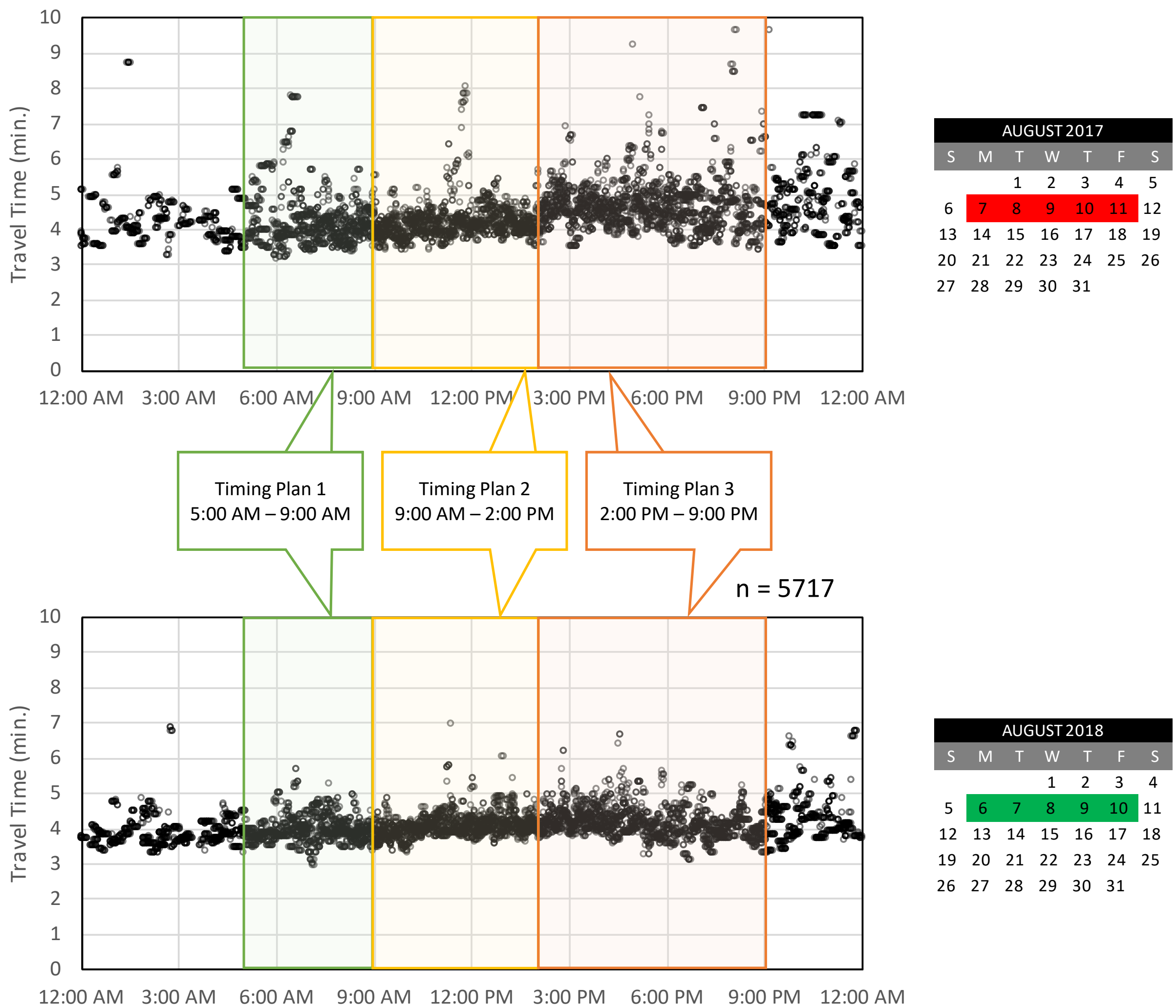


Figure 33. Southbound US-31 in Holland original vs. updated offset travel times

The overall impact in both the southbound and northbound direction can be seen more easily in the cumulative distribution graphs shown in Figure 34. For all time periods and directions the travel times were reduced. Average travel time reductions ranged between 6 seconds and 29 seconds. The daily travel time reduction totaled 187.3 hours (48872.2 hours per year). The user cost savings per year for the offset optimization was $935,414.59 with an additional $9,073.52 benefit associated with emissions reductions. The breakdown of the delay reduction and cost savings is displayed in Table 8.

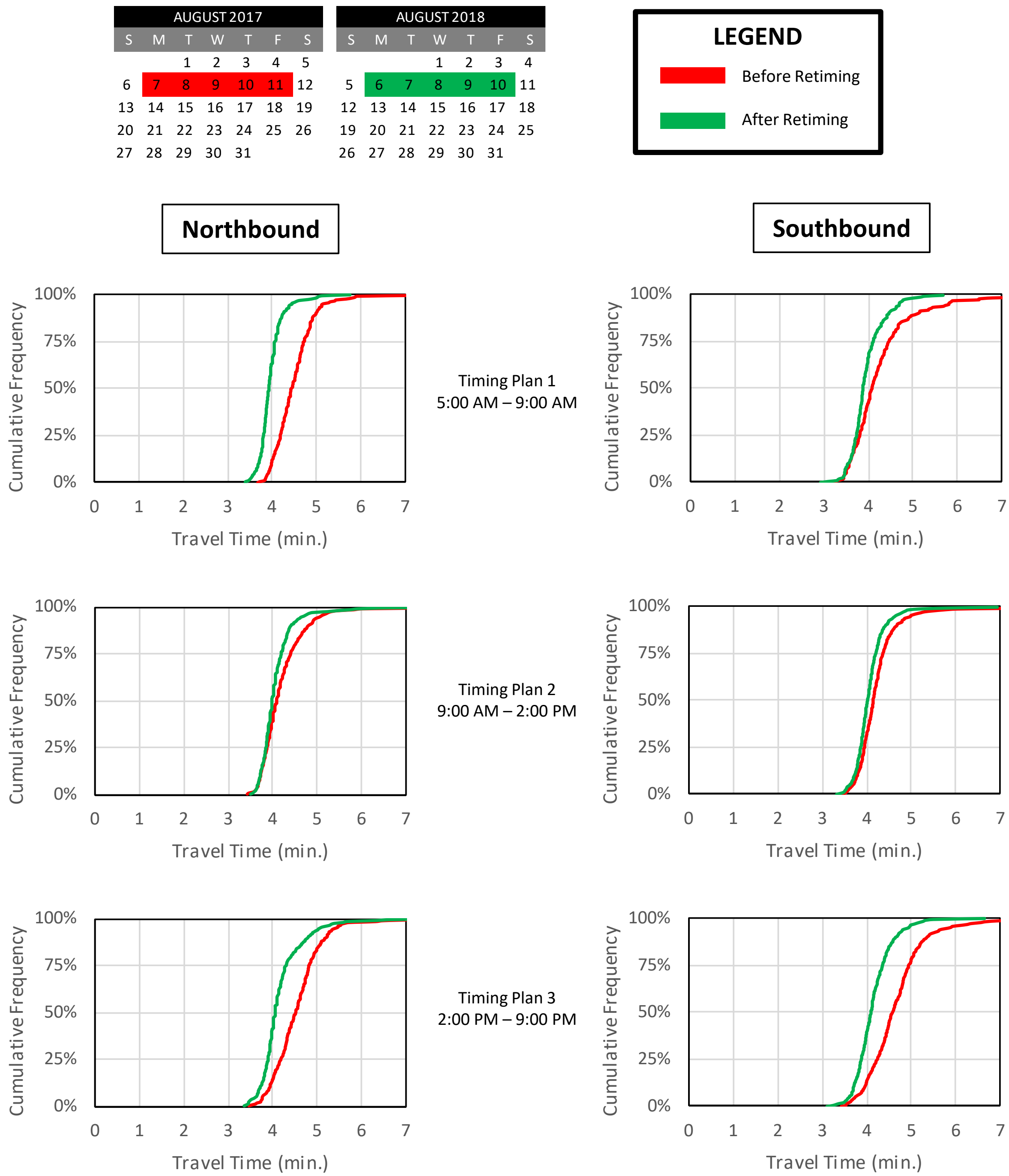


Figure 34. Probe vehicle assessment of travel time before and after optimization

Table 8. User cost assessment of Holland optimization using probe vehicle data

	Timing Plan	Median TT Savings (min)	% of Daily Traffic	TT Savings (hr)	TTI Travel Time Savings ($)	CO2 Reduction (tons)	CO2 Emission Savings ($)
Northbound US-31	Plan 1 (5:00 AM - 9:00 AM)	0.48	7.30%	22.61	$432.71	0.1908	$4.20
	Plan 2 (9:00 AM - 2:00 PM)	0.12	14.47%	11.20	$214.43	0.0945	$2.08
	Plan 3 (2:00 PM - 9:00 PM)	0.46	22.50%	66.78	$1,278.13	0.5635	$12.40
Southbound US-31	Plan 1 (5:00 AM - 9:00 AM)	0.18	9.02%	10.48	$200.50	0.0884	$1.94
	Plan 2 (9:00 AM - 2:00 PM)	0.11	15.36%	10.90	$208.65	0.0920	$2.02
	Plan 3 (2:00 PM - 9:00 PM)	0.48	21.08%	65.28	$1,249.53	0.5509	$12.12
	Daily Totals		89.73%	187.25	$3,583.96	1.5802	$34.76
	Per Year			48872.24	$935,414.59	412.43	$9,073.52

11.1.2 Holland Riley Misstep

As discussed above, an error occurred while entering signal offsets to the Riley intersection and the N. Riley Xover due to some complications with communications to the corridor. This resulted in the wrong offsets being implemented on two of the intersections on the corridor. Being able to verify the impact of the signal timing adjustments using ATSPMs, the issue was immediately evident from the PCDs (Figure 35, callout 'i'). Within a few days, the problem was identified and fixed. Using the ATSPMs the problem was verified as solved immediately after the prescribed adjustments were input into the signal controller (Figure 36, callout 'ii').

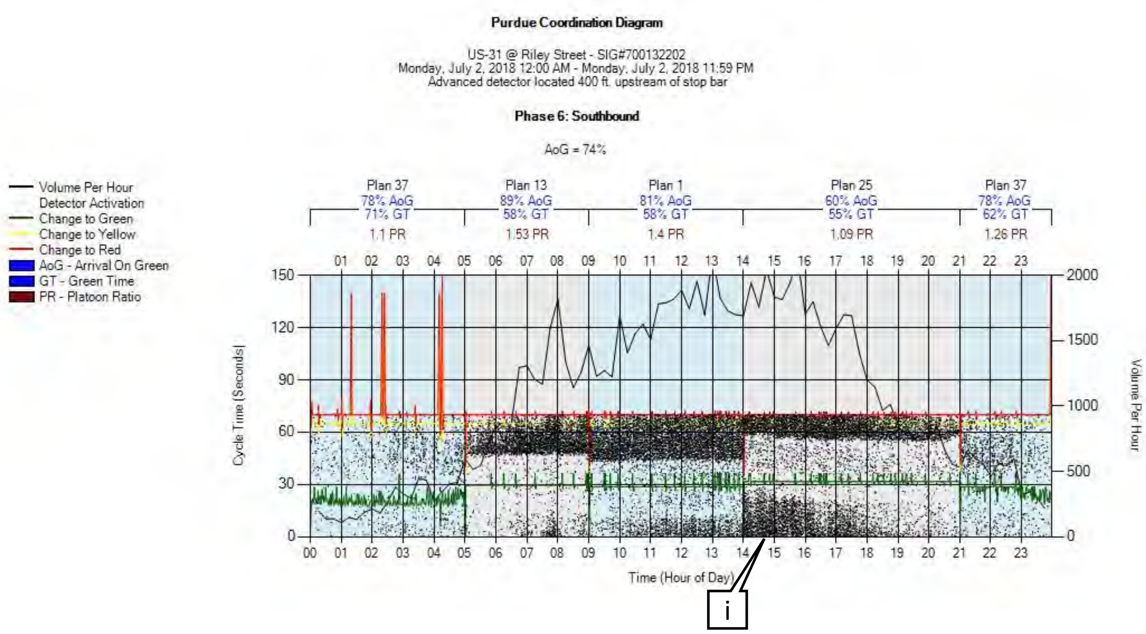


Figure 35. PCD of SB Riley during the input error

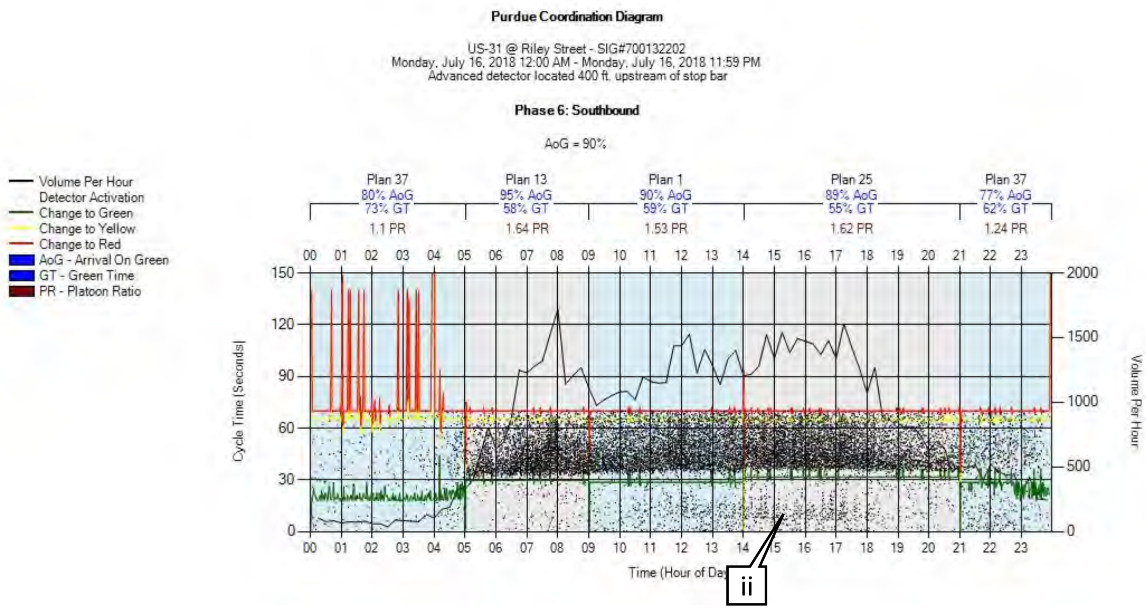


Figure 36. PCD of SB Riley after the input error was resolved

The issue presented above illustrates the potential for using ATSPMs as part of real-time verification of signal timing changes. The cause and effect of any changes along a corridor can be characterized within a day, and in some instances in less than an hour. The benefits realized from identifying the issues at the N. Riley Xover were quantified using probe vehicle data. The daily travel time reduction totaled 12.9 hours (3367.3 hours per year). The user cost savings per year were $64,458.37 with an additional $625.25 benefit for emissions reductions. The breakdown of the delay reduction and cost savings is displayed in Table 9.

Table 9. Riley misstep user cost with probe vehicle data

	Timing Plan	Median TT Savings (min)	% of Daily Traffic	TT Savings (hr)	TTI Travel Time Savings ($)	CO2 Reduction (tons)	CO2 Emission Savings ($)
Southbound US-31	Plan 1 (5:00 AM - 9:00 AM)	0.28	9.02%	8.55	$163.57	0.0721	$1.59
	Plan 2 (9:00 AM - 2:00 PM)	0.00	15.36%	0.00	$0.00	0.0000	$0.00
	Plan 3 (2:00 PM - 9:00 PM)	0.06	21.08%	4.36	$83.40	0.0368	$0.81
	Daily Totals		45.46%	12.90	$246.97	0.11	$2.40
	Per Year			3367.73	$64,458.37	28.42	$625.25

11.1.3 Holland Overnight Timing

The next issue identified and mitigated on the Holland corridor was occurring during the overnight timing plan operations. After assessing AOG along the corridor between 9pm and 5am, it was determined that an unexpected number of vehicles were arriving on red. Given that the corridor utilizes detector actuations during this time, it was expected that AOG numbers overall would be higher than they were during the peak time periods. However, the assessment revealed that the AOG were actually lower. Figure 37 callout 'i' shows vehicles arriving at the northbound Felch approach relatively late during the green phase. These late arrivals were indicative of offsets not being optimized for that specific time period based upon actual traffic patterns. After reviewing the timing plans and traffic patterns, it was determined that the off-peak offsets would work well with the overnight timing plan and require minimal engineering time to implement when compared with developing a unique coordination pattern and offsets using traffic models. On August 8th, 2018, a series of adjustments were made in the programmed timing plans and the new offsets were installed along with changes in how the actuation features were being used. After the final adjustments were applied vehicle arrival times along the corridor improved (Figure 38 callout 'I'). Overnight and weekend timing adjustments, such as this example, are some of the most beneficial impacts of implementing an ATSPM system. Midnight and weekend periods are typically times where no data is available for engineers or operators to make systematic adjustments. ATSPMs provide a tool for identifying issues that otherwise would have gone unnoticed.

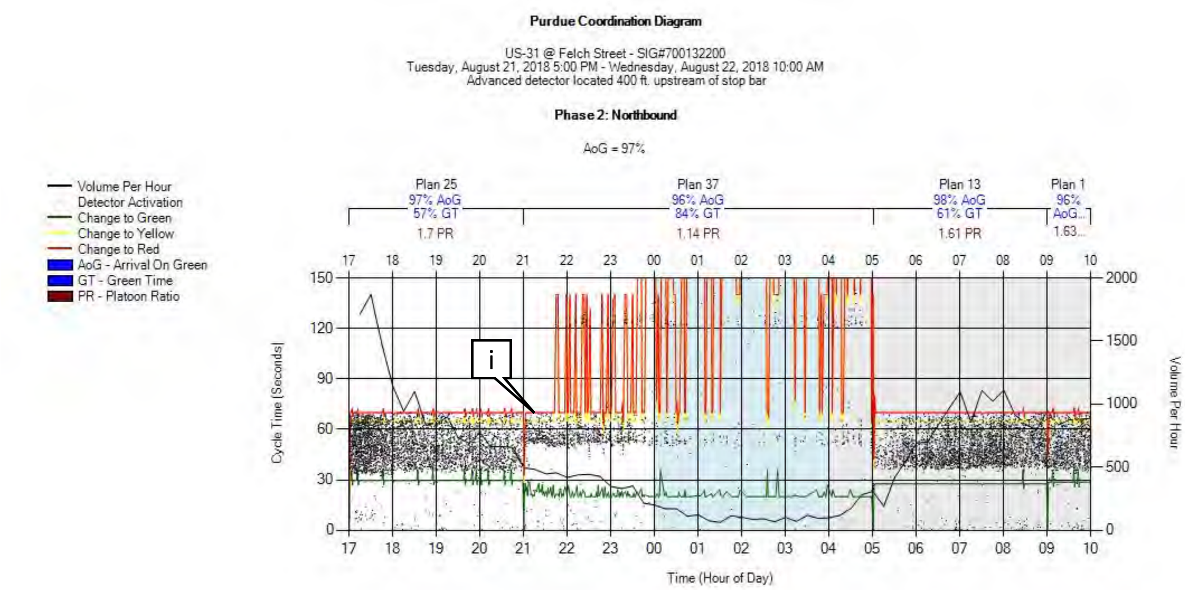


Figure 37. Original PCD of Felch for overnight timing plan

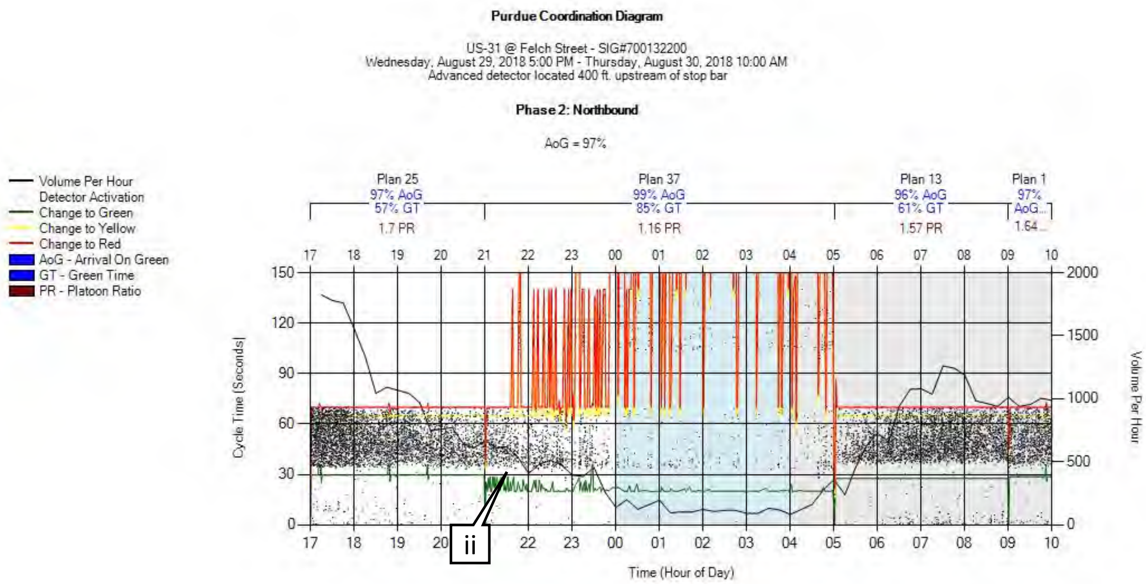


Figure 38. PCD of Felch for overnight timing plan after adjustment

The benefit seen from identifying the issues during the overnight timing plan was quantified using probe vehicle data. The daily travel time reduction totaled 13.25 hours (3457.21 per year). The user cost savings per year was $66,171.00 with an additional $641.86 benefit for emissions reductions. The breakdown of the delay reduction and cost savings is displayed in Table 10.

Table 10. Benefit of retiming the overnight plan in Holland

	Timing Plan	Median TT Savings (min)	% of Daily Traffic	TT Savings (hr)	TTI Travel Time Savings ($)	CO2 Reduction (tons)	CO2 Emission Savings ($)
Northbound US-31	Plan 0 (12:00 AM - 5:00 AM)	0.32	1.57%	3.38	$64.77	0.0286	$0.63
	Plan 0 (9:00 PM - 12:00 AM)	0.17	3.74%	4.28	$81.97	0.0361	$0.80
Southbound US-31	Plan 0 (12:00 AM - 5:00 AM)	0.12	1.63%	1.32	$25.22	0.0111	$0.24
	Plan 0 (9:00 PM - 12:00 AM)	0.19	3.33%	4.26	$81.57	0.0360	$0.79
	Daily Totals		10.27%	13.25	$253.53	0.11	$2.46
	Per Year			3457.21	$66,171.00	29.18	$641.86

11.1.4 Traverse Link Pivot (Summer)

Upon review of the PCDs from the Traverse City corridor, it was determined that the programmed offsets could be improved. Optimal offsets were computed using an 'exhaustive search' algorithm and the new values were implemented on the corridor on August 20th, 2018. The exhaustive search was able to be performed in Traverse City as a result of only having 3 signals, alternatively the link-pivot procedure mentioned above could have been used. The original PCDs for the corridor are displayed in Figure 39 and PCDs with the new offsets are displayed in Figure 40. However, upon implementing the offsets on the corridor, it was noted that at eastbound 4 Mile Road congestion during the PM peak timing period was creating arrival profiles which did not match the actual road conditions in Traverse City. Figure 41 shows the eastbound 3 Mile Road before and after the offset adjustment. Although an improvement was expected, the AOG for the PM time period was roughly the same. Additionally, indicators of congestion are evident in Figure 42 callout ‘i’. However, despite not fixing the congestion at 3 Mile Road the corridor saw an improvement overall. Figure 43 show before and after distributions of travel times along the corridor. With the exception of eastbound in the morning, all timing plans saw an improvement in progression.

