Automated Traffic Signal Performance Measures

User Case Examples

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List of Acronyms and Abbreviations

AoG/AOG	Arrivals on Green
ATSPMs	Automated Traffic Signal Performance Measures
UDOT	Utah Department of Transportation
MOE	Measures of Effectiveness
MPH	Miles per Hour
PCD	Purdue Coordination Diagram
VPH	Vehicles per Hour
HAWK	High-intensity Activated crosswalk
TOD	Time of Day
BIU	Bus Interface Unit

1. Signal System Monitoring

One of the benefits of Automated Traffic Signal Performance Metrics (ATSPMs) is the ATSPM Alerts email. The system identifies potential problems at traffic signals the day after the issue began, enabling a quick response, often before the public notices and reports the problem. Using ATSPMs in a pro-active manner via the automated alerts email is discussed in section 1.1.

Not all issues are caught by the ATSPM Alert system. Issues reported by the motoring public are critical for identifying operational concerns. ATSPM data is helpful for verifying and troubleshooting these complaints prior to dispatching field personnel. Examples of these concerns and practical ATSPM troubleshooting tips are discussed in section 1.2

1.1 ATSPM Alert Troubleshooting (ATSPM Alerts Email)

Once configured, the Watch Dog application will monitor the ATSPM data stream for irregularities against the previous reported period. The following sections describe how to troubleshoot the items listed in the ATSPM Alerts email. This is a daily email which flags issues that occurred on the previous weekday or earlier that same morning. The threshold and evaluation periods are set under the “Admin” privilege tree under the link for “Watch Dog”. Reference the *Automated Traffic Signal Performance Measures Component Details* Section 8.6 Watch Dog (Admin Only) for additional details about the configurable parameters of the Watch Dog service.

1.1.1 Too Few Records in the Database

The first sub-section of the ATSPM Alerts email reports intersections where there are too few records in the SQL database for the configured time interval. For the UDOT system, intersections are evaluated from 12:00 am on one day to 12:00 am the following day and flagged if there are less than 500 records in the database for that time period. Reference the Automated Traffic Signal Performance Measures Component Details Section 8.6 Watch Dog (Admin Only) for additional details about the configurable parameters of the Watch Dog service.

Figure 1.1 shows the evaluation process and when an email is sent. The troubleshooting process can vary depending on the controller type; however, the first couple of steps are usually the same regardless of the controller type.