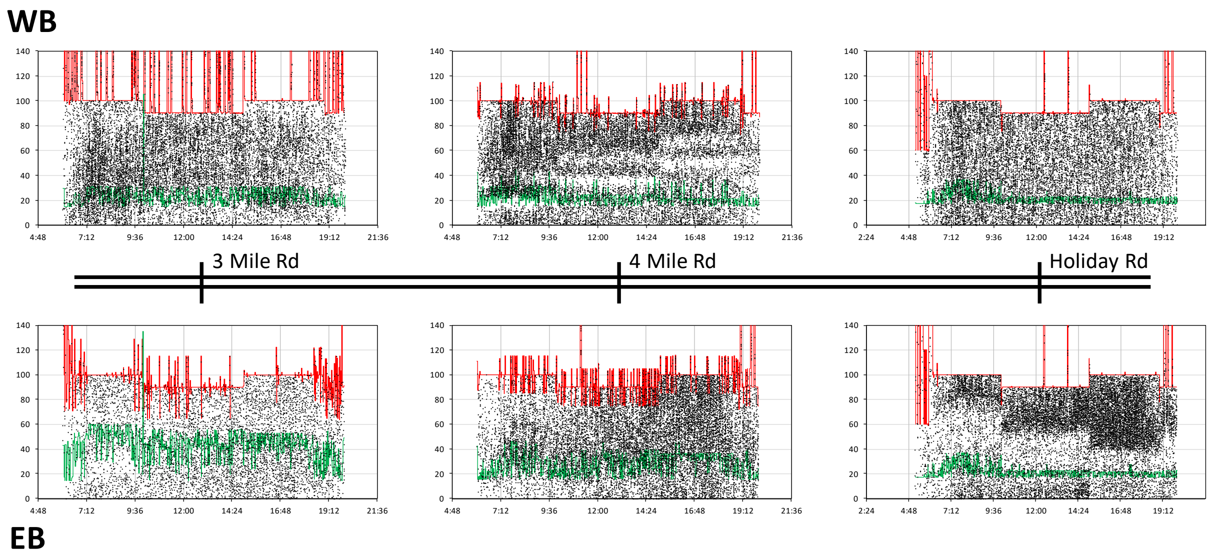


Figure 39. US-31 Traverse City corridor PCDs before offset optimization

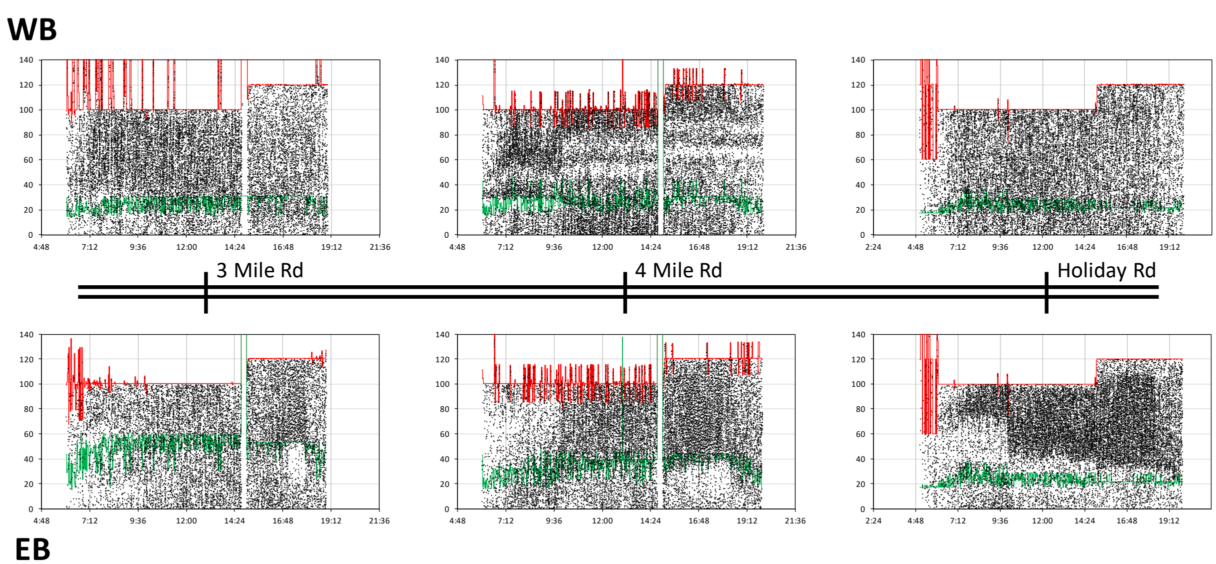


Figure 40. US-31 Traverse City corridor PCDs after offset optimization

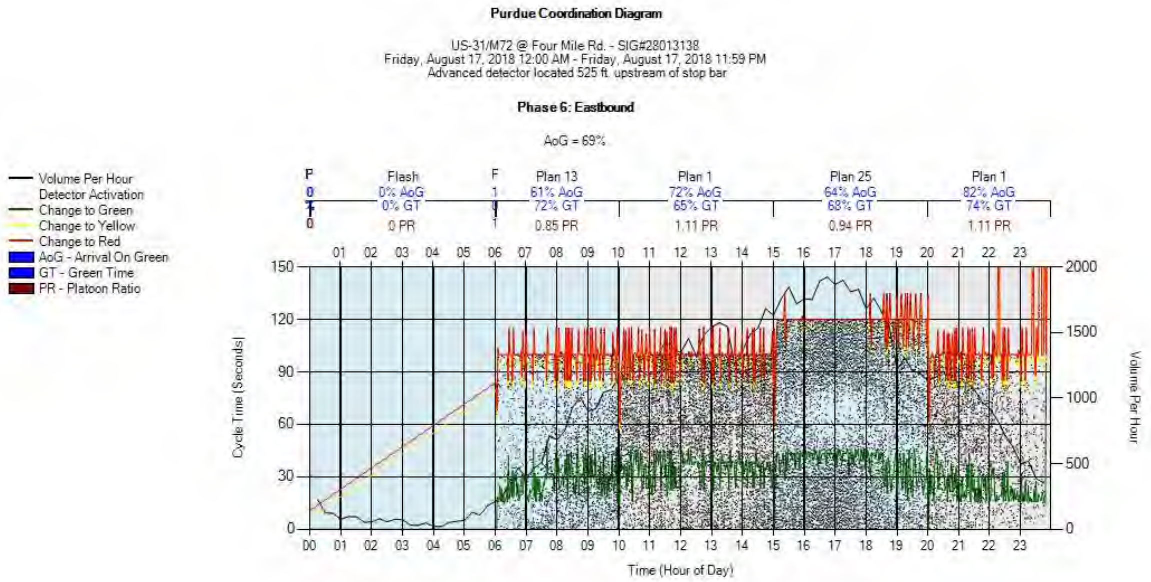


Figure 41. PCD of 3 Mile Road before offset optimization

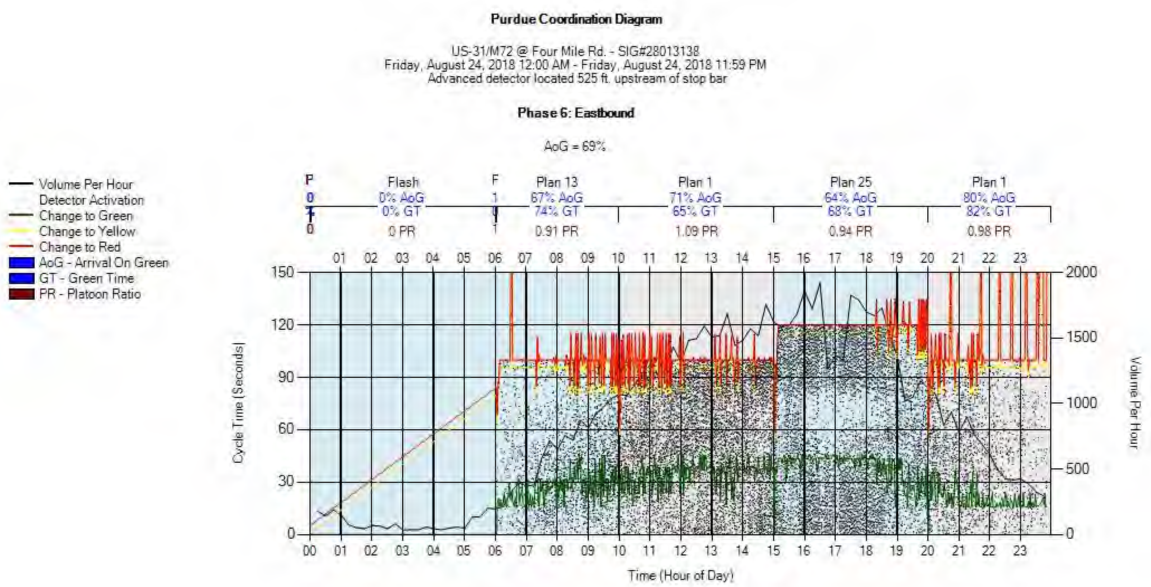


Figure 42. PCD of 3 Mile Road after offset optimization

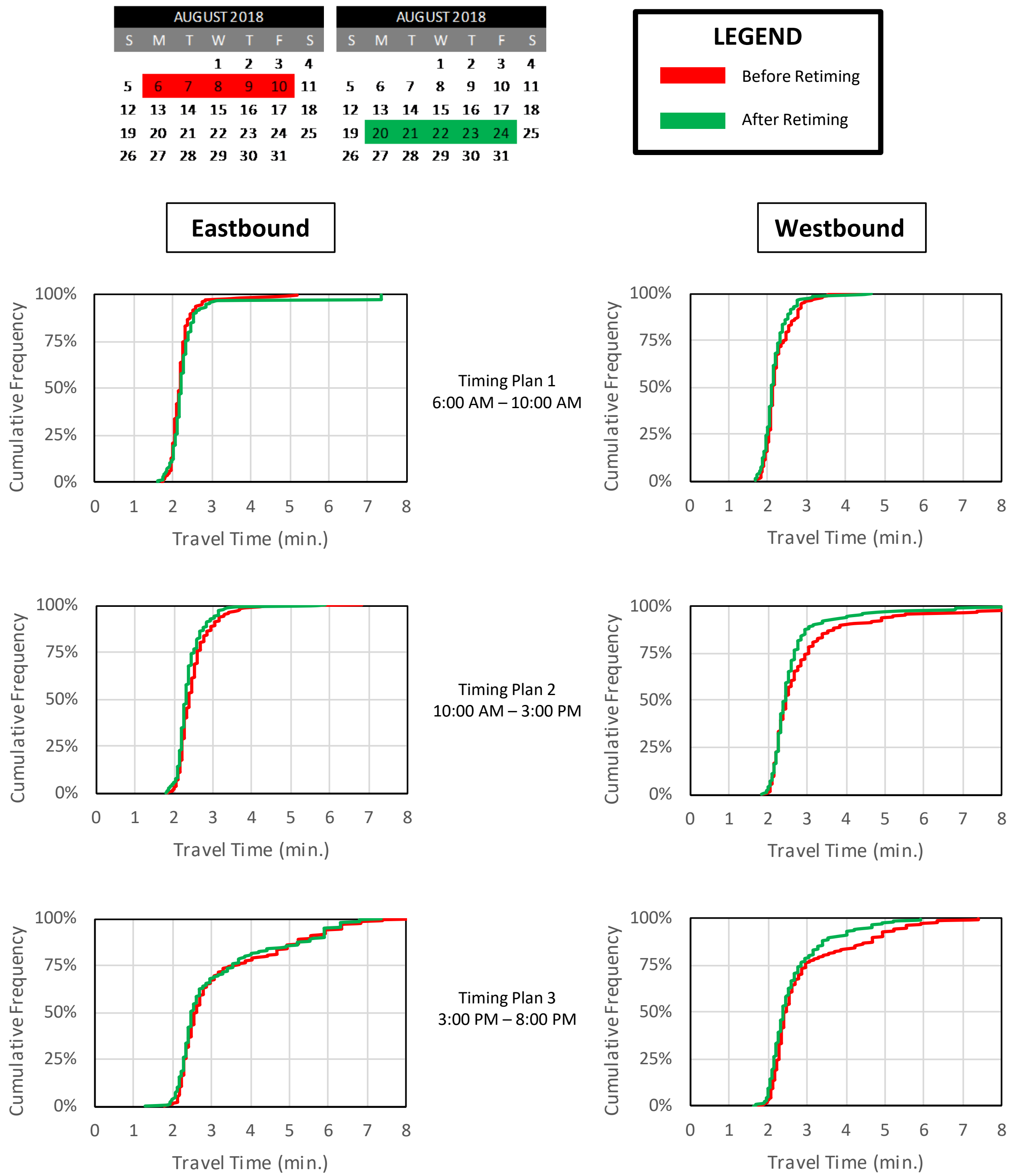


Figure 43. Traverse City Link Pivot before/after

The benefits realized from the offset optimization of the Traverse City corridor were quantified using probe vehicle data. The daily travel time reduction totaled 24.53 hours (6403.35 per year). The user cost savings per year was $118,974.19 with an additional $1,188.83 benefit for emissions reductions. The breakdown of the delay reduction and cost savings are displayed in Table 11.

Table 11. Traverse City offset optimization user benefit

	Timing Plan	Median TT Savings (min)	% of Daily Traffic	TT Savings (hr)	TTI Travel Time Savings ($)	CO2 Reduction (tons)	CO2 Emission Savings ($)
Eastbound M-72	Plan 1 (6:00 AM - 10:00 AM)	0.00	6.82%	0.00	$0.00	0.0000	$0.00
	Plan 2 (10:00 AM - 3:00 PM)	0.06	15.81%	6.44	$119.70	0.0544	$1.20
	Plan 3 (3:00 PM - 8:00 PM)	0.14	19.03%	18.09	$336.14	0.1527	$3.36
Westbound M-72	Plan 1 (6:00 AM - 10:00 AM)	0.00	12.78%	0.00	$0.00	0.0000	$0.00
	Plan 2 (10:00 AM - 3:00 PM)	0.00	17.46%	0.00	$0.00	0.0000	$0.00
	Plan 3 (3:00 PM - 8:00 PM)	0.00	14.69%	0.00	$0.00	0.0000	$0.00
	Daily Totals		86.60%	24.53	$455.84	0.2070	$4.55
	Per Year			6403.35	$118,974.19	54.04	$1,188.83

11.1.5 Traverse Link Pivot (Winter)

On September 18th, 2018 an offset optimization was conducted and implemented on the Traverse City corridor for the winter seasonal timing plan. Multiple datasets were analyzed to assess the impact of the offset adjustment; however, the assessments showed that no improvements to either reliability or delay occurred. Thus, it was concluded that the adjustment hand no major impact on the corridor and the net gains were deemed to be zero. The most likely cause of the low impact on the corridor was the limited number of signals and congestion in the PM period. Figure 44 and Figure 45 show the impact of the offset adjustment on Four Mile Road.

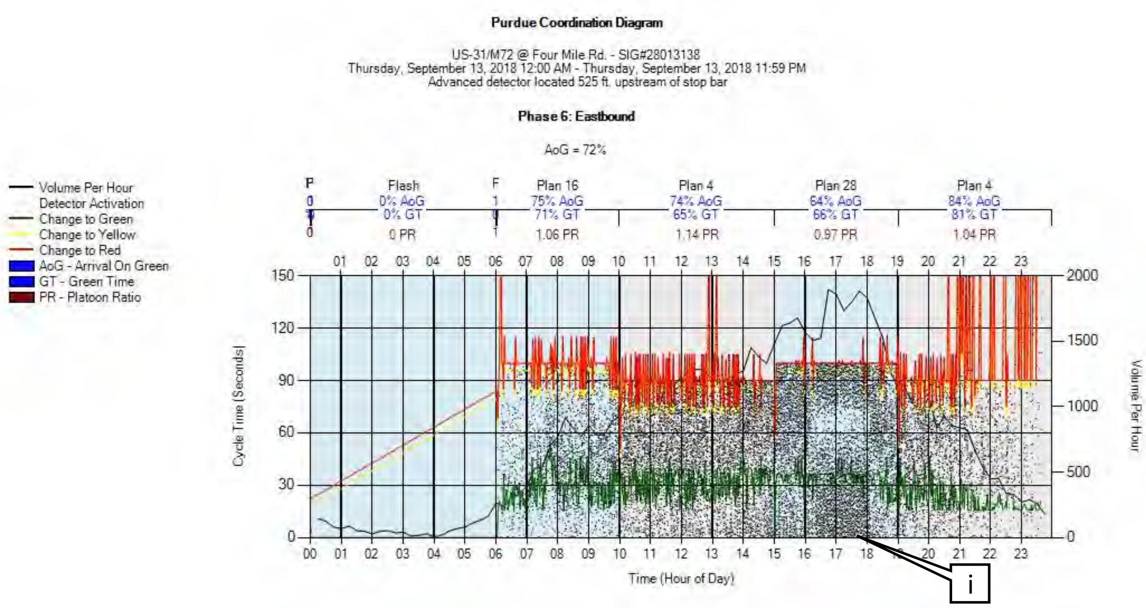


Figure 44. Four Mile Road PCD prior to offset adjustment

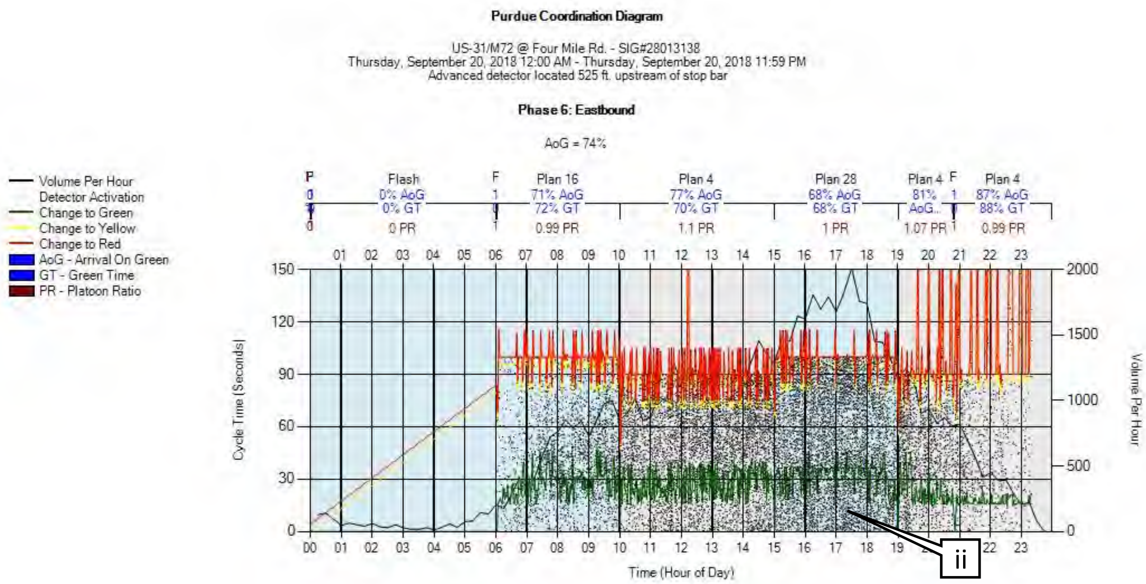


Figure 45. Four Mile Road PCD after offset adjustment

11.1.6 Traverse Wrong Cycle

On April 27th, 2018 the timing plans for the Traverse City corridor were reprogrammed because it was identified that the designed timing plans were not programmed correctly into the signal controllers. The timing plans that were running had varying cycle lengths which caused the intersections to function as if they had random vehicle arrivals. Thus, no progression was occurring along the corridor. The incorrect plans had been programmed and in place for approximately 8-months. The unequal cycle lengths within these plans created stratified arrival patterns in the PCDs which are shown in Figure 46 callout 'i'. Figure 47 callout 'ii' shows the arrival patterns after the cycle length was adjusted.

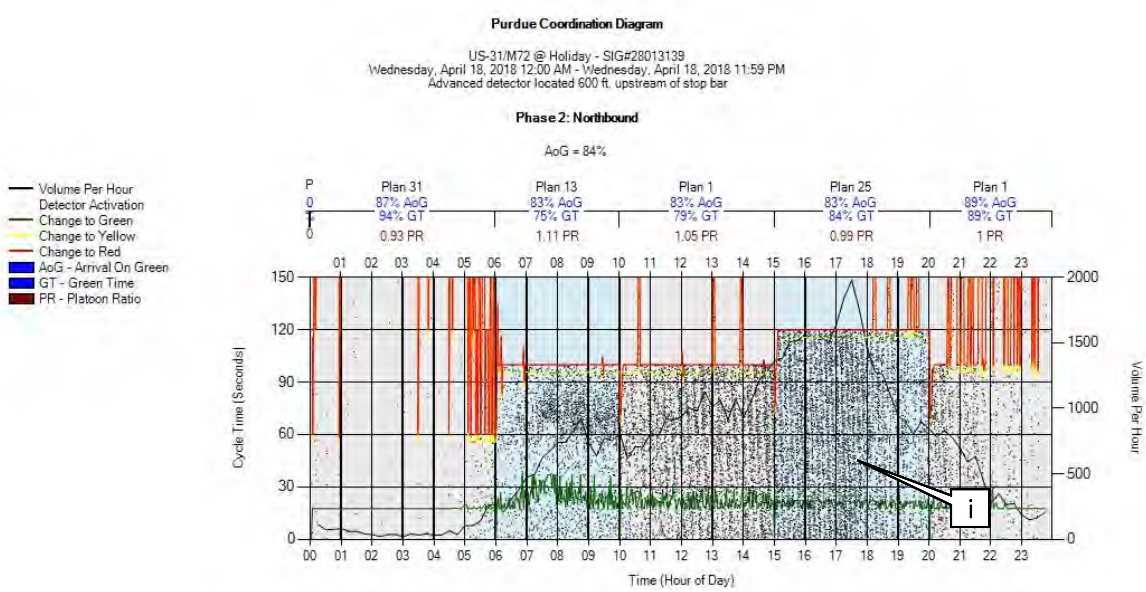


Figure 46. Holiday Road PCD (4/18/18)

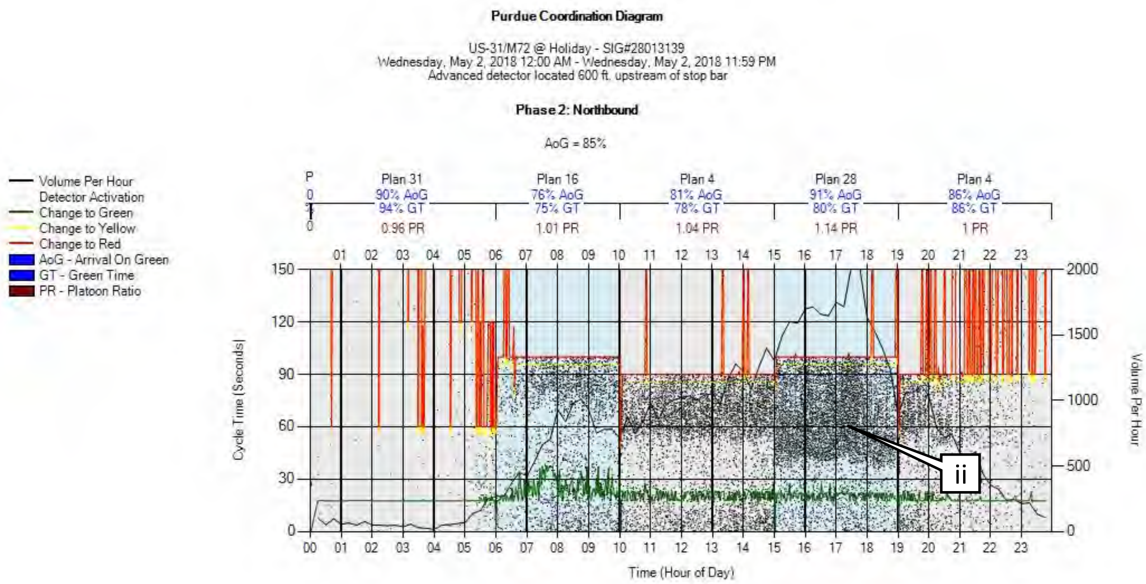


Figure 47. Holiday Road PCD (5/2/18)

The benefit seen from identifying these issues were quantified using probe vehicle data. The daily travel time reduction totaled -12.15 hours (-3170.06 per year). The user cost increase per year was $58,899.68 with an additional $588.55 for increased emissions. The breakdown of the delay reduction and cost savings is displayed in Table 12. However, given the nature of the changes made on the corridor, it should be noted that the cycles lengths were reduced, and the overall time given to the mainline decreased. Because of this the negative benefit values as achieved on the mainline would most likely be offset by benefits realized by vehicles on the side streets, due to the side street receiving additional time. Due to the data sets available for this study we were not able to quantify the net impact that these changes had when considering both mainline and side street operations.

Table 12. User delay cost Traverse wrong cycle length

	Timing Plan	Median TT Savings (min)	% of Daily Traffic	TT Savings (hr)	TTI Travel Time Savings ($)	CO2 Reduction (tons)	CO2 Emission Savings ($)
Eastbound M-72	Plan 1 (6:00 AM - 10:00 AM)	0.06	6.82%	2.22	$41.16	0.0187	$0.41
	Plan 2 (10:00 AM - 3:00 PM)	0.00	15.81%	0.00	$0.00	0.0000	$0.00
	Plan 3 (3:00 PM - 7:00 PM)	-0.06	19.03%	-6.18	-$114.81	-0.0521	-$1.15
Westbound M-72	Plan 1 (6:00 AM - 10:00 AM)	-0.05	12.78%	-3.46	-$64.24	-0.0292	-$0.64
	Plan 2 (10:00 AM - 3:00 PM)	-0.05	17.46%	-4.72	-$87.78	-0.0399	-$0.88
	Plan 3 (3:00 PM - 7:00 PM)	0.00	14.69%	0.00	$0.00	0.0000	$0.00
	Daily Totals		86.60%	-12.15	-$225.67	-0.1025	-$2.25
	Per Year			-3170.06	-$58,899.68	-26.75	-$588.55

12 ATSPM COSTS

There are many costs and benefits of the implementation of automated traffic signal performance measures. A simplified overview of the cost and benefit categories can be seen in Table 13 and Table 14, respectively. The costs are made up of both the physical infrastructure costs, as well as the costs to install, maintain, and operate the system. The benefits of the signal performance measurement systems can be simplified into agency benefits and user benefits. The sections below will build upon these figures and explain the category, discuss the methodology for measuring each category, and quantifying the costs and benefits under each category.