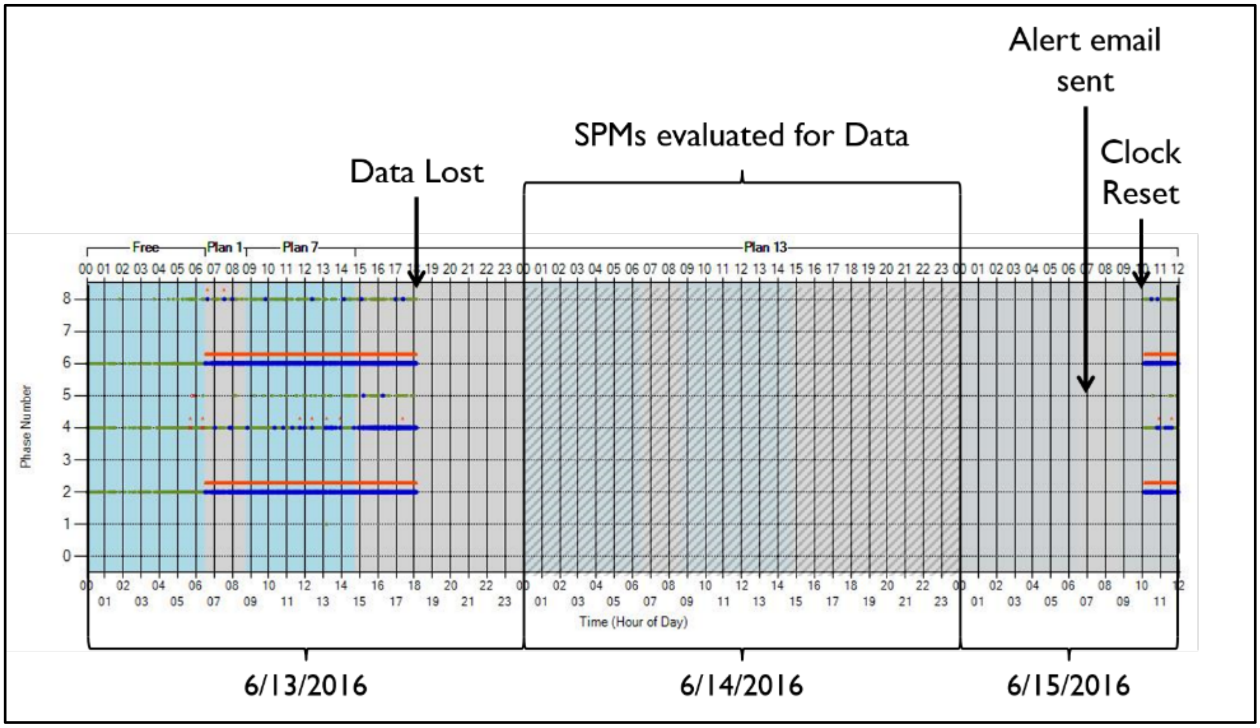


Figure 1.1 ATSPM Evaluation for Too Few Records

In order to get any data, please ensure that the signal controller has a firmware that includes a high resolution data logger. The data logger records events every 1/10th of a second with a time-stamp, such as the beginning of a green, beginning of a yellow, a detector activation, etc. The Econolite controllers will buffer approximately 24 hours of data logs before it starts to overwrite the data (as of May 2019). The Intelight controllers will buffer 4000 lines of code or 10 minutes of data logs before it starts to override the data (as of May 2019). Table 1.1 shows the typical controller types and the minimum firmware requirements they need in order to work with the ATSPM website.

Table 1.1 System Requirements for ATSPMs

Controller Type	Minimum Firmware Requirement for ATSPMs
Econolite Cobalt	Any
Econolite ASC3 NEMA	Version 2.50+ and OS 1.14.03+
Econolite 2070 with 1C CPU Module	Version 32.50+
Intelight Maxtime	Version 1.7.0+
Peek ATC Greenwave	Version 03.05.0528+
Trafficware 980 ATC	Version 76.10+
Siemens M50 Linux & M60 ATC	ECOM Version 3.52+ NTCIP Version 4.53+
McCain ATC Omni	eX 1.6+

If the signal controller has the proper firmware requirements but is still not providing data, check the signal controller communication status. If the controller does not respond to a system ping request on the network, the ATSPM server will not be able to pull the controller logs. Once the communication issue is resolved, the next thing to check is that the IP address and controller type found on the ATSPM website match the field site, Figure 1.2. If the controller type or IP address is changed in the field and not updated on the ATSPM configuration tool, no data will be recorded. These two settings instruct the ATSPM programs which intersections to communicate with, and what process are necessary to transfer the log files from the controller to the ATSPM server for decoding and insertion into the ATSPM database.

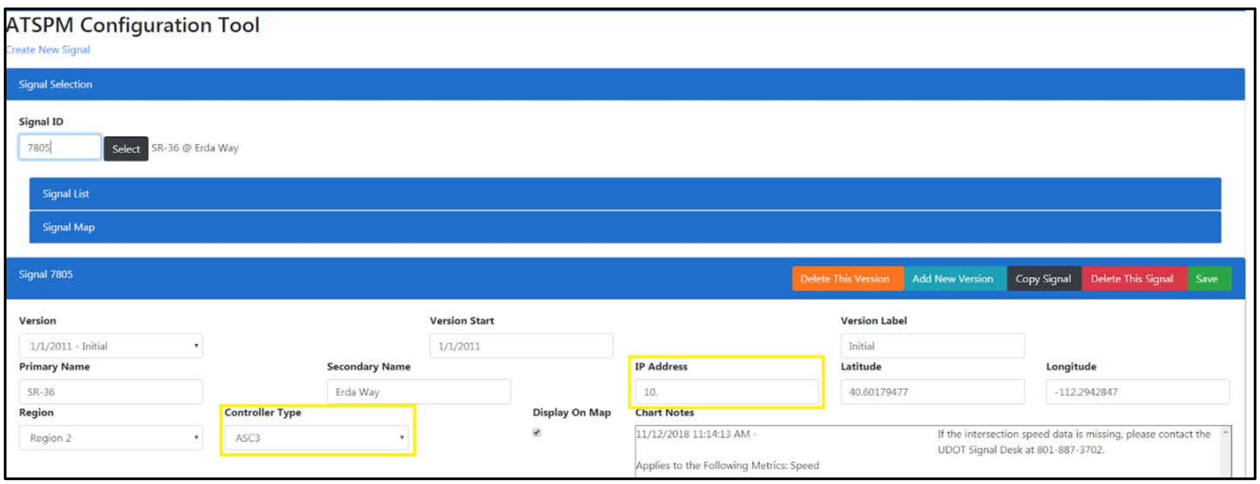


Figure 1.2 ATSPM Configuration Tool

The supported ATSPM controllers log each of the defined enumerations on a tenth of a second basis and will batch everything into an exportable log once the reporting period is complete. These periods can range from 15 minutes to several hours based on the controller manufacturer. One of the setup steps of an ATSPM system is to pull the log files from the controllers at regular intervals. The controller log files use the controller time, so a daily time sync is important to maintain consistency across the system.