Table 13. Overview of ATSPM costs

Costs		
Infrastructure	**Equipment**	Physical
		Other
	Labor	Engineering
		Construction
		Systems Engineering
Upkeep	**Maintenance**	Physical
		Server
	Operations	Monitoring
		Implementation

Table 14 . Overview of ATSPM benefits

Benefits		
Agency	**Maintenance**	False Call Prevention
		Routine Maintenance Assistance
	Operations	Optimization
		Traffic Studies
		Research/Other
User	**Delay**	Main-line
		Side Street
	Safety	Crash Reduction
	Emissions	Reduction in Carbon Emissions

12.1 EQUIPMENT AND MONITORING LEVELS

After numerous discussions and dialogue with MDOT, a cost assumption tool was created to determine a baseline cost for various effort assumptions, configurations of ATSPM equipment, and ATSPM based monitoring approaches. These assumptions will be outlined in this document. The basis of this tool are the pre-defined equipment levels and monitoring levels. The equipment levels, established by MDOT, are defined as follows:

- *Level 0 – Use existing system while continuing to upgrade back haul communications from landline to cell modem.*

- *Level 1 – Use existing systems, but ensure upgraded communications and signal status alerts via an ATSPM tool. Upgrade server space. Upgrade signal controllers to provide data logging capabilities. Existing serial interconnect systems should be upgraded to IP-based communications to add more reliability. Backhaul communications shall be upgraded from landline to cell modem.*
- *Level 2 – Same as Level 1 with the following additions: Fixed-time signals will require side street detection. Existing semi-actuated signals may require updated detection depending on existing detection type.*
- *Level 3 – Same as Level 2 with the following additions: Advanced vehicle detection installation on the main line.*

The monitoring strategies will change with the equipment levels as each equipment level allows different measures to be used. For example, Level 3 equipment allows all ATSPM tools to be used, including main line performance functions such as Purdue Coordination Diagrams (PCDs). Level 2 equipment allows only side street performance to be measured. Level 1 equipment would only allow the investigation of signal states and ensuring that the signal timings were properly placed in the field. It is important to note that the ATSPM systems will include a Watch Dog application which will be used to continuously monitor equipment and signal status, however this application does not currently have functionality to continuously monitor performance. The performance monitoring levels are thus defined as a frequency of performance optimization using the available equipment. In this sense the performance monitoring levels are defined below:

- *Level 0 – MDOT's current level of signal monitoring. Equipment health checks are seldom applied and varies by Region. The central system is seldom used to change signal timings even during emergency events (some exceptions in Metro Region). A central system is mostly used to collect existing timing parameters for record keeping (this is done infrequently). Although the current central system has more capabilities, its benefit is limited primarily due to staffing and funding.*
- *Level 1 – FHWA recommended practice is to retime a signal every three to five years. With advance capabilities provided by ATSPMs, two year frequencies are possible. Level 1 monitoring consists of an optimization every other year.*
- *Level 2 – An optimization will occur twice per year to correspond with seasonal variations.*
- *Level 3 – Monthly optimizations will occur to allow the system to continuously perform at the optimal level.*

The overall objective of these equipment and monitoring levels is to provide flexibility to MDOT when establishing and building their ATSPM system. It is not likely that every intersection in the state will require monthly monitoring and advanced detection. For example, a rural intersection with low volume would likely not need to be equipped or monitored in a similar fashion compared to a high volume critical corridor in the Metro region. This tool will allow MDOT to understand the costs associated with each of these various equipment and monitoring levels moving forward.

12.2 Overall Cost Metric

There is a temporal element when defining the cost of signal equipment because certain aspects of the ATSPM related equipment will need replacement over time. This makes comparing the costs and benefits of ATSPM systems difficult to comprehend. This was overcome by calculating the costs as the cost per intersection per year (CPI). This allows for inclusion of temporal assumptions regarding equipment replacement costs and still provides a clear comparison between the overall costs and benefits of the ATSPM system. For instance, if the cost of new detection would be $10,000 and that detection would last 10 years, the cost per intersection per year for detection would be $1,000. The final CPI for the defined assumptions are located in the CPI tab of the ATSPM cost excel sheet. Table 15 below shows an example of the CPI for monitoring level 3 and equipment level 3. The following sections briefly describe each of the sheets that are used to calculate the CPI and the assumptions for each.

Table 15. Cost per intersection per year (CPI) – equipment level 3 and monitoring level 3

Sheet	Costs	Amount
A	Installation/Equipment	$4,612.50
B	Installation Labor (MDOT)	$165.64
C	Systems Labor	$1.43
D	Initial Operations Labor	$23.68
E	Physical Maintenance	$1,016.87
F	Server Cost	$3.82
G	Tool Maintenance	$13.83
H	Watchdog Monitoring	$327.29
H	Monitoring & Implementation	$284.10
	Total	**$6,449.16**

12.3 Overall Assumptions

The high level assumptions for the cost calculations are included in the CPI sheet of the cost calculator. These assumptions are currently based on discussions with MDOT and limited MDOT traffic signal system inventory data, but as future studies improve the content of MDOT traffic signal inventories these numbers can be adjusted. The assumed numbers are listed in Table 16. In the excel tool, if these numbers are adjusted the CPI numbers will change accordingly. Descriptions of the assumptions are included below:

- *# of Signals equipped with ATSPMs* – Assuming all intersections owned by MDOT are equipped. In the future this can be broken up into monitoring and equipment levels to understand the overall cost of MDOT's desired system.
- *Avg. # of Signals per Corridor* – The average number of signals in an MDOT corridor was determined to be 10 based on discussions with MDOT signal engineers.
- *Monthly Server Costs* – DTMB provided MDOT with a $1,000 per month cost for the operation and maintenance of a server that includes unlimited data storage.
- *Hours Per Week For Tool Maintenance* – This is the assumed number of hours a systems engineer would need to keep the ATSPM dashboard operational. The current 8 hour assumption is based on the time Ken Yang from AECOM is spending to keep the system operational.
- *Average Engineering Loaded Rate* – Loaded hourly rate of the average engineer on the project. This number was determined using the average engineering costs for the installation and implementation of both the Holland and Traverse City system.

- *Average Technician Loaded Rate* – Loaded hourly rate of the average technician on the project. This number was determined using the average technician costs for the installation and implementation of both the Holland and Traverse City system.
- *Average Systems Engineering Loaded Rate* – Loaded hourly rate of a systems engineer. This number is collected from the IT specialist 15 category on the MCSC Job specifications page.
- *Average Entry Engineer (monitor) Loaded Rate* – Loaded hourly rate of an entry level transportation engineer. This number is collected from the Transportation Engineer 9 category on the MCSC Job specifications page.
- *Monitoring Level 0 Optimization Frequency* – Frequency of yearly performance optimizations for monitoring level 0.
- *Monitoring Level 1 Optimization Frequency* – Frequency of yearly performance optimizations for monitoring level 1.
- *Monitoring Level 2 Optimization Frequency* – Frequency of yearly performance optimizations for monitoring level 2.
- *Monitoring Level 3 Optimization Frequency* – Frequency of yearly performance optimizations for monitoring level 3.
- *Watchdog Failure Rate (How often is something wrong)* – How often an error is discovered by a monitor in the watchdog application that requires engineer and/or technician attention. The 1% is assumed based on the number of critical issues that have been identified on the Holland and Traverse City corridors.
- *Engineering Time Required to Fix Watchdog Error* – Average engineering time to diagnose and recommend a solution to a problem that is identified by the watchdog application. This number is assumed based on discussions with MDOT signal engineers.
- *Technician Time to Fix Watchdog Error* – Average technician time required to address an issue in the field and implement a change. The 2.64 hours is based on the average of all MDOT regions from a maintenance survey.

Table 16. High level assumptions for cost calculations

# of Signals equipped with ATSPMs	3143
Avg. # of Signals per Corridor	10
Monthly Server Costs	$1,000
Hours Per Week For Tool Maintenance	8
Average Engineering Loaded Rate	$85.00
Average Technician Loaded Rate	$61.00
Average Systems Engineering Loaded Rate	$104.50
Average Entry Engineer (monitor) Loaded Rate	$46.95
Monitoring Level 0 Optimization Frequency	0
Monitoring Level 1 Optimization Frequency	0.5
Monitoring Level 2 Optimization Frequency	2
Monitoring Level 3 Optimization Frequency	12
Watchdog Failure Rate (How often is something wrong)	1%
Engineering Time Required to Fix Watchdog Error	2
Technician Time to Fix Watchdog Error	2.64

12.4 Equipment

The equipment costs are based on the physical infrastructure and installation costs of the equipment in the field. The assumptions made in this sheet are based upon the average equipment necessary per intersection. These assumptions were determined from discussions with MDOT signal engineers. Table 17 illustrates the average amount of infrastructure that was used at each of the various equipment levels. The costs use Sensys magnetometers as the MDOT preferred detection type and that was the detection used at the intersections being studied. These costs can be modified to use other forms of detection such as video, inductive loops, or radar. Table 18 shows the average 10-year equipment costs by intersection for each equipment level. The main assumptions in this table are the lifespan of the equipment. The costs were collected using a combination of MDOT discussions and quotes from equipment vendors.

Table 17. Average equipment per intersection by equipment level

	Cards	Wireless Access Point	Magnetometer	Data Logging Controller	Repeater	Communication Device	Communication Fees
Level 3	4	2	22	1	2	1	1
Level 2	2	2	14	1	0	1	1
Level 1	0	0	0	1	0	1	1
Level 0	0	0	0	1	0	1	1

Table 18. Average equipment costs per intersection by equipment level

Type	Equipment	Cost (include Labor)	Lifespan (years)	10 Year Cost (Level 3)	10 Year Cost (Level 2)	10 Year Cost (level 1)	10 Year Cost (Level 0)
Sensys Detection	Card	$525.00	10	$2,100.00	$1,050.00	$-	$-
	Wireless Access Point	$5,000.00	10	$10,000.00	$10,000.00	$-	$-
	Magnetometers	$550.00	5.5	$22,000.00	$14,000.00	$-	$-
		Sensys Detection Sub Total		$34,100.00	$25,050.00	$-	$-
Controller	Data Logging Controller	$3,525.00	10	$3,525.00	$3,525.00	$3,525.00	$3,525.00
Communications	Device	$3,500.00	10	$3,500.00	$3,500.00	$3,500.00	$3,500.00
	Monthly Fee	$25.00	0.083	$3,000.00	$3,000.00	$3,000.00	$3,000.00
		Communication Sub Total		$6,500.00	$6,500.00	$6,500.00	$6,500.00
Repeater	Device	$1,000.00	10	$2,000.00	$-	$-	$-
			Total Per Type	$46,125.00	$35,075.00	$10,025.00	$10,025.00

12.5 Installation Labor

The installation costs for the equipment are included in the equipment category, however there are additional costs that MDOT would need to spend to supervise and test the initial equipment deployment in the field. Table 19 highlights these expenses. The equipment Level 3 expenses were determined using the actual time spent in the field by MDOT engineers and technicians. The systems engineering time spent is based on a 15-minute assumption to enter the new signal into the ATSPM system. The Level 2 and Level 1 reduction are based on the reduction in time in the field as a result of having less equipment. It is assumed the lack of advanced detection in the field will reduce the required engineering and technician time by 25%. If no detection is present in the field, as is the case for Equipment Levels 1 and 0, a 90%

reduction in time is expected. The remaining time will be used to establish the phasing numbers and communication at the intersection.

Table 19. Installation labor for MDOT staff

Assumptions		Hours Spent	# Intersections	Level 3 CPI	Level 2 Reduction	Level 2 Hours	Level 2 CPI	Level 1 Reduction	Level 1 Hours	Level 1 CPI
Average Engineering Loaded Rate	$85.00	118.2	12	$837.25	25%	88.65	$627.94	90%	11.82	$111.63
Average Technician Loaded Rate	$61.00	156	12	$793.00	25%	117	$594.75	90%	15.6	$105.73
Average Systems Engineering Loaded Rate	$104.50	0.25	1	$26.13	0%	0.25	$26.13	0%	0.25	$26.13
Total				$1,656.38			$1,248.81			$243.49

12.6 Systems Labor

The systems labor is based on a fixed cost for the initial set up of the ATSPM system. The number used in these calculations was $45,000, which was the cost of the systems engineer who set up the UDOT system for this study. The CPI is then determined using a ten year life, which results in a $1.43 CPI for the initial systems labor.

12.7 Initial Optimization Labor

The initial optimization of a system is critical to realizing the benefits of an ATSPM system. MDOT needs to develop an initial checklist once ATSPMs have been deployed on a corridor. Through discussion with MDOT the following steps were developed:

- *Signal Operation (Is it working?)* – Assess whether the signal is operating and the phases are mapped correctly.
- *Detector Operation (Are they working?)* – Assess whether all detection is mapped correctly and the correct volumes are coming through the system.
- *Effective use of green time on side streets?* – Using the phase monitor make sure the side street is getting enough time throughout the day.
- *Consistent Coordination?* - Assess that the intersection is coordinated and there are no severe temporal variations.
- *Common Cycle Lengths?* – Make sure that all of the cycle lengths along the corridor are the same length.
- *Time of Day Plan Correct?* – Check the various time of day plans and make sure there is no inconsistencies or opportunities to change the TOD plans.
- *Split Failure Assessment (side streets)?* – Check the side streets for split failures. If there are numerous split failures occurring determine if there is capacity available in another phase.
- *Optimize Progression (main line)* - Using link pivot or another optimization technique optimize the corridor offsets.
- *Consistent Performance from day to day* – Assess whether there is any daily variation in the timing plans. Check weekend timing plans for opportunities to improve.

The engineering and technician times to complete these steps were assumed based on conversations with DOT signal engineers. Each equipment level will have different steps according to the type of detection available on the corridor. Table 20, Table 21, and Table 22 display the assumed times for equipment levels 3, 2, and 1, respectively.

Table 20. Level 3 initial optimization assumptions

Initial Optimization	Engineering Hrs	Technician Hours	Engineering Costs	Technician Costs
Signal Operation (Is it working?)	0.5	0	$42.50	$-
Detector Operation (Are they working?)	0.5	4	$42.50	$244.00
Effective use of green time on side streets?	1	16	$85.00	$976.00
Consistent Coordination?	1		$85.00	$-
Common Cycle Lengths?	0.5		$42.50	$-
Time of Day Plan Correct?	2		$170.00	$-
Split Failure Assessment (side streets)?	2		$170.00	$-
Optimize Progression (main line)	4		$340.00	$-
Consistent Performance from day to day.	2		$170.00	$-
TOTALS	13.5	20	$1,147.50	$1,220.00

Table 21. Level 2 initial optimization assumptions

Initial Optimization	Engineering Hrs	Technician Hours	Engineering Costs	Technician Costs
Signal Operation (Is it working?)	0.5	0	$42.50	$-
Detector Operation (Are they working?)	0.5	2	$42.50	$122.00
Effective use of green time on side streets?	1	8	$85.00	$488.00
Consistent Coordination?	0		$-	$-
Common Cycle Lengths?	0.5		$42.50	$-
Time of Day Plan Correct?	1		$85.00	$-
Split Failure Assessment (side streets)?	2		$170.00	$-
Optimize Progression (main line)	0		$-	$-
Consistent Performance from day to day.	1		$85.00	$-
TOTALS	6.5	10	$552.50	$610.00

Table 22. Level 1 initial optimization assumptions

Initial Optimization	Engineering Hrs	Technician Hours	Engineering Costs	Technician Costs
Signal Operation (Is it working?)	0.5	0	$42.50	$-
Detector Operation (Are they working?)	0	0	$-	$-
Effective use of green time on side streets?	0	4	$-	$244.00
Consistent Coordination?	0		$-	$-
Common Cycle Lengths?	0.5		$42.50	$-
Time of Day Plan Correct?	0.5		$42.50	$-
Split Failure Assessment (side streets)?	0		$-	$-
Optimize Progression (main line)	0		$-	$-
Consistent Performance from day to day.	1		$85.00	$-
TOTALS	2.5	4	$212.50	$244.00

12.8 Server Costs

The server costs are based on DTMB prices. The price for a server capable of running the ATSPM system is $1000 per month. Assuming every MDOT signal in the state is equipped the CPI for the server would be $3.82.

12.9 Physical Maintenance

The current MDOT expenditures on maintenance per intersection are 16.67 hours per year by a technician. The current assumed values are a 100% increase in maintenance for level 3 equipment and a 50% increase for level 2 equipment (Table 23). These values are as a result of the increased detection that will be placed at each intersection. The level 1 and level 0 maintenance increases will be minimal, only needing marginally more maintenance to keep communication running at the intersections.

Table 23. Physical maintenance costs by level

Level	% Increase	Hours per Intersection	Cost
Current MDOT Expenses	-	16.67	$1,016.87
Level 0 Estimated Increase	10%	1.667	$101.69
Level 1 Estimated Increase	10%	1.667	$101.69
Level 2 Estimated Increase	50%	8.335	$508.44
Level 3 Estimated Increase	100%	16.67	$1,016.87

12.10 Tool Maintenance

Costs need to be considered for the maintenance and upkeep of the ATSPM tool. Using the time currently being spent by the systems engineer as a baseline, it is assumed that 8 hours per week would be necessary to keep the ATSPM system operating and fixing bugs that would arise throughout the year. This will result in a CPI of $13.83 (Table 24).

Table 24. ATSPM tool maintenance

Hours per week	8
Signals	3143
Total Costs	$43,472.00
CPI	$13.83

12.11 Monitoring

Monitoring effort is separated into two categories, continuous monitoring using the watchdog application and performance monitoring using the initial optimization checklist above. Table 25 outlines the costs associated with the watchdog monitoring. The numbers are currently produced using the 12 intersections that are being studied in Traverse City and Holland. Approximately 15 minutes on average each day is being spent monitoring the watchdog application. Some of that time is spent investigating common data issues that occur, but these do not require engineering or technician time to resolve. The failure rate, engineering hours, and technician hours are discussed in the overall assumptions section above. The performance monitoring level costs are listed in Table 26. These are based on the monitoring frequency discussed in the overall assumptions section above.

Table 25. Continuous monitoring costs using Watchdog

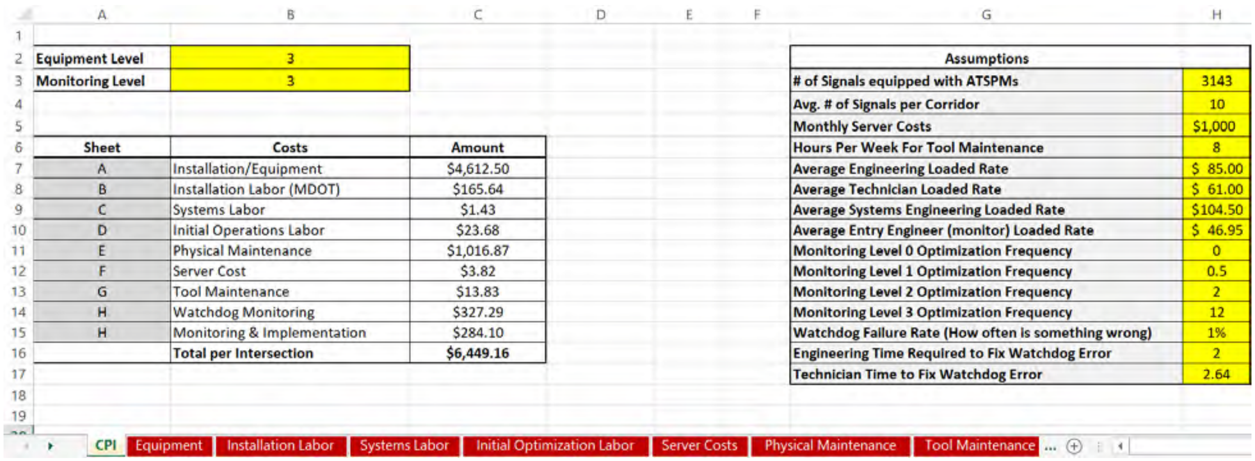
	Monitoring Hrs (daily)	**Signals Monitored**	**Monitoring Hrs per Int per yr**	**Failure Rate**	**Failures per int. per year**	**Engineering Hrs**	**Technician Hours**	**Monitoring Costs**	**Engineering Costs**	**Technician Cost**
Level 3	0.25	12	5.4375	1%	2.61	2	2.64	$255.29	$36.98	$35.03
Level 2	0.25	12	5.4375	1%	2.61	2	2.64	$255.29	$36.98	$35.03
Level 1	0.25	12	5.4375	1%	2.61	2	2.64	$255.29	$36.98	$35.03
Level 0	0	12	0	0%	-	2	2.64	$-	$-	$-

Table 26. Performance monitoring level costs

		Monitoring Levels			
		0	**1**	**2**	**3**
Equipment Levels	**0**	$-	$22.83	$91.30	$547.80
	1	$-	$22.83	$91.30	$547.80
	2	$-	$58.13	$232.50	$1,395.00
	3	$-	$118.38	$473.50	$2,841.00

12.12 Tool and Summary

The Excel based tool that was created allows for the assumptions to be easily adjusted and assumption impacts to be realized. A screen capture of the tool is shown in Figure 49. Any of the text highlighted in yellow can be adjusted based on new information provided to MDOT. The assumptions given above result in the CPI values shown below in Table 27. These costs can be used directly to compare to the benefits that are being calculated on the Holland and Traverse City corridors.



Equipment Level	3
Monitoring Level	3

Sheet	Costs	Amount
A	Installation/Equipment	$4,612.50
B	Installation Labor (MDOT)	$165.64
C	Systems Labor	$1.43
D	Initial Operations Labor	$23.68
E	Physical Maintenance	$1,016.87
F	Server Cost	$3.82
G	Tool Maintenance	$13.83
H	Watchdog Monitoring	$327.29
H	Monitoring & Implementation	$284.10
	Total per Intersection	$6,449.16

Assumptions	
# of Signals equipped with ATSPMs	3143
Avg. # of Signals per Corridor	10
Monthly Server Costs	$1,000
Hours Per Week For Tool Maintenance	8
Average Engineering Loaded Rate	$ 85.00
Average Technician Loaded Rate	$ 61.00
Average Systems Engineering Loaded Rate	$104.50
Average Entry Engineer (monitor) Loaded Rate	$ 46.95
Monitoring Level 0 Optimization Frequency	0
Monitoring Level 1 Optimization Frequency	0.5
Monitoring Level 2 Optimization Frequency	2
Monitoring Level 3 Optimization Frequency	12
Watchdog Failure Rate (How often is something wrong)	1%
Engineering Time Required to Fix Watchdog Error	2
Technician Time to Fix Watchdog Error	2.64

Figure 48. Screenshot of Cost Calculation Tool

Table 27. Total CPI by equipment and monitoring level

	Equipment Level			
Monitoring Level	**0**	**1**	**2**	**3**
0	$1,152.18	$1,479.47	$4,498.81	$6,165.06
1	$1,154.46	$1,481.76	$4,504.63	$6,176.89
2	$1,161.31	$1,488.60	$4,522.06	$6,212.41
3	$1,206.96	$1,534.25	$4,638.31	$6,449.16

13 ATSPM Benefits

13.1 Methodology

The benefits of ATSPMs were calculated with numerous methods. The Holland and Traverse corridors were used to determine the user delay improvement through the optimization strategies mentioned above. Past signal retiming projects were used to determine the continuous monitoring benefits. Literature was used to estimate the safety benefits. The maintenance survey was used to estimate the maintenance savings. It is important to note the benefits highlighted below can be attributed to Level 3 equipment and monitoring levels. Throughout the last three months of the project as the tool is being refined the other levels will be estimated.

13.2 User Delay Benefit

The primary benefit of ATSPMs will be realized in the form of user delay savings. These user delay savings will be split up into two categories. The first category is the initial user benefit of deploying the ATSPM system. This benefit can be defined as an improved initial optimization of the corridor. The second category is defined as the continuous benefit. This benefit is defined as the user benefit realized by continuously monitoring and repairing the performance of the intersections.

13.2.1 Initial Benefits

The initial benefits of the ATSPM system along the two corridors was highlighted above and is summarized in Table 28, below. In total using over $1 million was saved per year as a result of improving the signal timings with ATSPMs. This results in a benefit per signal per year, or BPI, of $87,413.

Table 28. Probe vehicle user cost savings

	Yearly Savings			
Adjustment	**Delay Reduction (hr)**	**User Savings**	**CO2 Reduction (tons)**	**Emissions**
Holland Link-Pivot	48872.24	$935,414.59	412.4	$9,073.52
Holland Overnight Timing	3457.21	$66,171.00	29.2	$641.86
Traverse Link-Pivot (Summer)**	1962.71	$36,467.18	54.0	$1,188.83
Traverse Link-Pivot (Winter)**	N/A	N/A	N/A	N/A
Total	**54292**	**$1,038,053**	**495.7**	**$10,904**

ATSPM Initial Benefit Total	**$1,048,957**
Benefit Total Per Signal Per year	**$87,413**

13.2.2 Continuous Benefits

Using five previous signal retiming projects, the user delay costs were evaluated. The data showed that the five projects saw a one-year user delay cost reduction of $26,166,676 over 174 signalized intersections (Figure 49 and Table 29). Averaging that over the number of signals reveals a $115,900 cost reduction per signal per year. Assuming that MDOT retimes their every five years this would equate to an increase in user costs of $23,180 each year between retiming. However, it should be noted that the estimated increase in delay per year is likely conservative because, due to increased traffic volumes, it is unlikely that a signal will be able to perform at the same level of efficiency as it was five years prior. Using $23,180 a year in increased costs Figure 50 shows the cost increase over the course of a traditional signal timing lifespan. Evaluating this five-year cost increase as a total cost per year can be derived as follows:

$$User\ Cost = \frac{1}{5}\int_0^5 \$23{,}180x\ dx$$

$$User\ Cost = \frac{\$57950}{Per\ Signal\ Per\ Year}$$

Being able to continuously monitor, evaluate, and improve signal timing deployments will prevent the steady decline of signals between retiming. As such, the continuous monitoring benefit for ATSPMs can be quantified as the prevention of this creeping user cost increase of $57,950 per signal per year.

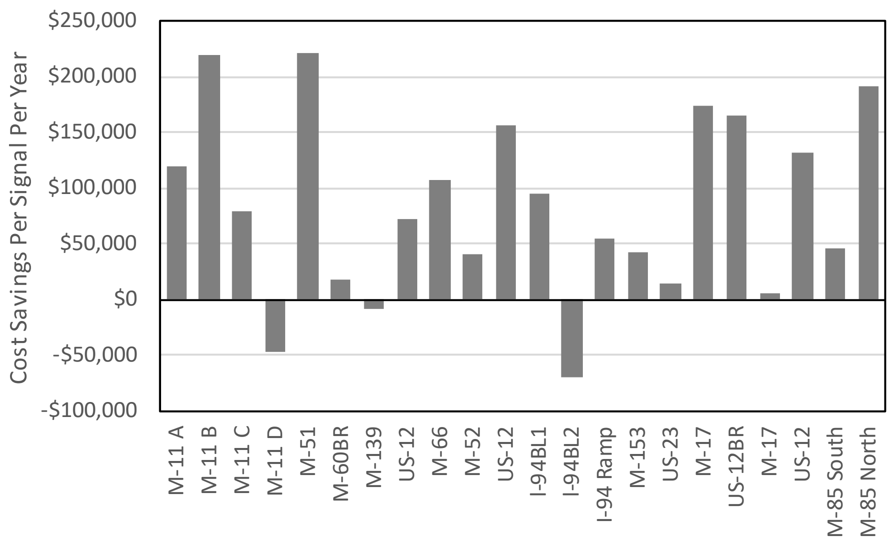


Figure 49. MDOT signal optimization projects cost savings per year per signal

Table 29. List of MDOT signal optimization projects

Project	Zone/Corridor	# of signals	TT Reduction	Daily Cost Savings	Yearly Cost Savings	Cost of Retiming	Savings Per Signal Per year
M-11	A	5	148.7	$ 2,406.00	$ 601,526.00	$ 17,500.00	$ 120,305.20
M-11	B	9	462.5	$ 7,903.00	$ 1,975,692.00	$ 31,500.00	$ 219,521.33
M-11	C	4	90.3	$ 1,272.00	$ 318,142.00	$ 14,000.00	$ 79,535.50
M-11	D	8	-95.5	$ (1,498.00)	$ (374,704.00)	$ 28,000.00	$ (46,838.00)
Niles	M-51	5	231.2	$ 4,431.00	$ 1,107,686.00	$ 21,500.00	$ 221,537.20
Niles	M-60BR	4	12.7	$ 285.00	$ 71,109.00	$ 30,100.00	$ 17,777.25
Niles	M-139	2	-3.3	$ (65.00)	$ (16,201.00)	$ 8,600.00	$ (8,100.50)
Sturgis	US-12	5	86.8	$ 1,449.00	$ 362,209.00	$ 22,000.00	$ 72,441.80
Sturgis	M-66	5	125.1	$ 2,137.00	$ 534,202.00	$ 22,000.00	$ 106,840.40
Washtenaw	M-52	4	34.5	$ 646.00	$ 161,475.00	$ 26,000.00	$ 40,368.75
Washtenaw	US-12	8	272.7	$ 4,996.00	$ 1,248,903.00	$ 52,000.00	$ 156,112.88
Washtenaw	I-94BL1	6	165.1	$ 2,303.00	$ 575,726.00	$ 39,000.00	$ 95,954.33
Washtenaw	I-94BL2	4	-66.3	$ (1,112.00)	$ (278,212.00)	$ 26,000.00	$ (69,553.00)
Washtenaw	I-94 Ramp	6	80.2	$ 1,332.00	$ 333,083.00	$ 39,000.00	$ 55,513.83
Washtenaw	M-153	2	21.7	$ 347.00	$ 86,692.00	$ 13,000.00	$ 43,346.00
Washtenaw	US-23	2	6.9	$ 113.00	$ 28,135.00	$ 13,000.00	$ 14,067.50
Washtenaw	M-17	12	472.3	$ 8,387.00	$ 2,096,089.00	$ 78,000.00	$ 174,674.08
Washtenaw	US-12BR	9	330.8	$59,949.00	$ 1,487,330.00	$ 58,500.00	$ 165,258.89
Washtenaw	M-17	4	56.5	$ 102.00	$ 25,670.00	$ 26,000.00	$ 6,417.50
US-12	US-12	23	595	$12,113.00	$ 3,028,102.00	$ 98,900.00	$ 131,656.61
US-13	M-85 South	15	163.9	$ 2,726.00	$ 681,646.00	$ 64,500.00	$ 45,443.07
US-14	M-85 North	32	1342	$24,450.00	$ 6,112,376.00	$137,600.00	$ 191,011.75

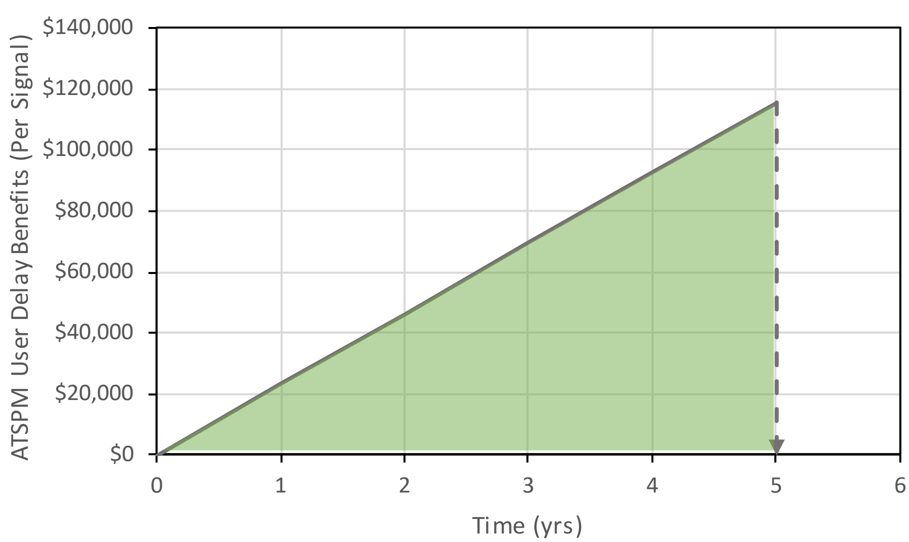


Figure 50. Continuous monitoring benefit calculations

13.3 User Safety Benefit

Current literature mentions that well timed signals will reduce the crashes at an intersection by between 8 and 30% [15,16,17]. Using crash data from 2016, over 18,000 crashes occurred at Michigan owned signalized intersections. The breakdown of these crashes by severity level can be seen in Figure 51. Using the KAB method of crash cost per type, which separated crashes into three categories- fatal/injury, possible injury, and no injury, an early safety impact value at MDOT owned signalized intersections was created. In 2016, via the KAB method, crashes caused $537,787,696 of impact. A conservative reduction of 8% of these crashes distributed across the different types of crashes would result in a total benefit of $43,023,015 or a BPI of $13,688.

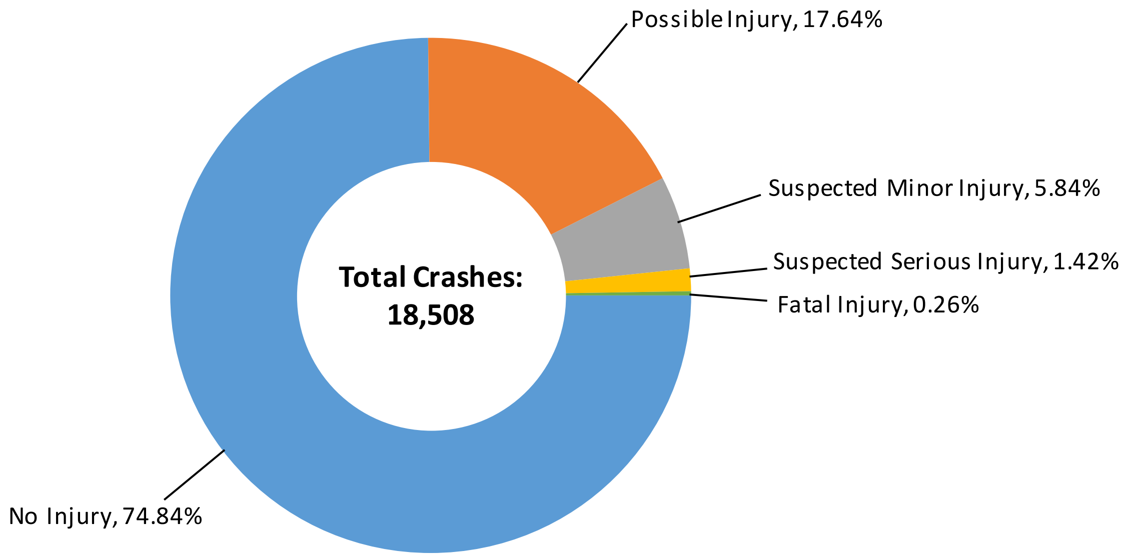


Figure 51. Crashes on US/Michigan routes at signalized intersections in 2016

Table 30. KAB method of crash cost per type

	Cost Per Crash	% of Crashes	Total Cost
Fatal/Injury	$158,200.00	9.86%	$15,598.52
Possible Injury	$44,900.00	17.64%	$7,920.36
No Injury	$7,400.00	74.84%	$5,538.16
		Average Crash Cost	$29,057.04

13.4 Vehicle Emission Benefit

The quantified emissions benefits gained from optimizing signal timings was based upon the assumption that travel time reduction equates to a reduction in time vehicles spent idling, and as a result less wasted fuel. Using this assumption, the fuel savings can be derived as follows:

$$Fuel = (\Delta travel\ time)(vol)(gallons/(hour\ idling))$$

In quantifying the amount of fuel savings, 0.84 gallons of gasoline per hour was used to determine total fuel savings. Once the fuel savings were calculated the amount of CO2 reduced and the associated benefit from the emissions reduction was quantified as follows:

$$CO2 = (Fuel)(0.0097\ tons/gallon)$$

$$Cost\_CO2 = (CO2)(\$22)$$

The savings were included in the user delay cost savings.

13.5 MDOT Maintenance Benefit

As previously discussed, a maintenance survey was conducted with MDOT regions and local agencies that maintain MDOT signals. It was estimated that false calls result in 1519.45 hours of wasted MDOT signal engineering time and 1,846.65 hours of other agency time. Considering the average cost of an MDOT technician is $61/hr. This results in an estimated $205,332.10 of wasted effort that would be a benefit if an ATSPM system were deployed. The BPI would be $65.32.

13.6 MDOT Operational Benefit

Operational benefits include better data to monitor and manage traffic signals. Currently, MDOT employs seven statewide signal operation engineers and they are responsible for 3,143 traffic signals owned by MDOT of which 1,645 are operated by MDOT. Although theoretically the operational benefit would mean MDOT requires less staff than they currently do using their current operations strategies. After discussing with both UDOT and GDOT, even with an ATSPM system, MDOT would still be understaffed. Therefore, there would be no labor savings by implementing an ATSPM system. Instead the current staff would be better equipped to optimize and manage traffic signals.

13.7 Research and Development Benefit

Currently when agencies or consultants perform traffic studies, it is typical practice to manually collect traffic volumes at signalized intersections. These manual counts are often labor intensive and costly. ATSPMs could be used in numerous traffic studies including traditional signal optimization projects and traffic impact studies when new traffic producing facilities are constructed. Another potential use is to improve active work zones by using detouring traffic volumes to adjust work zone operations. Although these benefits are difficult to quantify, it is important to state their value in this report.

13.8 Highway Performance Monitoring System (HPMS) Benefit

The Highway Performance Monitoring System is a national program that includes information for all of the nation's public roads. Volume information is typically collected on these roads via either permanent count stations or temporary deployments of traffic counting devices. The implementation of ATSPM technology can replace or supplement a number of these deployments, which will save MDOT time and effort. The data can also be used to validate factors used to scale temporary counts.

13.9 Overall Benefit

The overall benefit per intersection per year for equipment level 3 and monitoring level 3 were estimated to be approximately $159,116 per intersection per year. The cost from section 12 shows a cost per intersection per year of $6,449.16. This results in an estimated benefit to cost ratio of approximately 25 to 1. Table 31 shows the benefits per intersection per year by category. The operational benefit, research and operations benefit, and highway performance monitoring system benefits were not included in the tabulation, but would increase the BCR ratio if numbers were able to be developed for those categories.

Table 31. Benefits per intersection per year (BPI)

Sheet	Costs	Amount
A	User Cost (Initial)	$87,413
B	User Cost (Continuous)	$57,950
C	Safety Benefit	$13,688
D	Maintenance Benefit	$65.32
E	Operational Benefit	***
F	R&D Benefit	***
G	HPMS Benefit	***
	Total	**$159,116**

14 Conclusion and Recommendations

14.1 Organizational Structure

As previously mentioned MDOT is currently operating well under the FHWA recommended practice for signal engineers per number of signals statewide. The seven statewide signal engineers are currently responsible for the planning, scoping, design & construction, and operations & maintenance of 1,645 state owned and operated signals, or 235 signals per state traffic engineer. However, they are also responsible for some of these tasks for the other 1,498 traffic signals that are state owned and locally managed. Currently, the ITE Traffic Engineering Handbook and the ITE Traffic Control System Operations: Installation, Management, and Maintenance Guidebook recommend that one traffic engineer is needed to properly operate and maintain every 75 to 100 signals [18,19,20]. These guides also suggest one technician for every 40 to 50 traffic signals. A traffic signal engineer is defined as a staff person responsible for the day to day operations of the signal system. Detailed tasks defined by ITE include public comments, approving signal turn-ons, assisting in the TMC, evaluating signal timing on existing arterials, managing the operating staff, and coordinating with the signal design and maintenance supervisors. An internal estimate of MDOT signal engineering efforts provides a summary of percent time spent on the various tasks by work type. Table 32 lists the work type, the work description, and the estimated percentage of time currently spent on each task type.

Table 32. Seven MDOT signal engineers average estimated workload and type

Work Type	Work Description	% of time
Planning	Studies & memos for new phasing and new devices; Review & recommendations for traffic impact studies	50%
Scoping	Layout request for every signal impacted by a project; Scoping signal modernization contracts	16%
Design & Construction	Plan reviews; Signal timing permit for every signal impacted by a project (including staging timings)	16%
Operations & Maintenance	Optimization projects; Signal timing requests	16%
	Identify/troubleshoot timing or equipment issues using TACTICS	2%

Approximately 82% of the MDOT signal engineer's time is currently spent on tasks related to planning, scoping, design, and construction. Only an estimated 18% is currently available to be spent on tasks specifically related to ongoing signal operations and maintenance including signal timing requests, optimization projects, and using the central signal system. This lack of focused efforts on signal operations and maintenance is likely resulting in significant delay to the traveling public. Traditional signal optimizations are being done far less frequently than recommended, leading to extremely high benefit to cost ratios in traffic signal optimization reports. Additionally, only 2% of a traffic signal engineer's time is currently being spent using the existing central signal system to identify or troubleshoot issues such as faulty detection or poorly timed signals. Lack of communications or lack of a reliable central signal system makes ongoing signal operations and maintenance very time consuming because the engineer and electrician may travel to the intersection multiple times to assess, identify, and resolve an issue. This lack of resources specifically dedicated to signal operations and maintenance makes it more likely for issues to go unnoticed for months or years, unless a public complaint is made about a poorly operating signal.

MDOT's mission includes providing the highest quality integrated transportation system, which will require more active management of traffic signal operations and maintenance. ATSPM's are one of the strategies available to assist staff to more efficiently operate and maintain traffic signals, but additional resources will be required to implement and utilize such a system. The next section will describe a concept of implementation for MDOT to consider as they move toward more actively managed signal operations and maintenance strategies.

14.2 Concept of Implementation

The implementation of ATSPMs whether through expansion of this pilot deployment, or procurement of a central management system module, will lead to changes in staffing needs for MDOT to properly operate, manage and maintain the system. In deploying ATSPMs it is also likely that MDOT will have moved forward with other changes to their traffic signal system such as deploying a central management system, preparing for connected vehicles and expanding ITS deployments onto MDOT arterial roadways.

This implementation plan applies the outcomes from the research phase of the project moving forward into a conceptual deployment that allows for the definition of general staff roles, team composition, staffing location / estimated headcounts and costs. The plan is intended to serve as a starting point that future planning or deployment efforts can build upon as ATSPMs or other actively managed arterial traffic signal systems are employed by MDOT. Future planning efforts will refine this conceptual plan to include the specific operational needs of each geographic area, stakeholders and other system attributes that may have changed since this research was completed.

14.2.1 System Deployment

It is envisioned that ATSPMs will be adopted by MDOT as standard requirements for all new traffic signal installations and that retrofitting of existing traffic signals will occur to create a statewide deployment of ATSPMs. Statewide deployment of ATSPMs provides MDOT with a traffic system that is able to be uniformly managed and measured regardless of make, model and type of traffic signal controller or software in place. MDOT contracts traffic signal system maintenance to a several local agency partners and deploying ATSPMs at those locations would provide similar value to the local agency in executing their maintenance of the MDOT system while allowing MDOT to actively monitor the operational performance of the system. Additionally, in deploying ATSPMs statewide MDOT can accomplish several key aspects to improving their signal systems that contribute to success of broader MDOT TSMO objectives:

- Communications – improving the capability of MDOT to execute daily operations, monitor maintenance needs and lower costs associated with items such as implementing timing plan changes or conducting initial traffic signal system diagnostics
- Data Generation – improving the ability of MDOT to generate the data necessary to support the monitoring of existing operations, optimizing operations with improved granularity as changes occur, and making more robust data sets available to support MDOT transportation planning efforts
- Data Driven Operations –MDOT is able to change the way in which daily business decisions are made relative to the daily operations and maintenance needs of the system by using data to support how tasks are prioritized, executed, and evaluated

1. The deployment should be prioritized to occur over a very short timeframe (three or fewer years) positioning MDOT to aggressively improve the operational outcomes of their traffic signal systems which directly impact the mobility and safety of motorists. Deploying over a longer timeframe also introduces other risks such as changes in funding, technology, MDOT direction and leadership. Phased deployment should be prioritized at locations where the greatest volume of vehicles travel and other detrimental events to optimized conditions are likely to occur. The following is a high-level phased deployment approach targeted at a three year duration.

    - Phase 1 – Metro Region; 1,307 traffic signals
    - Phase 2 – Bay, Grand and University Region; 1,349 traffic signals
    - Phase 3 – North, Southwest and Superior Region; 487 traffic signals

2. Design of the system could be accomplished through development of a log-style design approach as many aspects of the system design such as detection, communications and configurations can be standardized. Construction may be accomplished through selection of several traffic signal contractors to deploy the physical infrastructure in the various MDOT regions. ATSPM System Management and integration should be contracted to a singular entity to provide continuity in the system configuration and operation as it is expanded, updated and maintained.

14.2.2 Staffing Roles and Responsibilities

Sustaining a statewide ATSPM system will require a range and depth of staff skills with defined roles and responsibilities for daily operations, monitoring and maintenance. Many of the staff skills necessary exist within MDOT and consultant community; however new skills and positions will be required to create the correct combination of both production and expertise. The following is a summary of the staff roles and responsibilities defined at this time.

- MDOT Lansing Signals Unit
  - Operations Manager:
    - Oversees ATSPM program, sets goals, and measure progress
  - Region Engineering Leads:
    - ATSPM SME's, resolve unique issues, and supports regions
- MDOT Region
  - Region Traffic Engineers:
    - Liaise between public, stakeholder and agencies for operational needs; leverage ATSPMs / reports to confirm needs are addressed
  - TOC Program Managers:
    - Oversee ATSPM contracts, coordinates integration of ATSPM, arterial operations and traditional ITS into a collective data driven mobility/safety focused operation
  - Region Electricians / Technicians:
    - Maintain detection, communications and equipment configurations
- Contracted Resources
  - Customer Service / System Technicians
    - Intake of public / stakeholder inquiries on system operations
    - Periodically reviews system and identifies issues
    - Initial troubleshooting and generation of work orders to team
  - Graduate Signal System Engineers / Technicians
    - 1st level diagnostics and resolution of work orders; escalates as needed
  - Signal System Engineers / Senior Technicians
    - 2nd level diagnostics; experienced with MDOT arterial operations and ATSPMs
  - Sr. Lead Engineers / Team Leaders
    - SMEs, mentors staff, resolves complex issues, manages system metrics
  - Sr. Experts / Program Manages
    - Execute contracts, manage/mentor teams, and responsible for regional areas

14.2.3 Staffing Location and Headcounts

MDOT has heavily invested in the creation and expansion of their transportation operation centers located in Detroit (SEMTOC - Southeast Michigan TOC), Grand Rapids (WMTOC – West Michigan TOC), Lansing (Statewide TOC), and Port Huron (BWBTOC – Blue Water Bridge TOC). These TOCs are a centralized location for the daily operation, coordination and mitigation of incidents on MDOT roadways. Technology systems and roadways managed at each TOC are continually evolving and include active traffic management systems such as the US-23 Flex Route, Metro Region Integrated Corridor Management Systems and I-94 Truck Parking Information System. TOCs actively manage and coordinate traffic incidents and operation of arterial roadways whether part of daily operations, special events and unplanned incidents.

Past investment, current roles and future intents of MDOT TOCs makes them an ideal space to expand the monitoring and management of a statewide ATSPM deployment. The majority of TOCs are open 24/7 and have space available whether on the control room floor or adjacent offices that can support the staffing needs for daily ATSPM management, monitoring and operations.

Conceptual staffing plans for each of the TOCs and traffic signals are presented below. Equivalent full time employee estimations were derived based upon the estimated number of FTEs multiplied by the percentage of effort estimated to be applied to ATSPM and/or active traffic signal system management.

- Southeast Michigan TOC
  - ~1,307 traffic signals (Metro Region)
  - MDOT – Increased headcount by 4.65 FTE
  - Consultant – Service headcount need of 12.5 FTE
  - Proposed to serve as statewide 24/7 signal system call center thereby reducing the overall staffing requirement of Customer Service / System Technicians

Table 33. SEMTOC staffing plan

FTE	% of FTE Effort	Equiv. FTE			FTE	% of FTE Effort	Equiv. FTE
SEMTOC							
			MDOT	**MDOT**			
1	15%	0.15	MDOT TOC Program Managers	MDOT Traffic Signals Unit - Operations Manager	1	10%	0.1
			Consultant	**MDOT**			
1	50%	0.5	Sr. Experts / Program Managers	MDOT Traffic Signals Unit - Region Engineering Leads	1	50%	0.5
1	100%	1	Sr. Lead Engineers / Team Leaders	MDOT Region Traffic Engineers	1	50%	0.5
2	100%	3	Signal System Engineers / Senior Technicians	MDOT Electrician / Technician	3	80%	2.4
2	100%	3	Graduate Signal System Engineers / Technicians	MDOT TMW	1	100%	1
5	100%	5	Customer Service / System Technicians				

- Statewide TOC
  - ~1,458 traffic signals (Bay, North, Southwest, Superior, and University Region)
  - MDOT – Increased headcount by 6.8 FTE
  - Consultant – Service headcount need of 7.5 FTE

Table 34. Statewide TOC Staffing Plan

FTE	% of FTE Effort	Equiv. FTE			FTE	% of FTE Effort	Equiv. FTE
STOC							
			MDOT	MDOT			
1	15%	0.15	MDOT TOC Program Managers	MDOT Traffic Signals Unit - Operations Manager	1	15%	0.15
			Consultant	MDOT			
1	50%	0.5	Sr. Experts / Program Managers	MDOT Traffic Signals Unit - Region Engineering Leads	3	50%	1.5
1	100%	1	Sr. Lead Engineers / Team Leaders	MDOT Region Traffic Engineers	5	25%	1.25
2	100%	3	Signal System Engineers / Senior Technicians	MDOT Electrician / Technician	5	55%	2.75
2	100%	3	Graduate Signal System Engineers / Technicians	MDOT TMW	1	100%	1

- West Michigan TOC
  - ~378 traffic signals (Grand Region)
  - MDOT – Increased headcount by 2 FTE
  - Consultant – Service headcount need of 2.5 FTE

Table 35. West Michigan TOC Plan

FTE	% of FTE Effort	Equiv. FTE			FTE	% of FTE Effort	Equiv. FTE
			WMTOC				
			MDOT	**MDOT**			
1	15%	0.15	MDOT TOC Program Managers	MDOT Traffic Signals Unit - Operations Manager	1	10%	0.1
			Consultant	**MDOT**			
1	50%	0.5	Sr. Experts / Program Managers	MDOT Traffic Signals Unit - Region Engineering Leads	1	50%	0.5
	100%	0	Sr. Lead Engineers / Team Leaders	MDOT Region Traffic Engineers	1	25%	0.25
1	100%	1	Signal System Engineers / Senior Technicians	MDOT Electrician / Technician	1	50%	0.5
1	100%	1	Graduate Signal System Engineers / Technicians	MDOT TMW	1	50%	0.5

14.2.4 Deployment Costs

The following provides a summary level estimation of costs to deploy and staff a statewide deployment of ATSPMs that may serve as a starting point for MDOT to plan for the future deployment of ATSPMs or other active arterial traffic signal management systems.

14.2.4.1 Equipment Costs

The equipment costs were previously discussed in this report, but were not scaled to a statewide level. The cost to fully equip an existing intersection with no detection, communication, or data logging controller would be approximately $46,125. This cost includes both side street and mainline detection and is the 10-year estimated cost for an intersection including detection, communication, equipment, and installation. Additionally, there are initial deployment costs that includes setting up and verifying the detection in the field. This cost is estimated to be $1,656 per intersection. If each of the 3,143 MDOT owned signals were starting with no detection, communication, or data logging abilities, the cost to equip every intersection with level 3 signal performance measures would be estimated to cost over $150 million. An improved signal inventory is necessary to determine the exact cost for MDOT.

14.2.4.2 Staffing Costs

The following is a summary of the annual staffing costs projected for a statewide deployment and including the estimated staffing costs as part of each proposed deployment phase.