During early development of the ATSPM system for UDOT, a clock error was observed where controllers would lose their time clock and revert back to default manufacturer settings (times in the past). The controller logs would continue to be written and the ATSPM server would continue to pull them into the database, but due to the time being off, no data would be available since the ATSPM server looks for logs with a current time stamp.

UDOT has since setup a daily time broadcast service to systematically push the local GMT time to all connected controllers to ensure that controller logging is always synced with the current time. This helps ensure proper operation of the ATSPM system as well as ensuring correct data for time of day coordination along corridors.

Controller clock management is an important issue. If the controller has a time that is different from the current one, the logs will be stored on the ATSPM server and since the date is not current, the ATSPM server cannot correctly produce the charts to the website when reports are queried. If issues are observed with intersection controllers not reporting data on the ATSPM website, check the timestamps of the logs stored on the Microsoft SQL Server (SQL) database. If the timestamps are indicating that the controller clock is set to a time in the past – sync the controller clock to the current time. If the SQL database timestamps are indicating that the clock is sometime in the future, the SQL entries of these “future” events will need to be removed from the SQL database prior to having successful current logs making it into the database.

Ultimately, if the controller is running the minimum firmware requirements for the high resolution data logger and there are no issues with the controller clock and associated SQL database timestamp, try re-installing the controller firmware/application or continue troubleshooting with a new controller at the location.

Econolite Controllers

If an Econolite controller is not getting any data through ATSPMs, there are a couple of additional items to check.

1. Database Diagnostics (MM 9-3-1)
    a. The database state should be “ALL SAVED”. If the database state is “SAVING – WAIT”, the ATSPM server will not be able to pull any data files because the controller is not able to write any log files.
        i. This issue can be resolved by either performing a cold-boot to the controller OR by resetting the controller to factory defaults and reinstalling the application and firmware (A backup to the data key is recommended).
    b. Also, on this same menu verify if the option “VIOT TRACE” is enabled or not. This line is not automatically shown in the diagnostics menu; enable the line by pressing the “Special Function” key 3 times shortly after opening the “Database Diagnostics” screen. For correct logging operations, ensure that “VIOT TRACE ENA.” is toggled to “NO.”

    Figure 1.3 shows the ASC-3 “Database Diagnostics” menu. Note, the “DATABASE STATE” is “ALL SAVED” and “VIOT TRACE ENA” is set to “NO”.

```
DATABASE DIAGNOSTICS
CONFIGURATION TRANSFER IN PROGRESS..  NO
DATABASE STATE................ ALL SAVED
DIAG CMD.. NO ACTION  VIOT TRACE ENA. NO
```

Figure 1.3 Econolite Controller - Database Diagnostics Menu

As noted, if the cold boot does not solve these issues, the controller may require a reformat of the operating system. This will require reloading the application (2.50+) and the OS (1.14.03+) onto the controller.

1.1.2 Too Many Force Off Occurrences

The ATSPM Alerts will evaluate signals and report phases that exceed the thresholds set for force off occurrences in the Watchdog Configuration. For the UDOT configuration, the signal ID will be on the email list if it had a phase with more than 90% force offs in at least 50 activations between 1 a.m. and 5 a.m. the same day, Figure 1.4. Reference the Automated Traffic Signal Performance Measures Component Details Section 8.6 Watch Dog (Admin Only) for additional details about the configurable parameters of the Watch Dog service.

This is the second sub-section of the ATSPM Alerts email and can assist in identifying detection errors. By definition, a force off occurs when the intersection is running a coordination pattern and the phase has a constant call during the entire time it serves. A force off is expected when the phase is coordinated. The ATSPM Alerts will often catch the signals that run overnight coordination and the phase in question is the coordinated phase. Other instances that may have force offs include peer-to-peer operations, clearance phases, and dummy phases. When getting this alert, be careful not to confuse normal operation with a bad detector. In the instances where the force offs are normal operation, it may be advantageous to make a note on the Purdue Phase Termination chart within the ATSPM configuration. Reference the Automated Traffic Signal Performance Measures Component Details Section 8.1 Signal Configuration (Admin Only) for additional details about the chart specific configurable “Chart Notes” for unique intersections operations.