Table 36. Estimated annual staffing costs for a statewide deployment

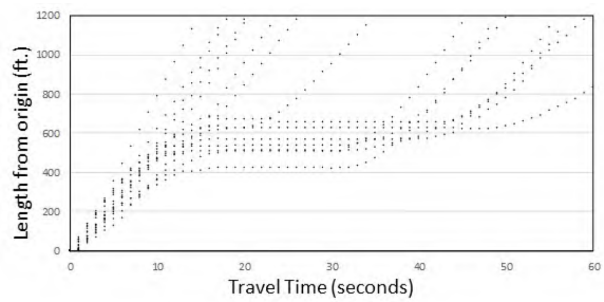
MDOT - Statewide Signal System Management and Operations					
MDOT Staffing:	**Equiv. FTE**	**Phase 1 Deployment**	**Phase 2 Deployment**	**Phase 3 Deployment**	**Total Annual Cost**
MDOT Traffic Signals Unit - Operations Manager	0.35	$16,178.40	$32,340.16	$8,105.84	**$56,624.40**
MDOT Traffic Signals Unit - Region Engineering Leads	2.5	$71,904.00	$215,564.05	$72,051.95	**$359,520**
MDOT Region Traffic Engineers	2	$71,904.00	$155,668.71	$60,043.29	**$287,616**
MDOT TOC Program Managers	0.45	$24,267.60	$40,429.36	$8,105.84	**$72,802.80**
MDOT Electrician / Technician	5.65	$301,996.80	$293,370.66	$115,583.34	**$710,950.80**
MDOT TMW	2.5	$89,460.00	$104,308.64	$29,881.36	**$223,650**
	13.45	**$575,711**	**$841,682**	**$293,772**	**$1,711,164**
Consultant Services Staffing:	**Equiv. FTE**	**Phase 1 Deployment**	**Phase 2 Deployment**	**Phase 3 Deployment**	**Total Annual Cost**
Sr. Experts / Program Managers	1.5	$149,160.00	$248,497.70	$49,822.30	**$447,480**
Sr. Lead Engineers / Team Leaders	2	$231,000.00	$153,841.56	$77,158.44	**$462,000**
Signal System Engineers / Senior Technicians	7	$554,400.00	$554,019.75	$185,180.25	**$1,293,600**
Graduate Signal System Engineers / Technicians	7	$424,800.00	$424,508.64	$141,891.36	**$991,200**
Customer Service / System Technicians	5	$472,000.00	$0.00	$0.00	**$472,000**
	22.5	**$1,831,360**	**$1,380,868**	**$454,052**	**$3,666,280**
		$2,407,071	**$2,222,549**	**$747,824**	**$5,377,444**

15 FUTURE CONSIDERATIONS

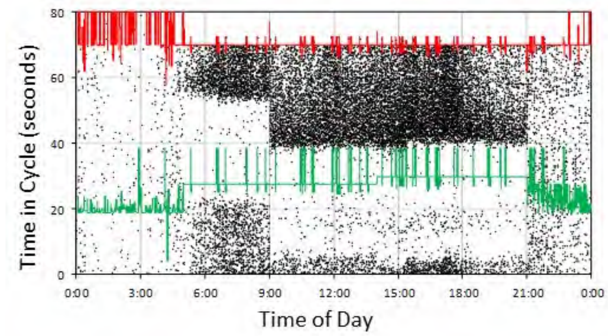
Throughout the research project the research team was considering opportunities for future research and development. This section highlights possible future research or improvement areas that MDOT can investigate.

15.1 PROBE VEHICLE TRAJECTORY DATA

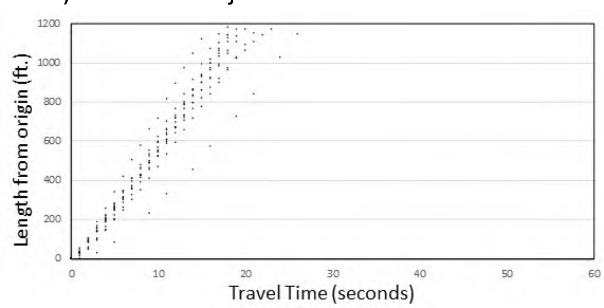
The data used for the benefit analysis in this project was segmented probe vehicle data, which is currently the state of the practice nationwide. Segmented probe vehicle data works well for interstate segments or longer, high-volume arterials, but does not work all that well to measure signal performance. Third-party data providers are beginning to provide raw trajectory waypoint data from individual vehicles. This data can be used to replicate signal performance metrics and does not require vehicle detection, which could provide cost savings long term. Figure 52 shows the example shown above of the NB James Xover offset adjustment. Figure 52a shows the aggregated trajectory data from the AM timing plan prior to the adjustment. Figure 52b shows the Purdue coordination diagram from the AM timing plan prior to the adjustment. Figure 52c shows the aggregated trajectory data from the AM timing plan after the adjustment. Figure 52d shows the Purdue coordination diagram from the AM timing plan after the adjustment. In both the trajectory graphs and the PCDs the improvement is clear. As this trajectory data is further explored numerous applications in the traffic signal space will be developed.



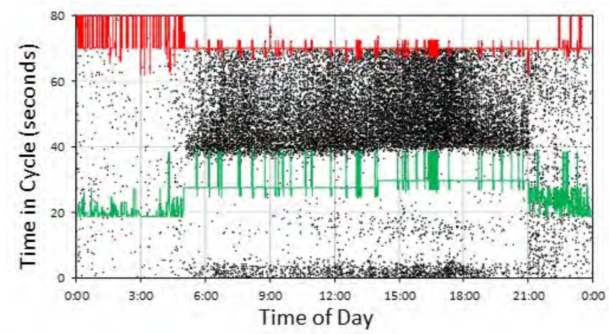
a) Vehicle Trajectories – Before



b) Purdue Coordination Diagram - Before



c) Vehicle Trajectories – After



d) Purdue Coordination Diagram - After

Figure 52. NB James Street before and after offset adjustment

15.2 Longitudinal Performance Measures

Traffic Signal Performance Measures are still evolving. The Utah ATSPM software has released a new version within the last year of this project. Other industry providers are constantly updating their tools and dashboards. The current deficiency in the market is longitudinal performance measures that can show how intersections are performing over time. This would allow an agency or DOT to look at improvements continuously, as opposed to the traditional before and after analysis, where there is a risk of cherry-picking data or selecting an anomaly. Figure 53 shows an example of longitudinal metrics developed using the ATSPM data from this project. The figure shows hourly percent arrivals on green over three months on northbound James. The offset adjustment shown above occurred in September. A clear improvement can be seen in the weekday AM period.

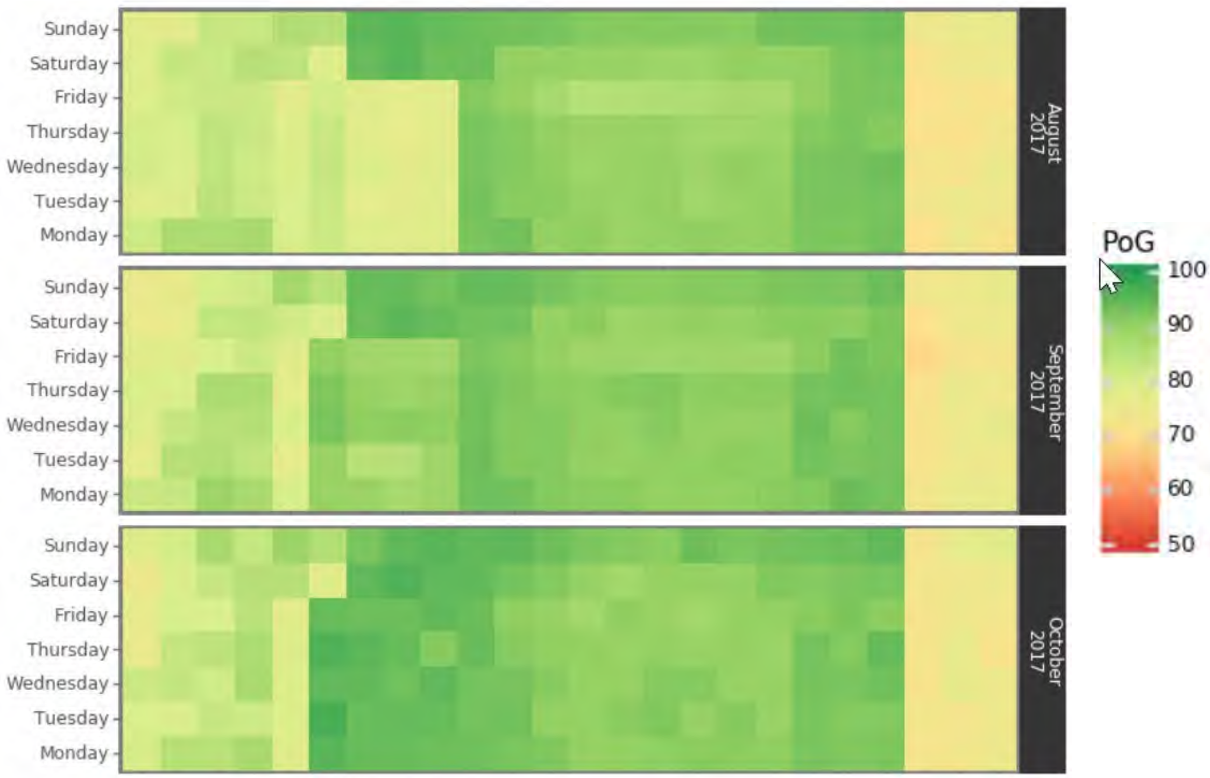


Figure 53. Longitudinal Performance Measures – Percent Arrivals on Green Before, During, and After NB James Street Offset Adjustment

15.3 Improved Intersection Inventory

The MDOT intersection inventory (shown in Appendix A) will need to be improved to support new ATSPM and connected vehicle initiatives. The most critical information to keep updated will be the type and location of the detection. The current inventory lacks specifics on detection location. It would be recommended to include detector channels, lane location, approach, and detector location in the inventory. Additionally, signal timing information should be included in the inventory including links to the current signal timing plan and dates and times when the timings were last updated.

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17 APPENDICES

17.1 List of Acronyms

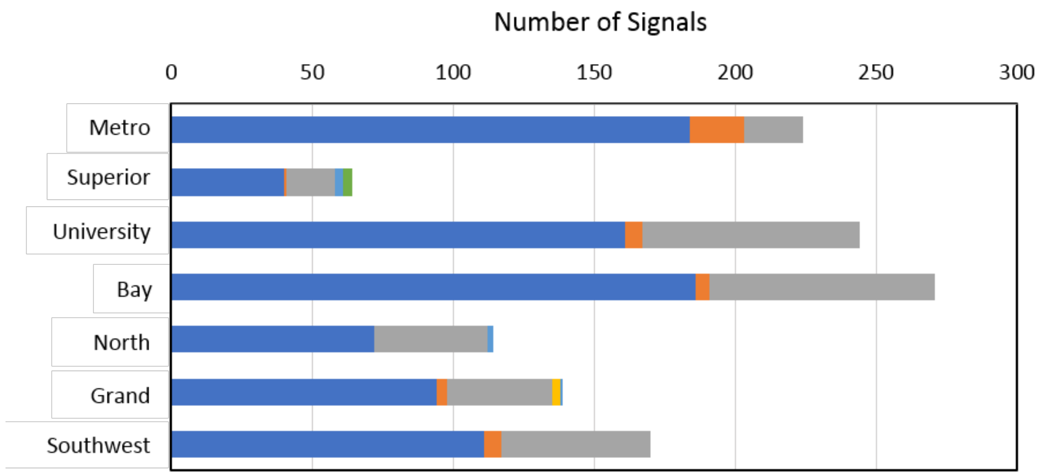
AADT	Annual Average Daily Traffic
AOG	Arrivals on Green
ATSPM	Automated Traffic Signal Performance Measures
BCR	Benefit Cost Ratio
BPI	Benefit Per Intersection Per Year
CPI	Cost Per Intersection Per Year
DOT	Department of Transportation
DTMB	Department of Technology, Management and Budget
EB	Eastbound
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GPS	Global Positioning System
ITE	Institute of Transportation Engineers
KAB	Fatal, A-Level, and B-Level injury crashes
MAC	Media Access Control
MCSC	Michigan Civil Service Commission
MDOT	Michigan Department of Transportation
NB	Northbound
PCD	Purdue Coordination Diagram
POG	Percent Arrivals on Green
SB	Southbound
SPM	Signal Performance Measures
TMC	Traffic Management Center
TOC	Transportation Operation Center
UDOT	Utah Department of Transportation
WB	Westbound
WSU	Wayne State University
Xover	Crossover

17.2 APPENDIX A - SIGNAL INVENTORY SUMMARY

- Equipment Level -1 - Not capable of communication with central office, therefore not capable of Signal Performance Measures
- Equipment Level 0 - Communication is available, but do not have ATSPM functionality
- Equipment Level 1 - ATSPM capable, but does not have detection for performance measurement
- Equipment Level 2 - ATSPM capable, no progression performance measurements on mainline (no PCDs)
- Equipment Level 3 - Fully ATSPM capable

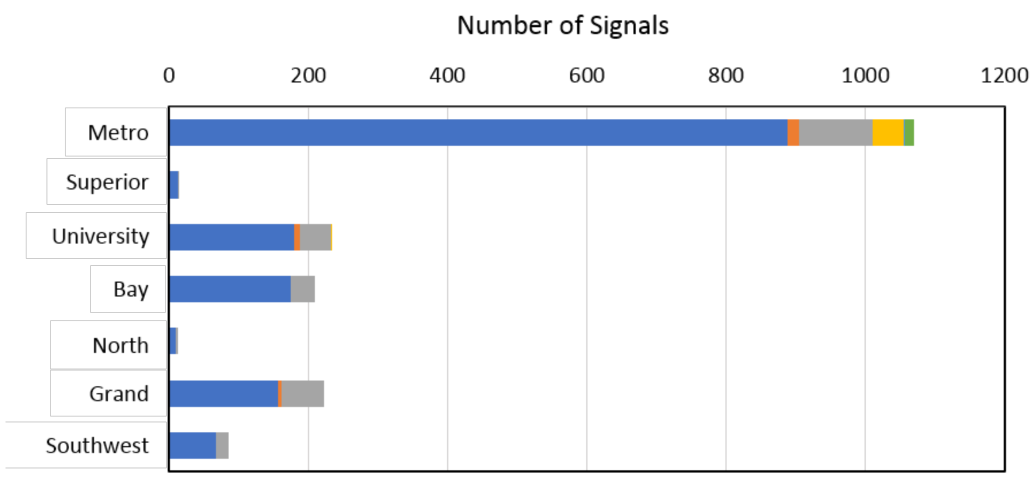
Table 37. MDOT maintained equipment levels

Level	Controller	Communication	Detection	Advanced Detection
-1a				
-1b	✓			
-1c			✓	
0a		✓		
0b		✓	✓	
1	✓	✓		
2	✓	✓	✓	
3	✓	✓	✓	✓



	Southwest	Grand	North	Bay	University	Superior	Metro
-1a	111	94	72	186	161	40	184
-1b	6	4	0	5	6	1	19
-1c	53	37	40	80	77	17	21
0a	0	3	0	0	0	0	0
0b	0	1	2	0	0	3	0
1	0	0	0	0	0	3	0

Figure 54. MDOT managed and owned signals
**No signals are at levels 2, 3*



	Southwest	Grand	North	Bay	University	Superior	Metro
-1a	67	157	9	174	179	12	889
-1b	0	5	0	0	8	0	16
-1c	19	61	3	36	45	3	105
0a	0	0	0	0	2	0	45
0b	0	0	0	0	0	0	1
1	0	0	0	0	0	0	14

Figure 55. County managed MDOT owned signals
**No signals are up to levels 2 or 3*

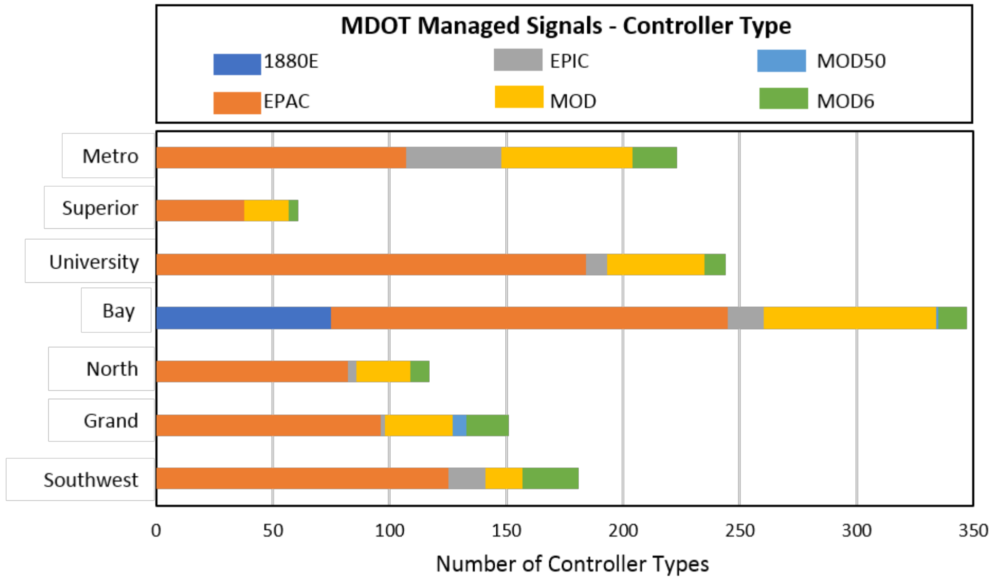


Figure 56. MDOT managed signals – controller type by intersection

**Controller types and amounts removed from graph are as follows: 2070 (Metro-1), EF14 (Superior-1, Bay-1, Southwest-4), EF140 (Grand-1), EF144 (University-3, North-2, Grand-1, Southwest-1), EFS833 (Bay-1), EPIC14 (Bay-1), FL (North-1, Southwest-2), MIC/FX (North-1), MOD5 (Bay-2).*

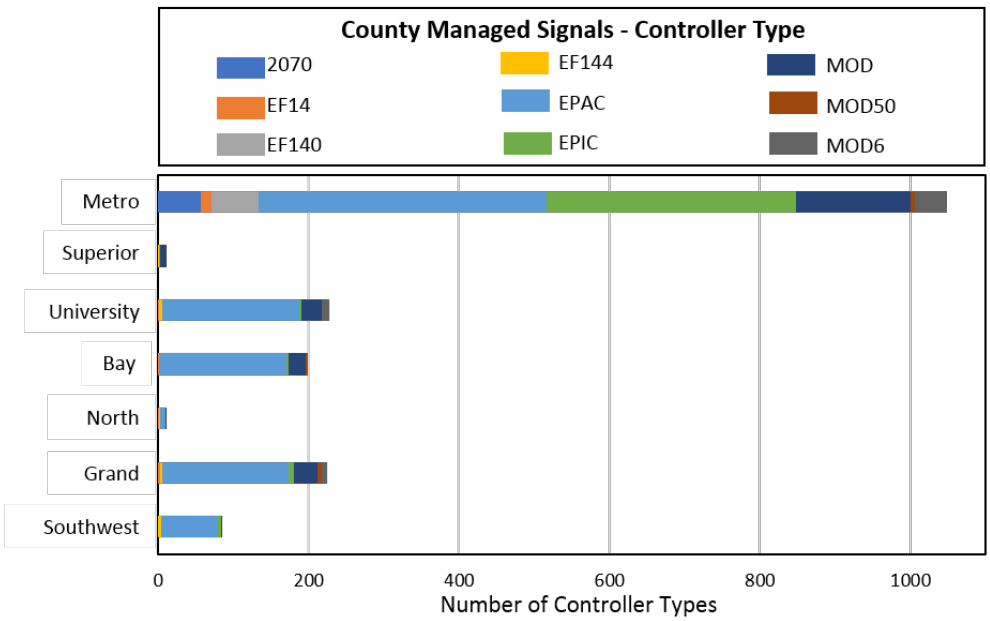


Figure 57. County managed signals – controller type by intersection

**Controller types and amounts removed from graph are as follows: 1880E (Bay-1), EF70 (Metro-1), EF72 (Bay-2), EF73 (Bay-2), EF735T (Bay-1), EF75 (Metro-1), EF815 (Metro-1), EFS103 (Metro-3), EPAC+ (University-1), EPIC14 (North-1), KST (Metro-2), MIC/FX (North-1, Southwest-1), MOD5 (University-1, Bay-1).*

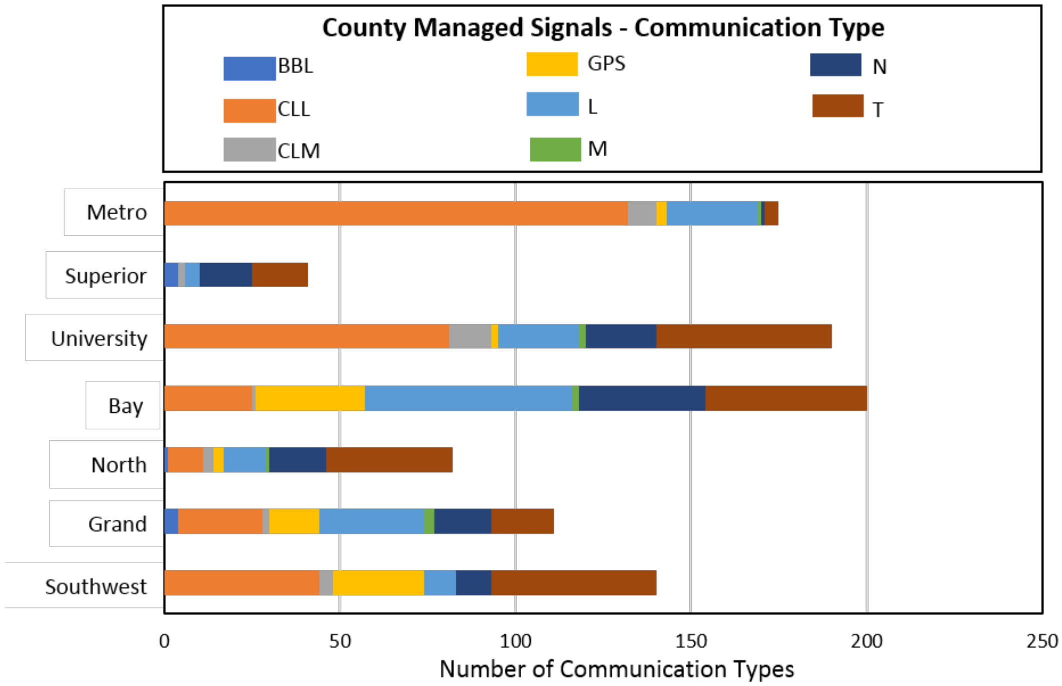


Figure 58. MDOT managed signals – communication type at each intersection

**Controller Types removed from graph are as follows: AA (University-1), B (Superior-1, North-1), BBM (Superior-2, North-1), S (Grand-2, Southwest-2).*

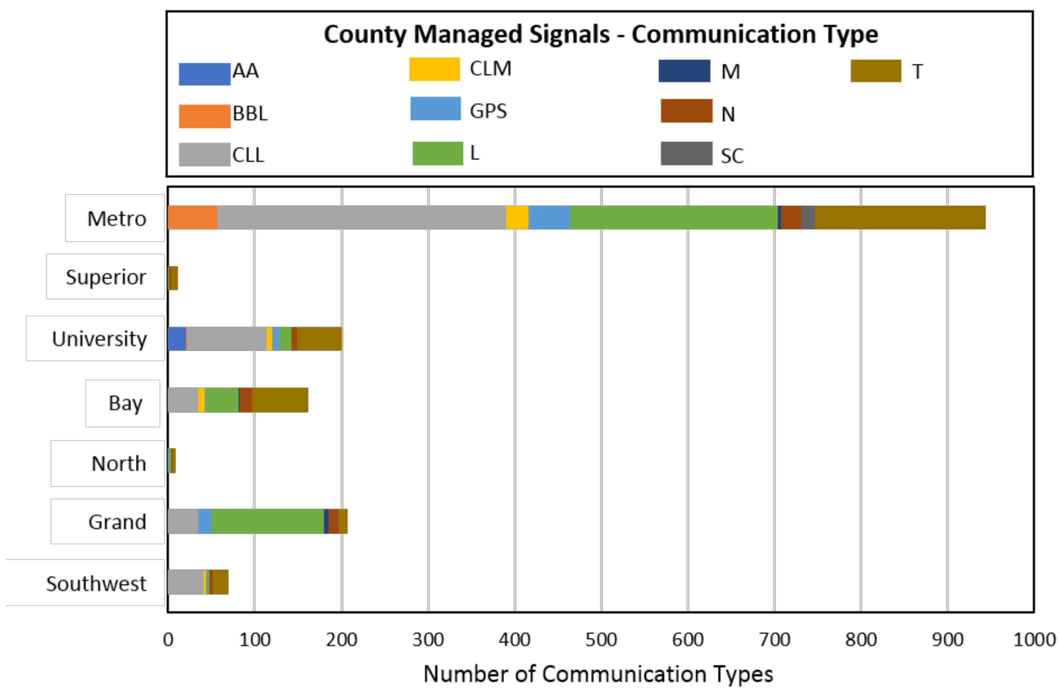


Figure 59. County managed signals – communication type at each intersection

**Controller Types removed from graph are as follows: B (University-1, Grand-1), BBM (Metro-3), S (Metro-2, University-1).*

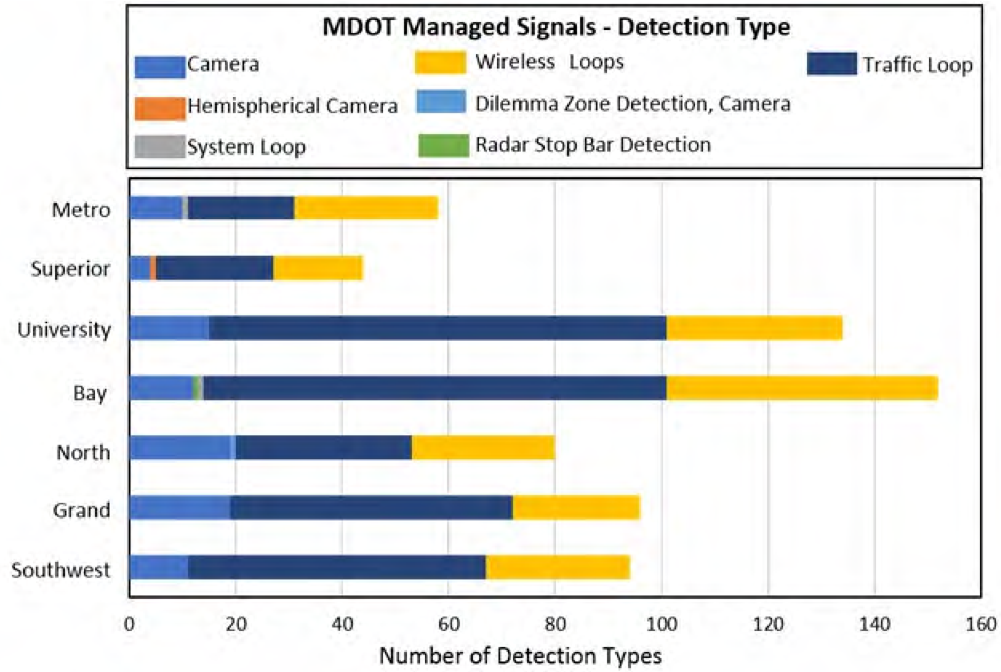


Figure 60. MDOT managed signals – detection type at each intersection

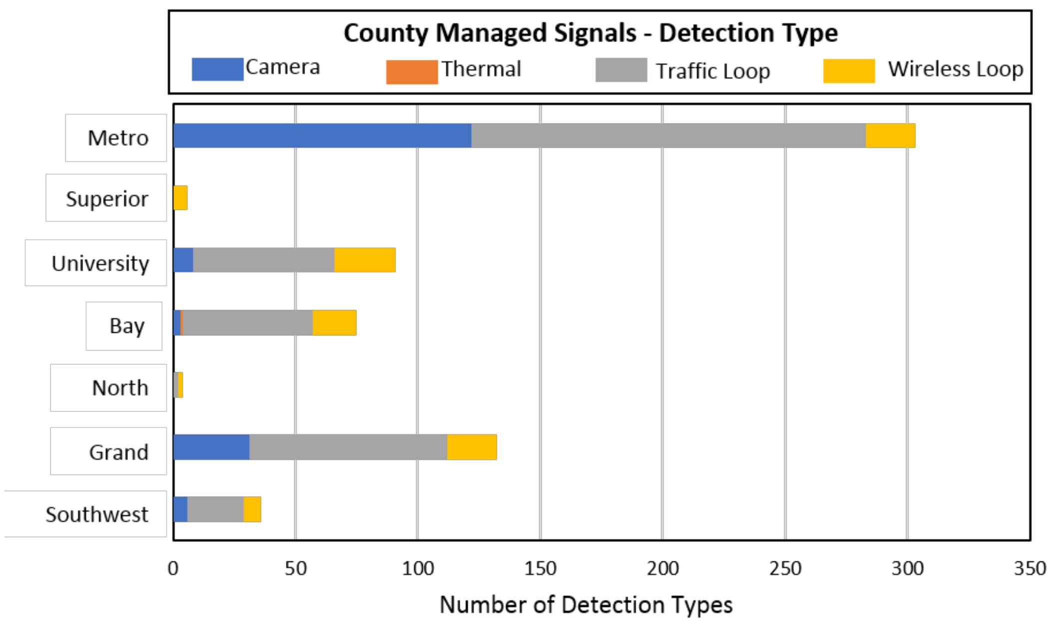


Figure 61. County managed signals – detection type at each intersection

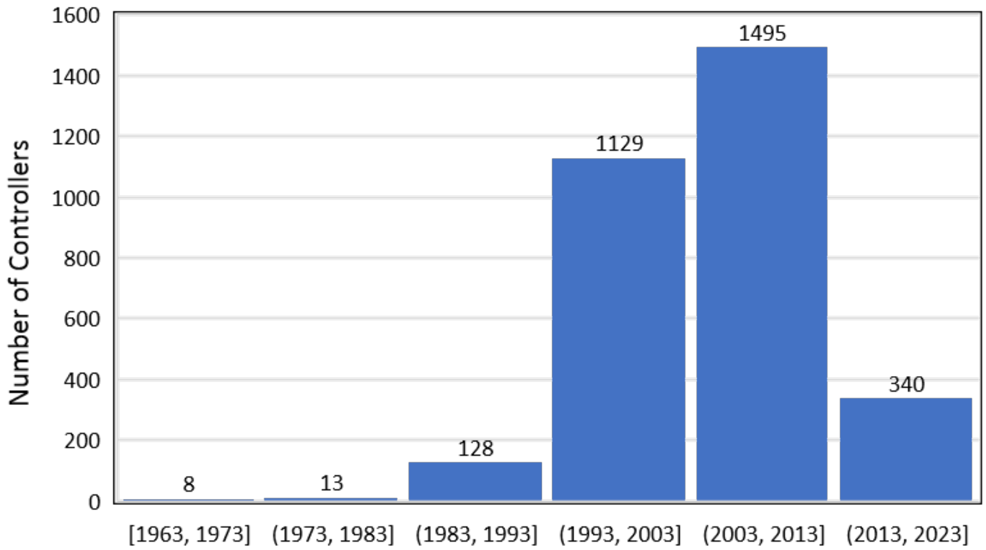


Figure 62. Statewide controller age

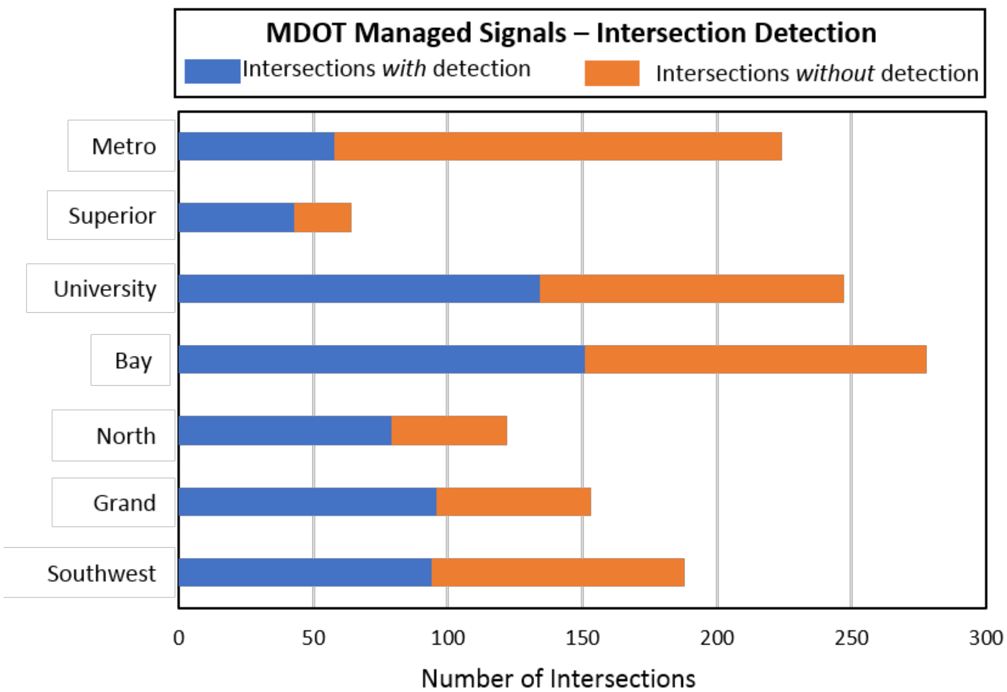


Figure 63. MDOT managed signals – intersections with or without detection

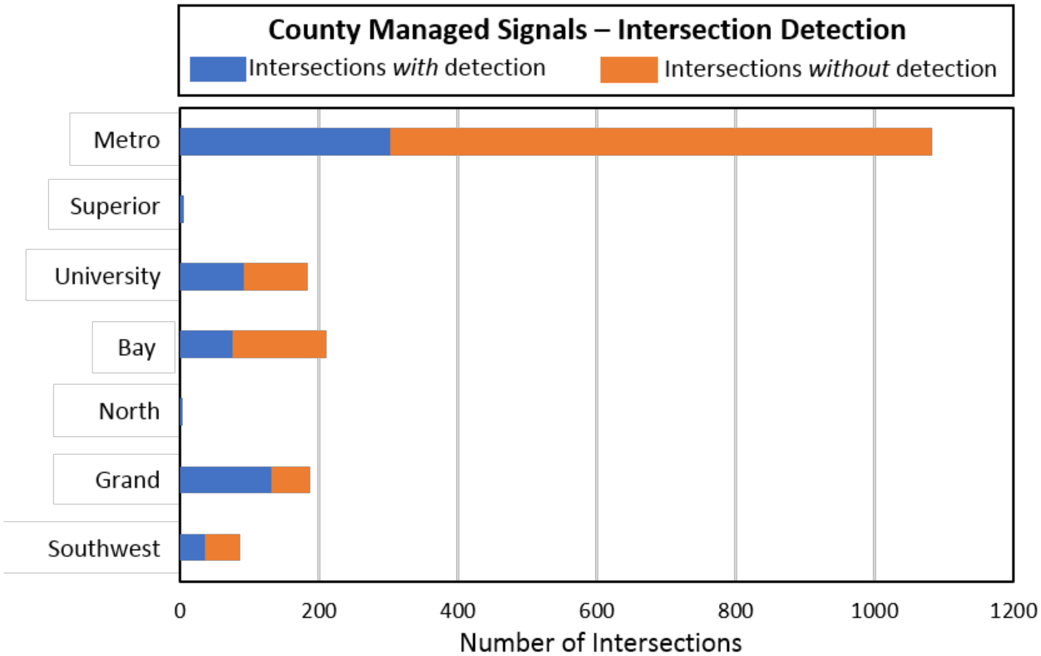


Figure 64. County managed signals – intersection with or without detection

17.3 APPENDIX B - MAINTENANCE SURVEY OVERVIEW

Below is an example signal unit survey that was used to determine typical maintenance practices by MDOT regions and agencies that maintain MDOT signals.

2018 Signal Unit Survey

The Signals Unit is in the process of evaluating traffic signal controller software and central system signal software from multiple manufacturers. The survey will give you an opportunity to express your group's input as it relates to the controller evaluation and to provide us information that will help us determine additional training that will be required. Additionally, we are also conducting a pilot research project for Signal Performance Measures so the survey includes questions related to workload and maintenance practices. We understand that each region and agency has different priorities and responsibilities assigned to the signal electricians which in some cases includes much more than maintaining signals. By providing us accurate and realistic information you will help us determine if any changes to priorities and/or additional resources are necessary in the event that MDOT decides to implement signal monitoring and performance measures in your area. Your feedback is a critical step for us to thoroughly evaluate these two tasks. Thank you for your time and we appreciate your feedback.

Respond in all yellow shaded boxes below. Most of these questions are focused towards maintenance electricians and will require you to come to a consensus as a group. Questions related to training are based on the average amount of time per person in the group (i.e. if one person has 12 hours and the other has 8 hours, the answer would be 10 hours) For inspectors and technicians, some of these questions may not relate to your specific job so a response of "N/A" may be most appropriate. For questions asking for percentages, please estimate to the best of your ability.

Background Information

Provide region or location (i.e. Bay Region, City of Grand Rapids, Statewide)		METRO REGION
Provide the number of signal electricians assigned to location or region		2
As a group provide the average time spent (by percentage of overall work) doing the following (must add to 100%):		
Maintaining and Monitoring Traffic Signals (Example Answer: **30%** of time)		92%
Implementing Signal Timing Permits in Field		2%
Maintaining other electronic traffic control devices (i.e. overhead flashers, sign beacons, etc.)		2%
Construction/Installation		1%
Maintaining Pump Stations		1%
Lighting		1%
Facilities		1%
Other (please describe other work below)		Other %
other 1		
other 2		
other 3		
Provide the number of traffic signals that your group is primarily responsible for to maintain		292

Maintenance and Time Spent

How frequently does your group perform routine or preventative maintenance (once a year at all locations, once a year at 50% of locations, We're too busy with trouble calls and other duties to perform routine maintenance)?	TOO BUSY W/ TROUBLE CALLS

Percentage of signals your group discovers a faulty detector, pushbutton, or communications issue while performing routine maintenance?	10%
What is the average time between receiving a complaint and field assessing the complaint (in days to the nearest 0.5 days)?:	
Signal Timing Complaint	0.5
Detector Not Working	0.5
Signal in Flash	0.5

Signal Timing Issues

Please provide the number of trouble calls your group receives for signal timing issues per year	12
What is the average time spent per signal timing trouble call (in hours to the nearest 0.5 hours):	
Travel Time	0.5
Time at Location	0.5
What is the percentage of "False Calls" - Calls when you arrive on site, but find no action is required (i.e. signal timing was okay, clocks were not drifting, detector was functioning, etc.)?	10%

Equipment Issues

Please provide the number of trouble calls your group receives for equipment malfunctions at a signal per year?	200+
What is your average time spent per equipment trouble call (in hours to the nearest 0.5 hours):	
Travel Time	0.5
Time at Location	0.5
What is the percentage of "False Calls" - You arrive on site, but find no action is required because equipment is working correctly (i.e. signal went back to stop and go operations; radios & detection were functioning properly, etc.)?	5%

SEPAC

Please provide the hours of training required to as it relates to EPAC controller software (SEPAC) only. Do not include training for the cabinet, detection, etc.	
When initially learning the EPAC controller, please provide the number of hours of training on average that each electrician received per year in order to become confident with troubleshooting/programming the signal controller:	
Formal Training (class room or seminar)?	80
Non-formal Training (meeting with vendor or coworker in field)?	3 YEARS
Self-Taught (reading manuals, etc.)?	ALL THE TIME
Who led any formal training (vendor, MDOT, other)? If multiple sources, list source and percentage of overall training received from each source.	

source 1	CARRIER AND GABLE	100%
source 2		
source 3		
What was the average amount of time (in years) needed to become confident in the ability to program/troubleshoot EPAC controller software?		3
After obtaining confidence in the ability to program/troubleshoot SEPAC software, please provide how many hours of continuing training on average each electrician receives per year to stay up to date with the latest version of EPAC controller software:		
	Formal Training (class room or seminar)?	40
	Non-formal Training (meeting with vendor or coworker in field)?	EVERY DAY
	Self-Taught (reading manuals, etc.)?	10
Who led any formal training (vendor, MDOT, other)? If multiple sources, list source and percentage of overall training received from each source.		
source 1	CARRIER AND GABLE	100%
source 2		
source 3		
Is being able to program and troubleshoot signal controllers critical for performing your job? (Yes or no)		"YES"
please explain why or why not	If you do not know what you are doing you are putting the public in danger.	

TACTICS

Does the central software (i.e. TACTICS) provide you notifications when equipment at a signal is malfunctioning? (Yes or No)		YES	
Please list the types of notifications you are able to receive (signal in flash, detector not working, power outage, etc.)? And provide the number of locations in your area for which this function is provided.			
		Provided (Y/N)	**# of Locations**
	Signal in Flash	N	
	Detector Not Working	N	
	Power Outage	N	
Other (please define below)			
other 1			
other 2			
other 3			
Do you find these notifications helpful? (Yes or No)		Yes	
Please explain why or why not	**It gives you a heads up on the status of the intersection.**		
Do you use TACTICS to actively monitor your traffic signal systems? (Yes or No)		YES	

Do you use TACTICS with little or no help from the vendor? (Yes or No)		YES
Please provide the number of hours of training on average that each electrician received per year in order to become confident in adding traffic signals to the TACTICS central system software and upload/download signal timing plans from TACTICS:		
Formal Training (class room or seminar)?		40
Non-formal Training (meeting with vendor or coworker in field)?		EVERY DAY
Self-Taught (reading manuals, etc.)?		10
Who led any formal training (vendor, MDOT, other)? If multiple sources, list source and percentage of overall training received from each source.		
source 1	CARRIER AND GABLE	100%
source 2		
source 3		
How many years until you were confident in your ability to program/troubleshoot TACTICS software? (If the group overall is not confident in the ability indicate "Novice")		3
After becoming confident in the ability to use the TACTICS central system, please provide how many hours of continuing training on average each electrician receives per year to stay up to date with the latest version of TACTICS central software:		
Formal Training (class room or seminar)?		40
Non-formal Training (meeting with vendor or coworker in field)?		EVERY DAY
Self-Taught (reading manuals, etc.)?		10
Who led any formal training (vendor, MDOT, other)? If multiple sources, list source and percentage of overall training received from each source.		
source 1	CARRIER AND GABLE	
source 2		
source 3		
Is being able to use TACTICS critical for performing your job? (Yes or No)		YES
please explain why or why not	Gives you a heads up warning or what to expect at the intersection.	
Are there any other factors which keep you from using TACTICS more frequently? (Yes or No) (ie, lack of communications, unreliable communications)		NO
If yes, please list factor(s)		

Ratings and Comments

Overall is your group satisfied with the amount of training you receive for the two components (TACTICS & SEPAC) above? Please respond with satisfied, neutral, or dissatisfied	SATISFIED
Please explain your answer above	**I believe we get enough training. I do not think more would make a noticeable difference.**

Is your group satisfied with the current vendor support? Please respond with satisfied, neutral, or dissatisfied		SATISFIED
Please explain your answer above	**CARRIER AND GABLE SUPPORTS OUR GROUP 100%**	
Is your group satisfied with the NEMA style cabinet?		YES
Do you have concerns with using a 2070 ATC signal controller in a NEMA style cabinet?		YES
If not, please explain why.		
Is your group open to using a ATC "ITS" style cabinet instead of the current NEMA style cabinet? If you are unaware of an ATC style cabinet, please respond with N/A.		YES
If not, please explain why.		
Additional Input or Comments		

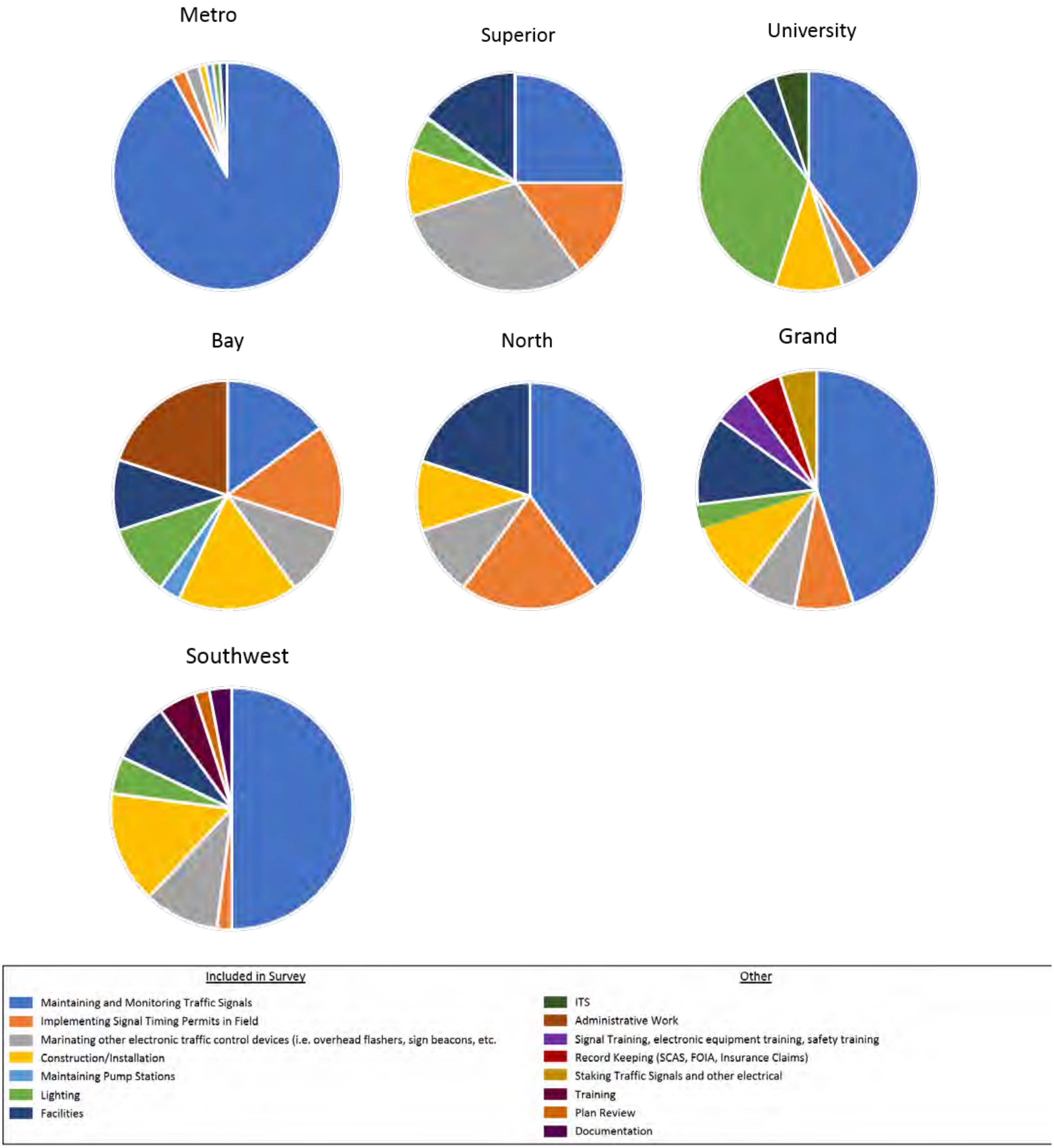


Figure 65. MDOT - average percent of time spent on each task

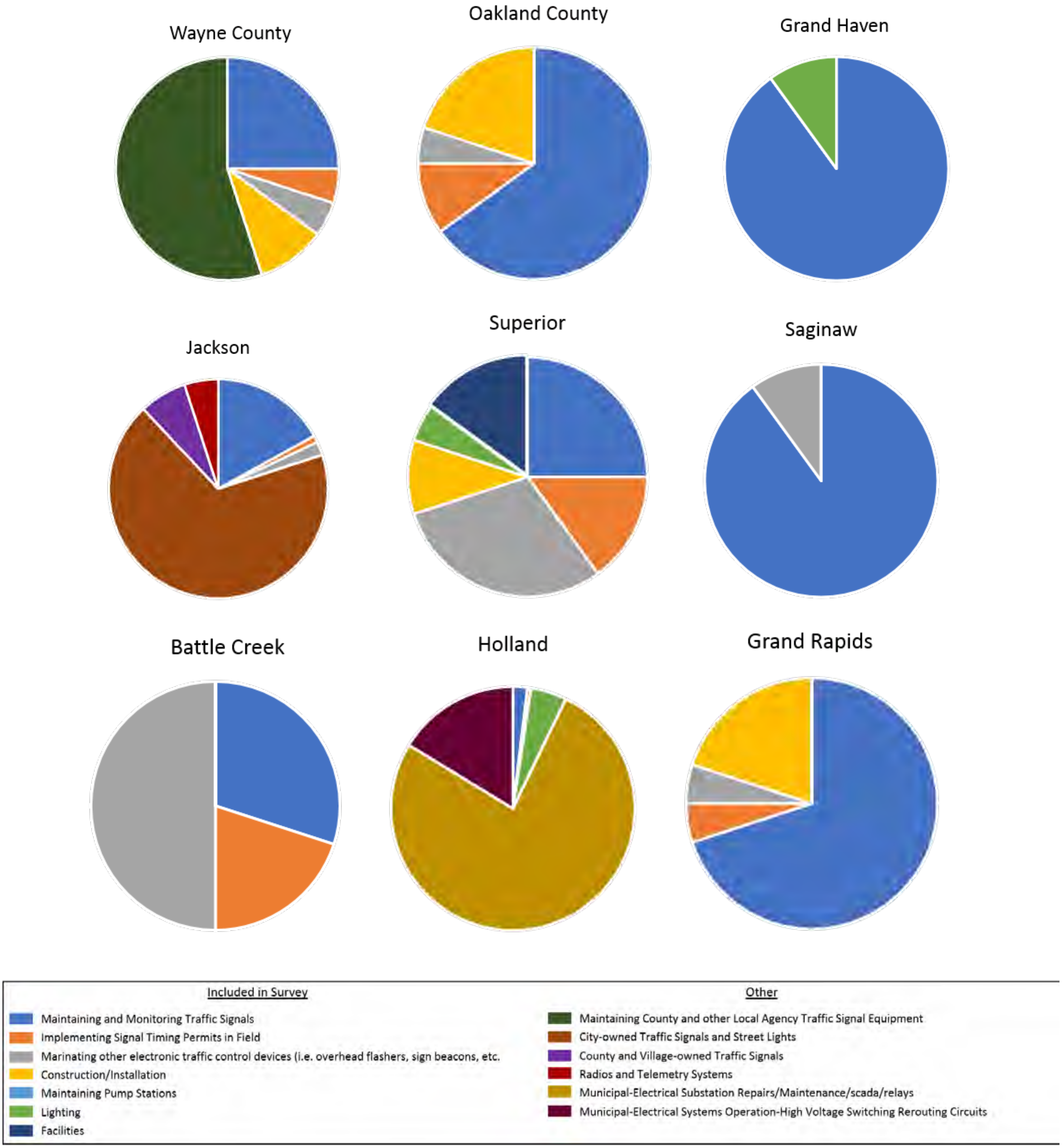


Figure 66. County - average percent of time spent on each task

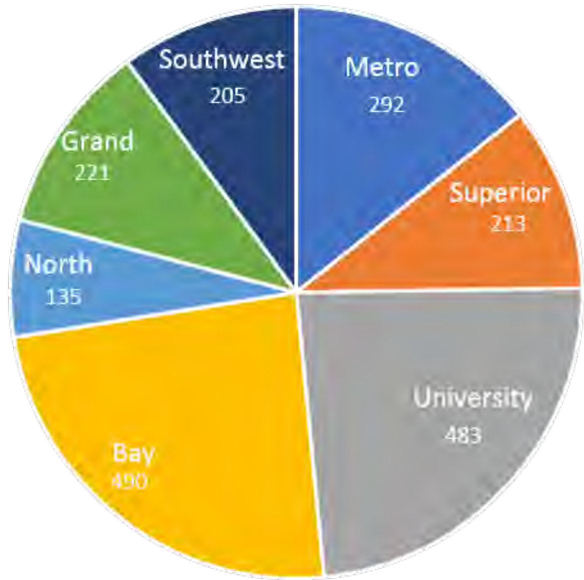


Figure 67.Number of MDOT owed signals maintained by MDOT

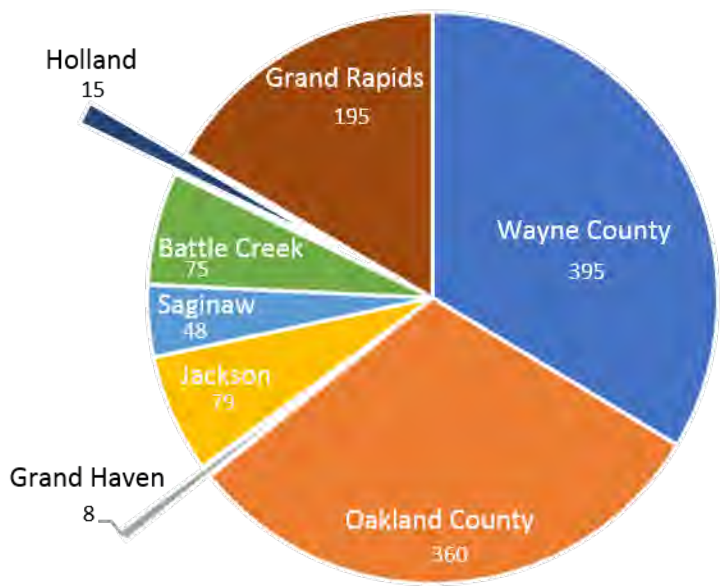


Figure 68. Number of MDOT signals maintained by counties

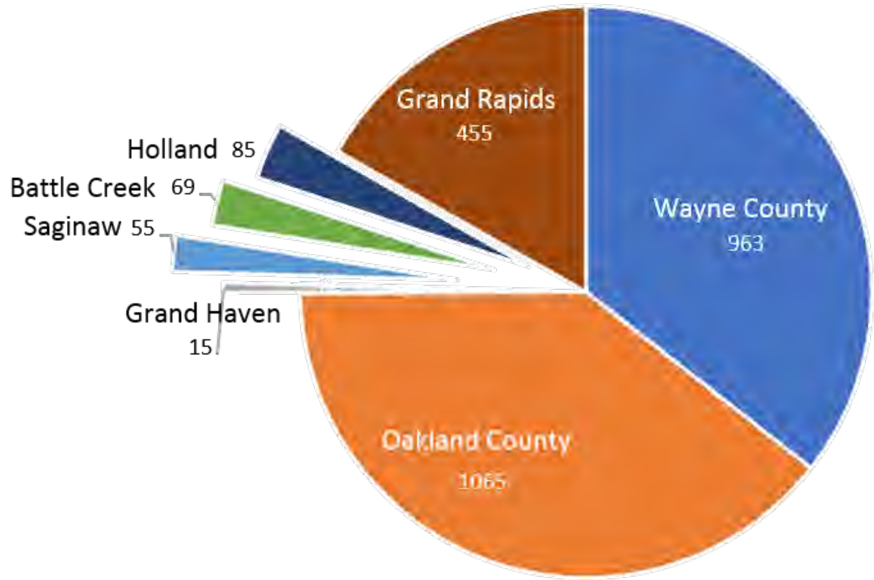


Figure 69. Number of non-MDOT signals maintained by counties

Maintenance and Time Spent

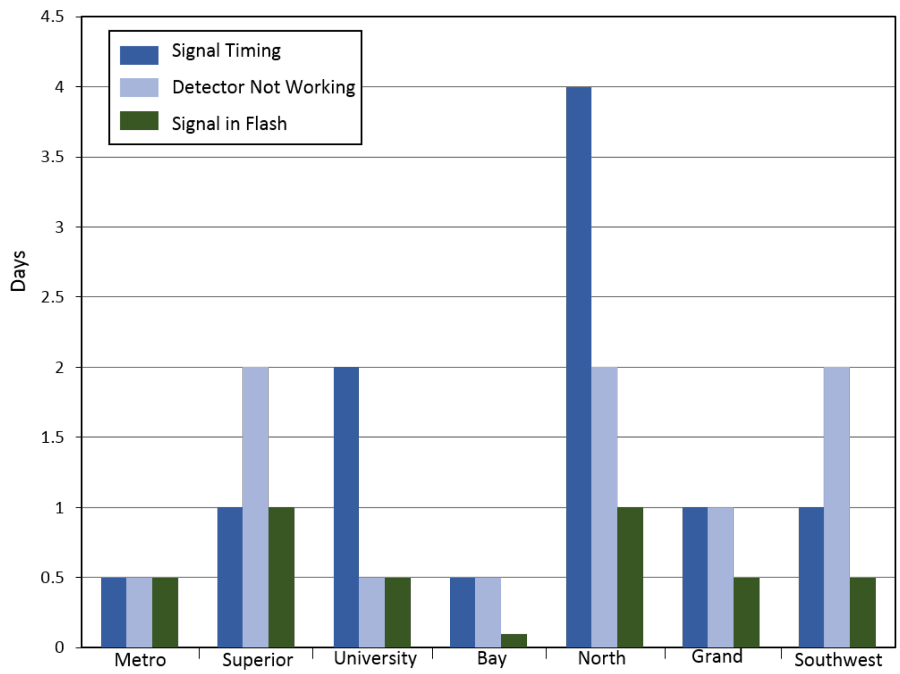


Figure 70. MDOT regions - average time between receiving a complaint and assessing it in the field

Table 38. MDOT regions - maintenance and time spent – short answer summary

	Metro	Superior	University	Bay	North	Grand	Southwest
How frequently does your group perform routine or preventative maintenance?	Too busy with trouble calls	Once a year at 60% of locations	Once a Year	Every 7-10 years for the entire region to have signal maintenance	Minimum 1 per year per location	Once per year at all locations	Once per year at about 25% of signals
Percentage of signals your group discovers a faulty detector, pushbutton, or communications issue while performing routine maintenance?	10%	5%	15%	80%	5%*	50%	20%

**North answered "Used to be more before started doing annual PMs 3-4 years ago"*

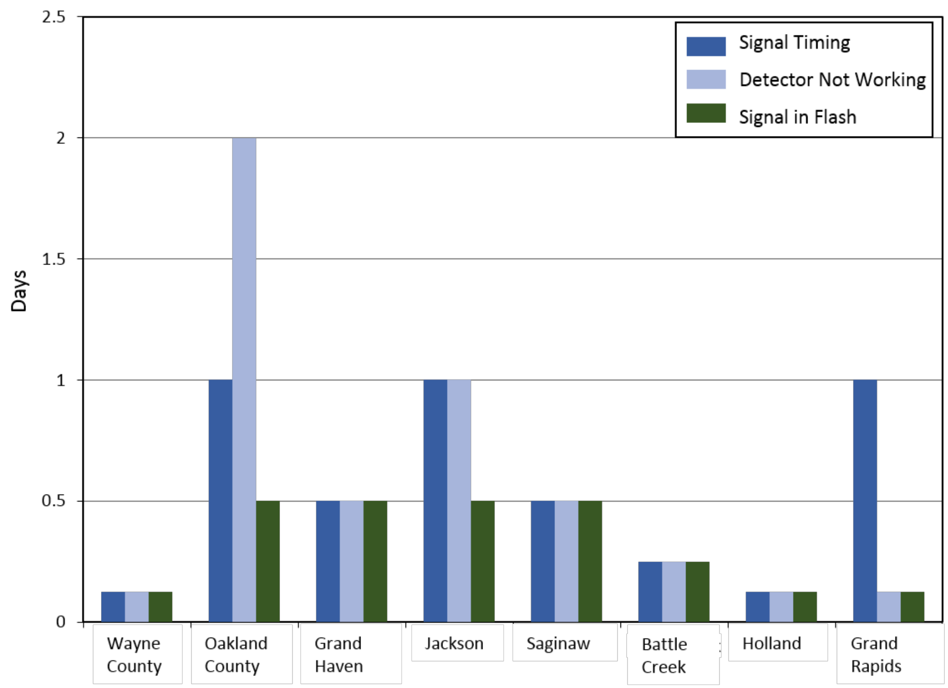


Figure 71. Counties – average time between receiving a complaint and accessing it in the field

Table 39. Counties - maintenance and time spent – short answer summary

	Wayne County	Oakland County	Grand Haven	Jackson	Saginaw	Battle Creek	Holland	Grand Rapids
How frequently does your group perform routine or preventative maintenance?	Twice a year to change the clocks for daylight savings.	Annually for 50% of locations. Also some maintenance functions performed twice per year with DST time change.	100 % all locations	Once per year	Once a year at all locations	Once a year	Once a year all locations.	About once every 4 years when staff is available
Percentage of signals your group discovers a faulty detector, pushbutton, or communications issue while performing routine maintenance?	25%	5%	10%	1%	0%	10%	15%	50%

Signal Timing Issues

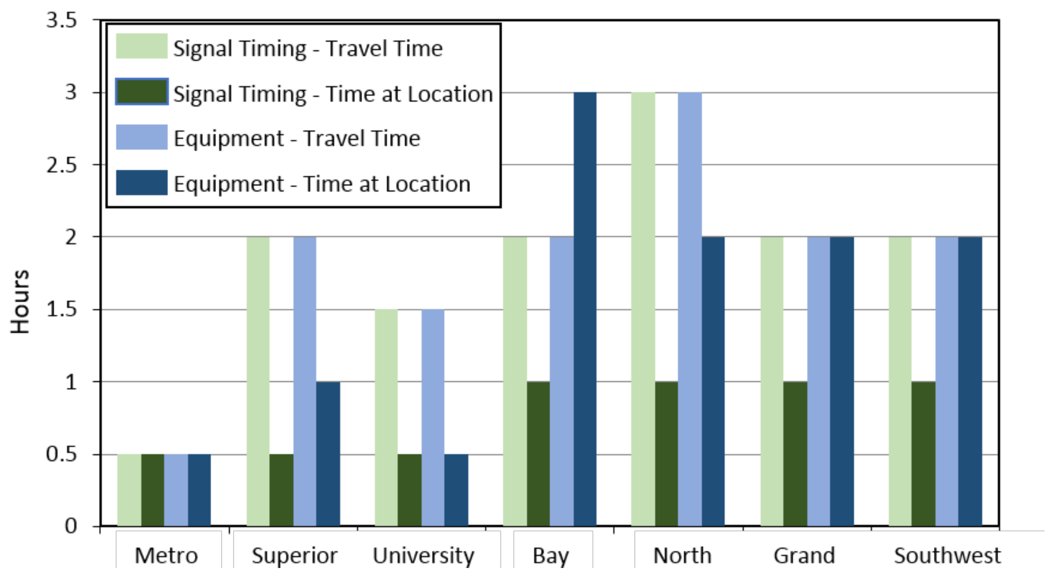


Figure 72. MDOT regions - average time per site per type trouble call

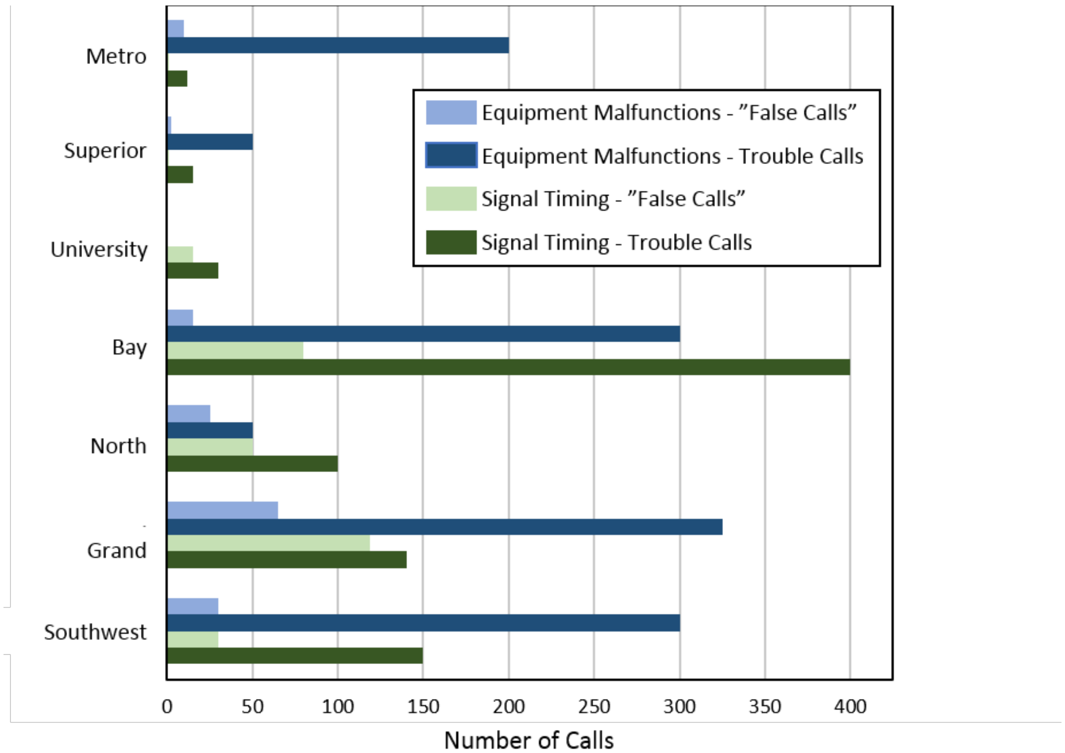


Figure 73. MDOT regions - signal timing and equipment malfunction calls

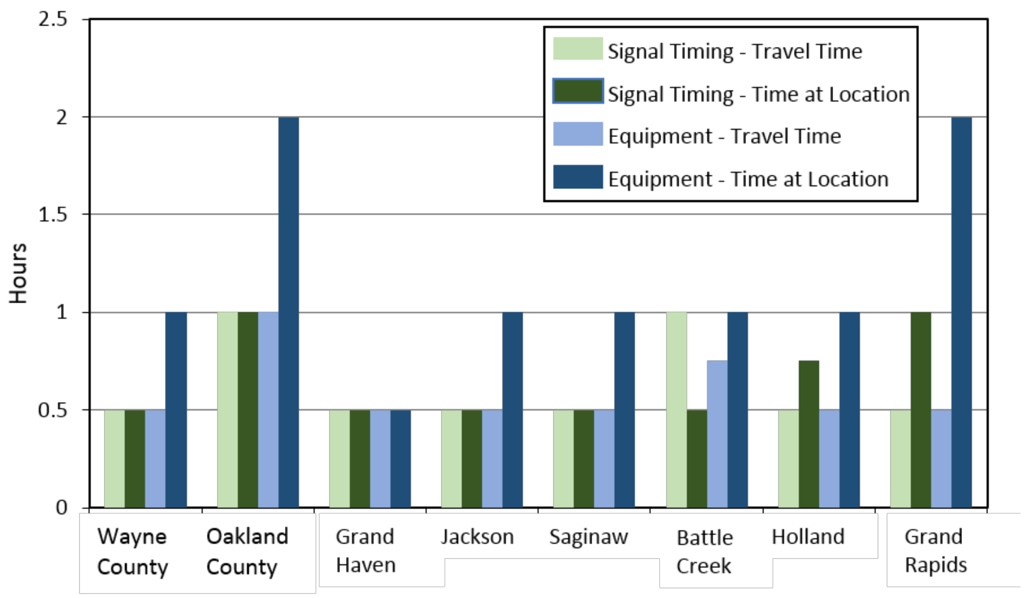


Figure 74. Counties - average time per site per type trouble call

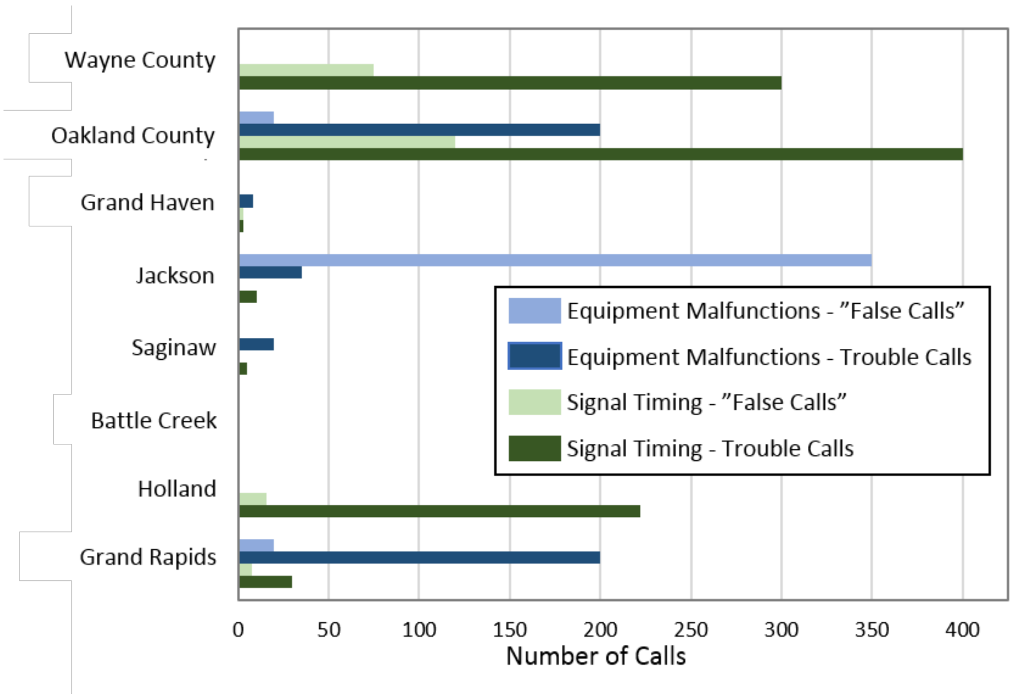


Figure 75. Counties - *signal timing and equipment malfunction calls*

SEPAC

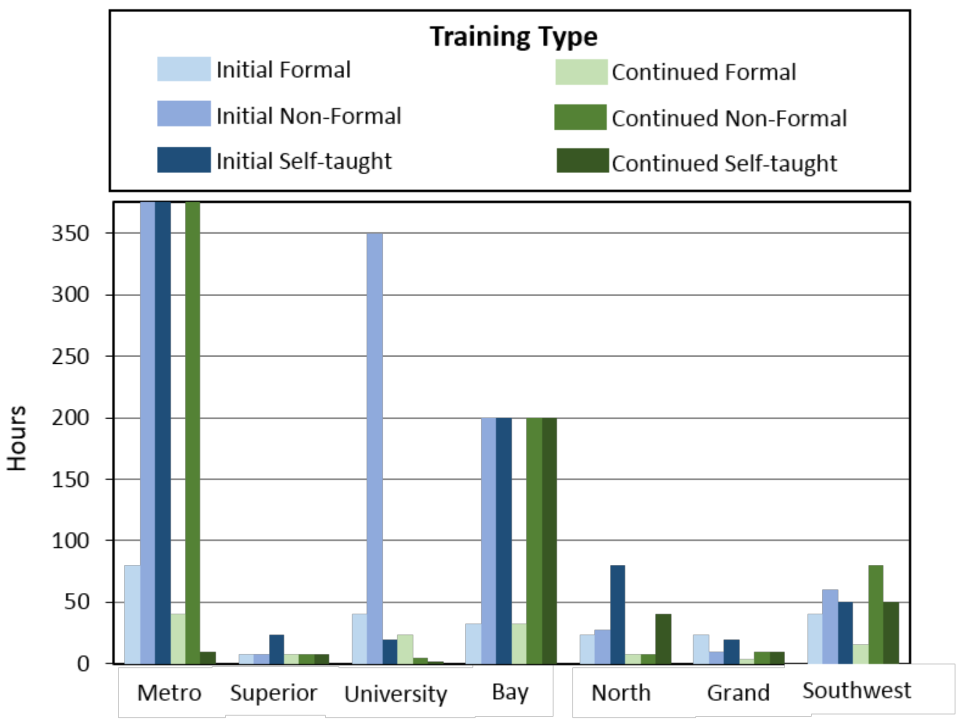


Figure 76. MDOT regions - SEPAC training levels

**Metro answered 3 Years for Initial non-formal trailing, "All the time" for initial self-taught training, and "Every day" for continued non-formal training*
**North initial non-formal training answered "24-32" hours, average shown on graph*

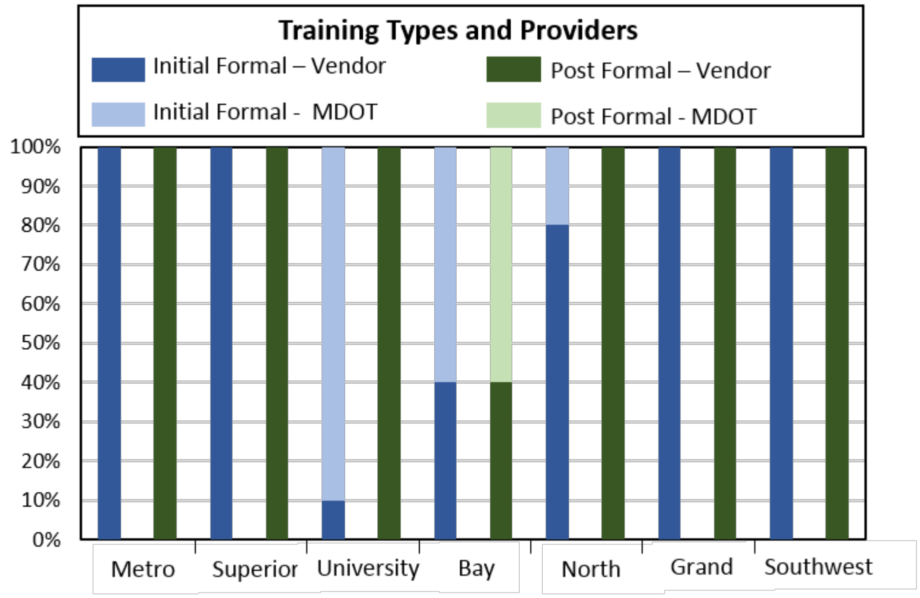


Figure 77. MDOT regions - percent training by vendor

Table 40. MDOT regions - SEPAC – short answer summary

	Metro	Superior	University	Bay	North	Grand	Southwest
What was the average amount of time (in years) needed to become confident in the ability to program/troubleshoot EPAC controller software?	3	-	6 months for simple to 2 years to complex	6	2	2	-
Is being able to program and troubleshoot signal controllers critical for performing your job? (Yes or no)	Yes	Yes	-	Yes	Yes	Yes	Yes
Please explain why or why not.							
Metro	If you do not know what you are doing you are putting the public in danger.						
Superior	The programming makes the signal run correctly, and navigating through the controller is how you troubleshoot some issues.						
University	Yes, because it is essential for the safe operations of the signal.						
Bay	If you cannot do this, how are we supposed to operate our intersections?						
North	This is what we use to operate our traffic signals, so understanding the controller is absolutely critical to troubleshooting issues.						
Grand	-						
Southwest	Knowing and being comfortable with a controller is essential to troubleshoot signal issues and resolve problems in a timely fashion. The controller is the core of the signal operations and not knowing it would mean not being able to perform essential job duties.						

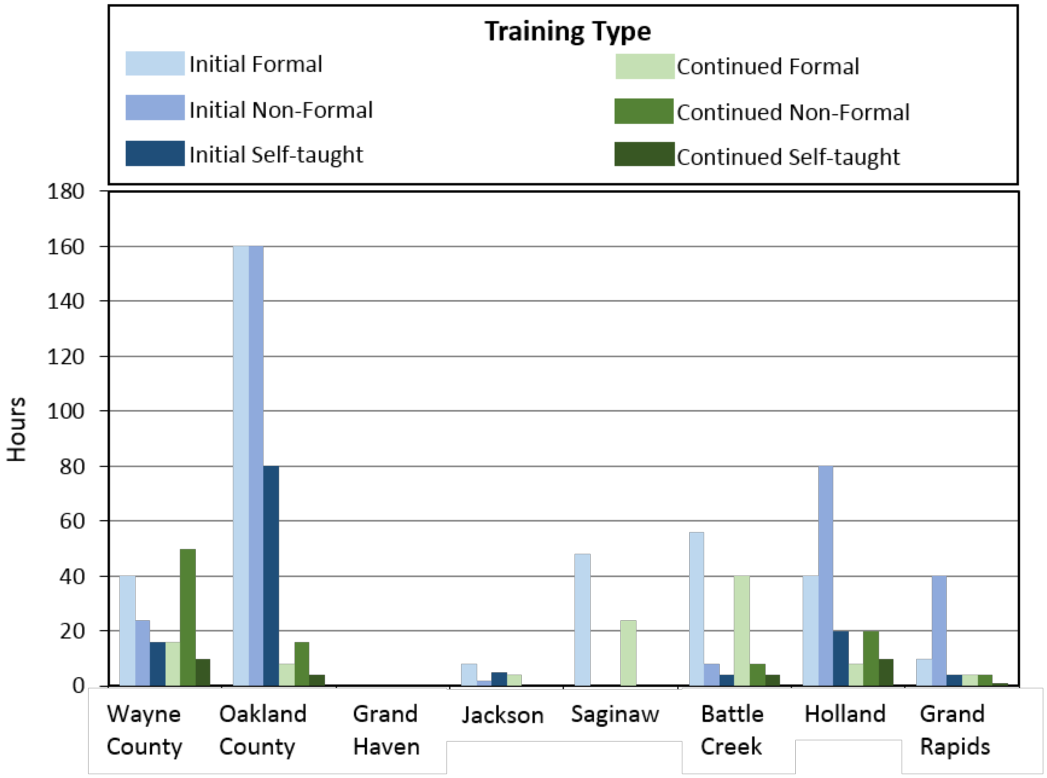


Figure 78. Counties - SEPAC training levels

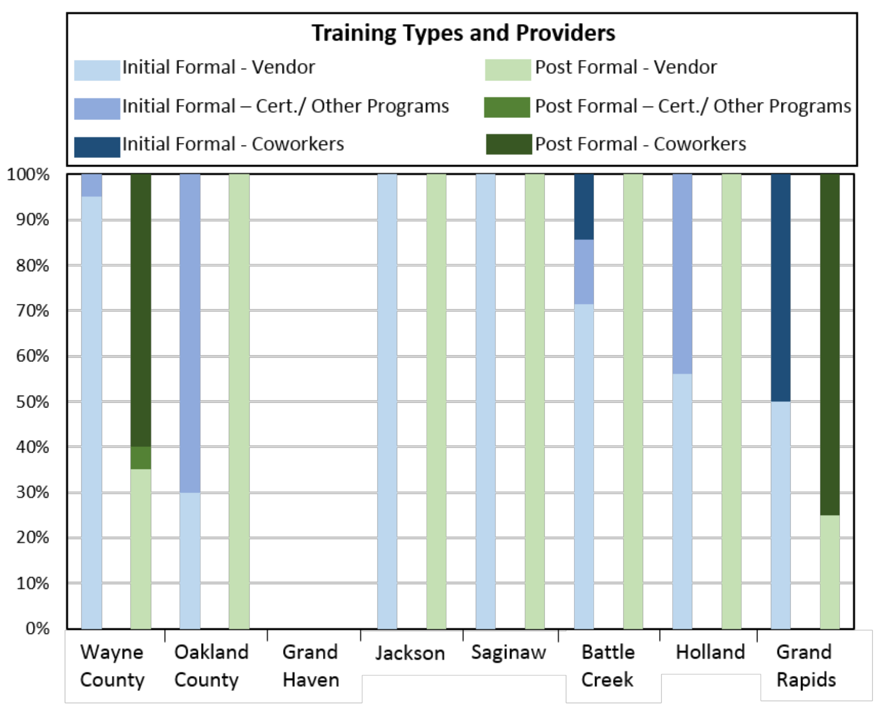


Figure 79. Counties - percent training by vendor

Table 41. Counties- SEPAC – short answer summary

	Wayne County	Oakland County	Grand Haven	Jackson	Saginaw	Battle Creek	Holland	Grand Rapids
What was the average amount of time (in years) needed to become confident in the ability to program/troubleshoot EPAC controller software?	-	4	-	3	2	3+	1 to 2-year with the support of Co-Workers	2
Is being able to program and troubleshoot signal controllers critical for performing your job? (Yes or no)	Yes	Yes	-	Yes	Yes	Yes	Yes	No

Please explain why or why not.

Wayne County	When troubleshooting traffic signal problems, the electrician must be able to determine if the problem is with the controller.
Oakland County	Because we are the maintaining agency for all MDOT signals in Oakland County.
Grand Haven	-
Jackson	Being responsible for many City, County and village Traffic signals you must be able to repair and make changes as needed to get the signal up and running this means knowing all aspects of the traffic signal and its operation.
Saginaw	Provides information to diagnose problems and how to correct.
Battle Creek	Not everything is a quick and easy install, you may have to look at a print to get a better understanding of the logic that is controlling the intersection.
Holland	Only in the field of traffic signals. Our electrician main job task is maintaining electrical substations equipment, high voltage switching rerouting distribution circuit for the electrical municipal Holland Board of Public Works. We already have additional training requirement for electrical safety, MIOSHA requirements, and substation equipment.
Grand Rapids	The City of Grand Rapids employs a Traffic System Programmer, it is not the responsibility of electricians to program signal controllers.

TACTICS

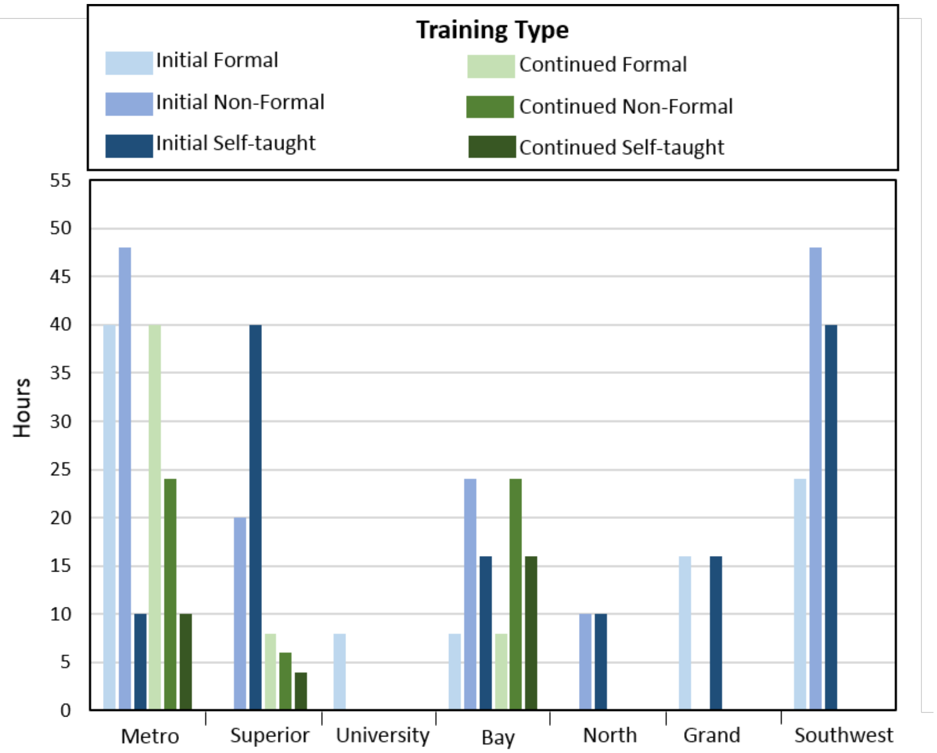


Figure 80. MDOT regions - Tactics training

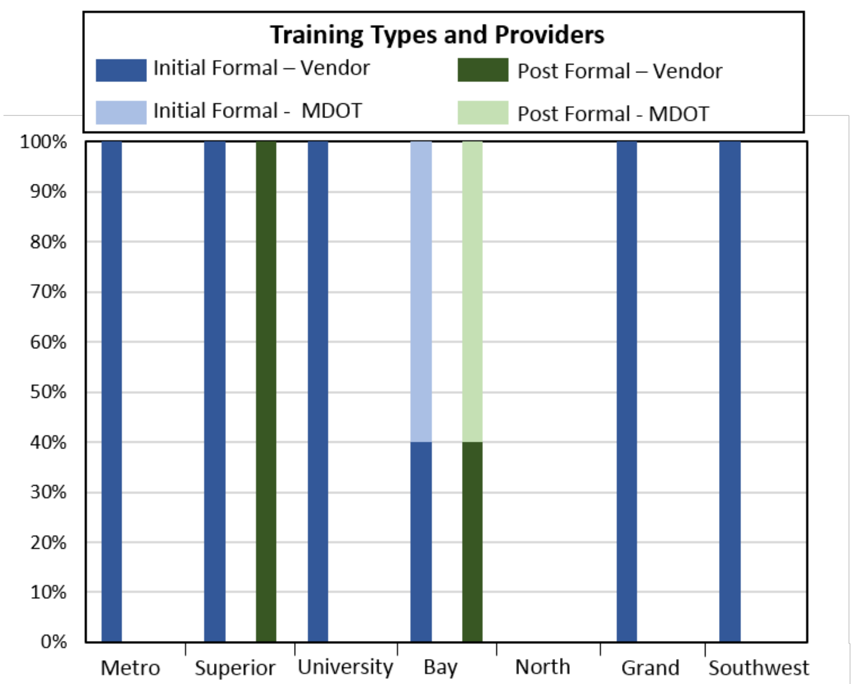


Figure 81. MDOT regions - Tactics percent training by vendor

Table 42. MDOT regions - Tactics – short answer summary

		Metro	Superior	University	Bay	North	Grand	Southwest
Does the central software (i.e. TACTICS) provide you notifications when equipment at a signal is malfunctioning? Please list the types of notifications you are able to receive. Provide the number of locations in your area for which this function is provided.	Signal in Flash	×	✓ (17)	×	×	×	✓ (98)	✓ (45)
	Detector Not Working	×	×	×	×	×	✓	×
	Power Outage	×	✓	×	×	×	×	✓ (1)
Do you find these notifications helpful? (Yes or No)		✓	✓	✓	N/A	N/A	×	✓
Please explain why or why not.								
Metro		It gives you a heads up on the status of the intersection.						
Superior		Travel time						
University		These would be helpful if we received them. They would provide a time savings and help us be better prepared.						
Bay		N/A						
North		Not using						
Grand		System is installed, but not yet fully functioning.						
Southwest		Getting notified cuts the time for issues getting fixed and potential safety issues of a malfunctioning signal. There is frequently delays in getting notified otherwise.						
Do you use TACTICS to actively monitor your traffic signal systems? (Yes or No) .		✓	✓	×	×	×	✓ manually connecting	✓
Do you use TACTICS with little or no help from the vendor? (Yes or No).		✓	✓	✓ Only for signal timing storage	×	×	×	×
How many years until you were confident in your ability to program/troubleshoot TACTICS software? (If the group overall is not confident in the ability indicate "Novice")		3	4	Novice	Novice	N/A	2	Novice
Is being able to use TACTICS critical for performing your job? (Yes or No).		✓	✓	×	✓ Standalone - yes; central	×	✓	✓

				system - no			
Please explain why or why not.							
Metro	It gives you a heads up warning or what to expect at the intersection.						
Superior	Cuts down on false trouble calls and response time.						
University	It is not critical, but it would be very beneficial.						
Bay	Bay Region doesn't have a Central Office System.						
North	We are not set up to use it regularly, so it isn't routinely used.						
Grand	Use the data base						
Southwest	Timely response to issues and troubleshooting.						
Are there any other factors which keep you from using TACTICS more frequently?(ie, lack of communications, unreliable communications).	×	×	✓	✓	✓	✓	✓
Please explain why or why not.							
Metro	-						
Superior	-						
University	The lack in central communications.						
Bay	Product unreliability, outdated (serial cable)						
North	Lack of communication at most signals. Lack of formal training.						
Grand	Waiting for vendor to troubleshoot installation and communication of Region Tactics software. Always waiting for latest software upgrade.						
Southwest	Lack of training; need a higher comfort level. Communication issues and errors in the field.						

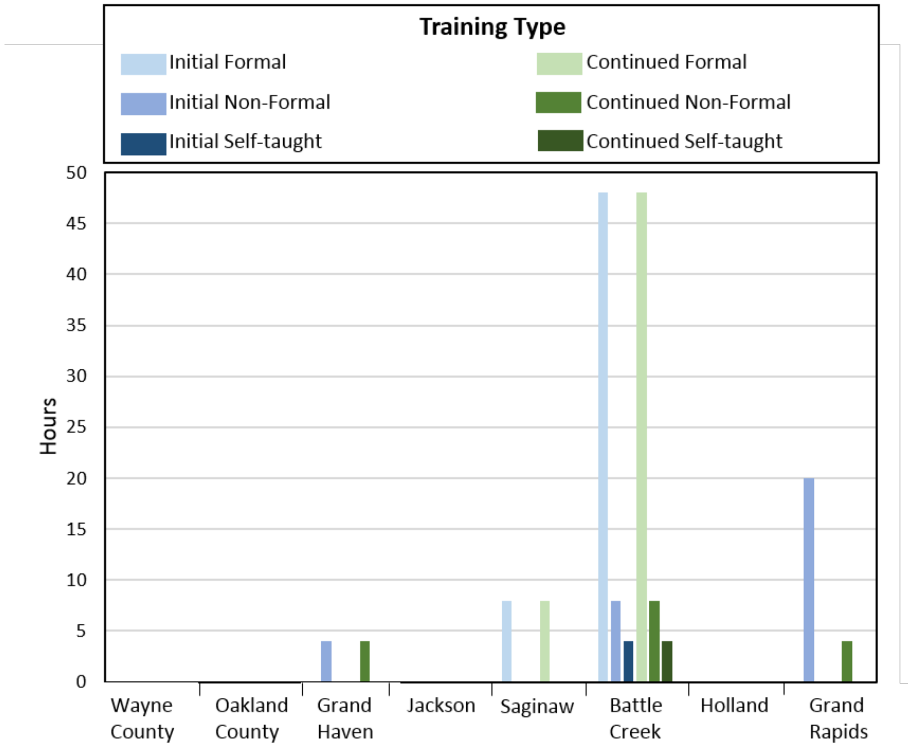


Figure 82. Counties - Tactics training

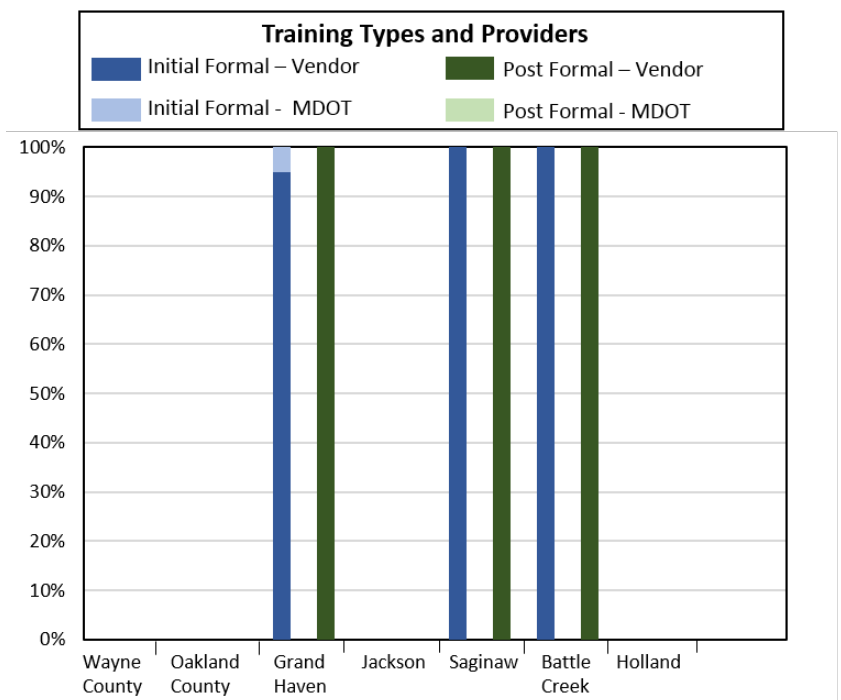


Figure 83. Counties - Tactics percent training by vendor

Table 43. Counties - Tactics – short answer summary

		Wayne County	Oakland County	Grand Haven	Jackson	Saginaw	Battle Creek	Holland	Grand Rapids
Does the central software (i.e. TACTICS) provide you notifications when equipment at a signal is malfunctioning? Please list the types of notifications you are able to receive. Provide the number of locations in your area for which this function is provided.	Signal in Flash	-	-	-	-	-	✓ (84)	×	✓ (270)
	Detector Not Working	-	-	-	-	-	✓ (84)	×	×
	Power Outage	-	-	-	-	-	✓ (84)	×	×
Do you find these notifications helpful? (Yes or No)		-	-	-	-	-	✓	N/A	✓
Please explain why or why not.									
Wayne County		-							
Oakland County		-							
Grand Haven		-							
Jackson		-							
Saginaw		-							
Battle Creek		It helps to prepare us on what need to put on the truck, not knowing exactly what is out.							
Holland		-							
Grand Rapids		We can provide a quicker response time to a signal in conflict flash.							
Do you use TACTICS to actively monitor your traffic signal systems? (Yes or No) .		-	-	×	-	×	✓	×	✓
Do you use TACTICS with little or no help from the vendor? (Yes or No).		-	-	✓	-	✓	×	-	✓
How many years until you were confident in your ability to program/troubleshoot TACTICS software? (If the group overall is not confident in the ability indicate "Novice")		-	-	Novice	-	2	2 years with on-going training	-	2
Is being able to use TACTICS critical for performing your job? (Yes or No).		0	-	✓	-	✓	-	-	-
Please explain why or why not.									

Wayne County	-							
Oakland County	-							
Grand Haven	Never know when you will need to use it.							
Jackson	-							
Saginaw	Provides information to diagnose problems and how to correct.							
Battle Creek	Yes, not knowing how to program a controller, up-load and download a controller could be a problem.							
Holland	-							
Grand Rapids	-							
Are there any other factors which keep you from using TACTICS more frequently?(ie, lack of communications, unreliable communications).	-	-	-	-	✓	✓	×	×
Please explain why or why not.								
Wayne County	-							
Oakland County	-							
Grand Haven	-							
Jackson	-							
Saginaw	Not compatible with Windows 10.							
Battle Creek	Lack of communication.							
Holland	-							
Grand Rapids	-							

Ratings and Comments

Table 44. MDOT regions - ratings and comments – short answer summary

	Metro	Superior	University	Bay	North	Grand	Southwest
Overall is your group satisfied with the amount of training you receive for the two components (TACTICS & SEPAC) above? Please respond with satisfied, neutral, or dissatisfied	Satisfied	Satisfied	Satisfied	Neutral	Dis-satisfied	Neutral	Neutral
Please explain your answer above.							
Metro	I believe we get enough training. I do not think more would make a noticeable difference.						
Superior	Without the training and support, TACTICS would be of no use.						
University	Training is sufficient but alerts from TACTICS are not available.						
Bay	Always welcome more training.						
North	Training is not offered frequently enough at close proximity to our work location.						
Grand	Available training is too basic.						
Southwest	Training courses exist, but it's difficult to find time to take more training. Informal training is good, but it's also an issue of everyone's time.						
Is your group satisfied with the current vendor support? Please respond with satisfied, neutral, or dissatisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Neutral	Satisfied
Please explain your answer above.							
Metro	Carrier and Gable supports our group 100%.						
Superior	If issues arise, they are prompt and helpful with trouble shooting over the phone, or will travel to remedy the issue in person.						
University	-						
Bay	Satisfied						
North	Carrier and Gable is very responsive and knowledgeable of equipment.						
Grand	We are waiting too long for response time and to complete installations. The vendor often waits to complete upgrades and new installations until "the next update" is available which delays or prevents us from using the software or equipment to complete current work. The vendor does not notify us of known issues until a problem arises.						

Southwest	Having availability of many training classes is great. Being able to make a call for questions and have on-site support is also very helpful. Their knowledge of our equipment is very high and they are very willing to provide support.						
Is your group satisfied with the NEMA style cabinet?	Yes	Yes	Yes	Yes	Yes	Neutral	Yes
Do you have concerns with using a 2070 ATC signal controller in a NEMA style cabinet?	Yes	Yes	Yes	Yes	N/A	Yes	Some
If not, please explain why.							
Metro	-						
Superior	-						
University	It does not seem compatible with our other signals.						
Bay	We do have concerns: Compatibility, reliability, corrosion.						
North	No experience with 2070.						
Grand	Field programming for immediate changes (i.e. if a ped signal goes out then intersection goes into flash until it is reprogrammed).						
Southwest	Assuming it works, training is necessary.						
Is your group open to using an ATC "ITS" style cabinet instead of the current NEMA style cabinet? If you are unaware of an ATC style cabinet, please respond with N/A.	Yes	N/A	Not as our standard installation at every location.	No	Yes, we are open to it as long as training is provided and support offered.	Yes	Depends
If not, please explain why.							
Metro	-						
Superior	-						
University	It is a very large cabinet to place near an intersection. It seems more advanced than needed for most locations.						
Bay	Product reliability, trouble shooting difficulties.						
North	-						
Grand	We are not totally clear on pros and cons but are open to reviewing it.						
Southwest	Having two doors makes it harder to troubleshoot depending on where the doors open up plus it prevents being able to see everything at once. Need more training.						
Additional Input or Comments.							

Metro	-
Superior	-
University	-
Bay	-
North	It was difficult to quantify our answers into # of hours. A lot of our time is spent traveling between locations over a large geographic area, so when we visit a site for PM, trouble call, or anything else….we do a full evaluation to make sure we are catching other items that may be an issue.
Grand	-
Southwest	Being able to keep up on training with new firmware, devices, and operational situations is difficult to make time for since there are always other things that must be done. Additional cabinet functionality (modems, switches, RSUs) will require some additional training and a review of appropriate work load for staff. Being able to respond to operational issues and associated safety concerns is a core function of MDOT and should be considered high priority. We are eager to provide that service but want to be able to do it to our best ability.

Table 45. Counties - ratings and comments – short answer summary

	Wayne County	Oakland County	Grand Haven	Jackson	Saginaw	Battle Creek	Holland	Grand Rapids
Overall is your group satisfied with the amount of training you receive for the two components (TACTICS & SEPAC) above? Please respond with satisfied, neutral, or dissatisfied	Satisfied (SEPAC)	SEPAC - Satisfied; TACTICS - N/A	Neutral	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
Please explain your answer above.								
Wayne County	C&G has given and continues to give us all the training we need.							
Oakland County	Our vendor, Carrier & Gable, provides excellent training classes. RCOC has a three-year-long formal training program, which allows us to identify and resolve problems ourselves as they occur.							
Grand Haven	I never used SEPAC							
Jackson	We do not use Tactics but C&G offers all the training and support needed							
Saginaw	Vendor provides ample training							
Battle Creek	It give us enough knowledge to approach a problem and work our way through the problem, to get a solution.							
Holland	-							
Grand Rapids	As previously stated, Grand Rapids electricians have very limited exposure to both signal controller programming and Tactics software because the City of Grand Rapids employees a Traffic System Programmer.							
Is your group satisfied with the current vendor support? Please respond with satisfied, neutral, or dissatisfied	Satisfied	SEPAC - Satisfied; TACTICS - N/A	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
Please explain your answer above.								
Wayne County	C& G has given and continues to give us all the support we need.							
Oakland County	Our vendor, Carrier & Gable, is always very responsive when we need assistance.							
Grand Haven	-							
Jackson	C&G provides training and repair as we need it							

Saginaw	Vendor provides ample training							
Battle Creek	They are prompt in returning phone calls when help is needed.							
Holland	-							
Grand Rapids	Vendor has always provided excellent support for Tactics and signal controllers.							
Is your group satisfied with the NEMA style cabinet?	Yes	Yes, we are happy with the RCOC-style cabinets	Yes	Yes	Yes	Yes	Yes	Yes
Do you have concerns with using a 2070 ATC signal controller in a NEMA style cabinet?	No	No	-	Yes	N/A	No, have not seen one in the field.	Unsure	Yes
If not, please explain why.								
Wayne County	C&G has assured us they will give us all the support we need.							
Oakland County	RCOC currently does not have any 2070 controllers in the field.							
Grand Haven	-							
Jackson	-							
Saginaw	Unfamiliar with this controller							
Battle Creek	-							
Holland	-							
Grand Rapids	Concerns about compatibility with Tactics software, or other central system software.							
Is your group open to using an ATC "ITS" style cabinet instead of the current NEMA style cabinet? If you are unaware of an ATC style cabinet, please respond with N/A.	No	Yes	N/A	N/A	N/A	Yes	Unsure	N/A
If not, please explain why.								
Wayne County	We prefer to keep in stock only one type of cabinet. It will place too much of a logistical burden on us to manage two types of cabinets.							
Oakland County	-							
Grand Haven	-							

Jackson	-
Saginaw	-
Battle Creek	-
Holland	Extensive training maybe an issue.
Grand Rapids	-
If not, please explain why.	
Wayne County	-
Oakland County	RCOC currently operates 770 traffic signals on the SCATS system (including MDOT signals as noted above).
Grand Haven	When upgrades or modifications are made to the cabinet, it would be beneficial to be trained on the upgrades.
Jackson	-
Saginaw	-
Battle Creek	-
Holland	-
Grand Rapids	-

17.4 APPENDIX C – PRESENTATION MATERIALS

Two presentations were made as part of this project. The first was a presentation of the executive summary of the project. The second was a training session to show technicians and electricians how to utilize signal performance measures. Materials from the sessions are located in the below links.

Link to Training Session: https://goo.gl/cmMgDZ

Link to Executive Discussion: https://goo.gl/34dqRv