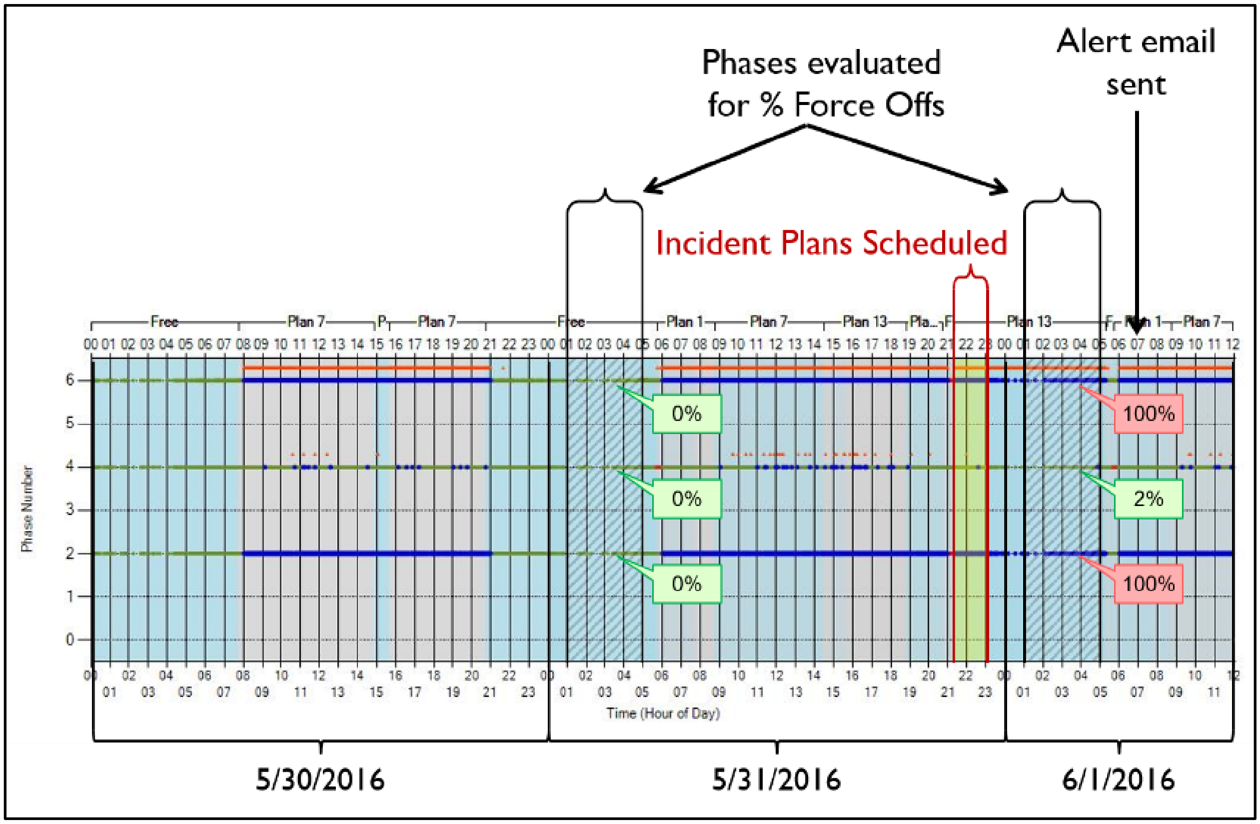


Figure 1.4 ATSPM Evaluations for Too Many Force Off Occurrences

Once it is verified that the phase in question should not be forcing off so much, check the detector status to see if there is bad detector input. These could be either the stop-bar presence zones or the advance detection zones; both must be checked. If the detector can be diagnosed remotely and cleared, the controller should then report that the constant call is no longer present and the ATSPM server will capture this change in the next log pull from the field controller. Otherwise, a field visit will be needed to further troubleshoot the detection. A stuck pedestrian button could also be a source for an intersection reporting too many force off occurrences. If the button is stuck on but the pedestrian clearance time is longer than the split time in the pattern, the phase will show that it is constantly forcing off in order to continually service the pedestrian movement. This would be indicated on the Purdue Phase Termination chart with the phase reporting force off in blue and the pedestrian active in orange constant over the time interval. This is the expected operation of the coordination phases, but any other phase or similar operation outside of coordinated operations would indicate the PED button operation as suspect.

1.1.3 Too Many Max out Occurrences

The ATSPM Alerts will evaluate signals and report phases that exceed the thresholds set for max out operations in the Watchdog Configuration. For the UDOT system, this is set at 90% max outs in at least 50 activations between 1 a.m. and 5 a.m. the same day. Reference the Automated Traffic Signal Performance Measures Component Details Section 8.6 Watch Dog (Admin Only) for additional details about the configurable parameters of the Watch Dog service.

This is the third sub-section of the ATSPM Alerts email and can assist in identifying detection errors. Figure 1.5 shows how phase 4 was evaluated after it had a constant call since the previous day. A max out is the same thing as a force off, except it occurs when the intersection is running free (no coordination). As mentioned in the force off category, there may be instances were constant max outs are normal for that signal; such as peer-to-peer operations, clearance phases, etc. Again, a note made in the Purdue Phase Termination chart may be advantageous for these intersections.

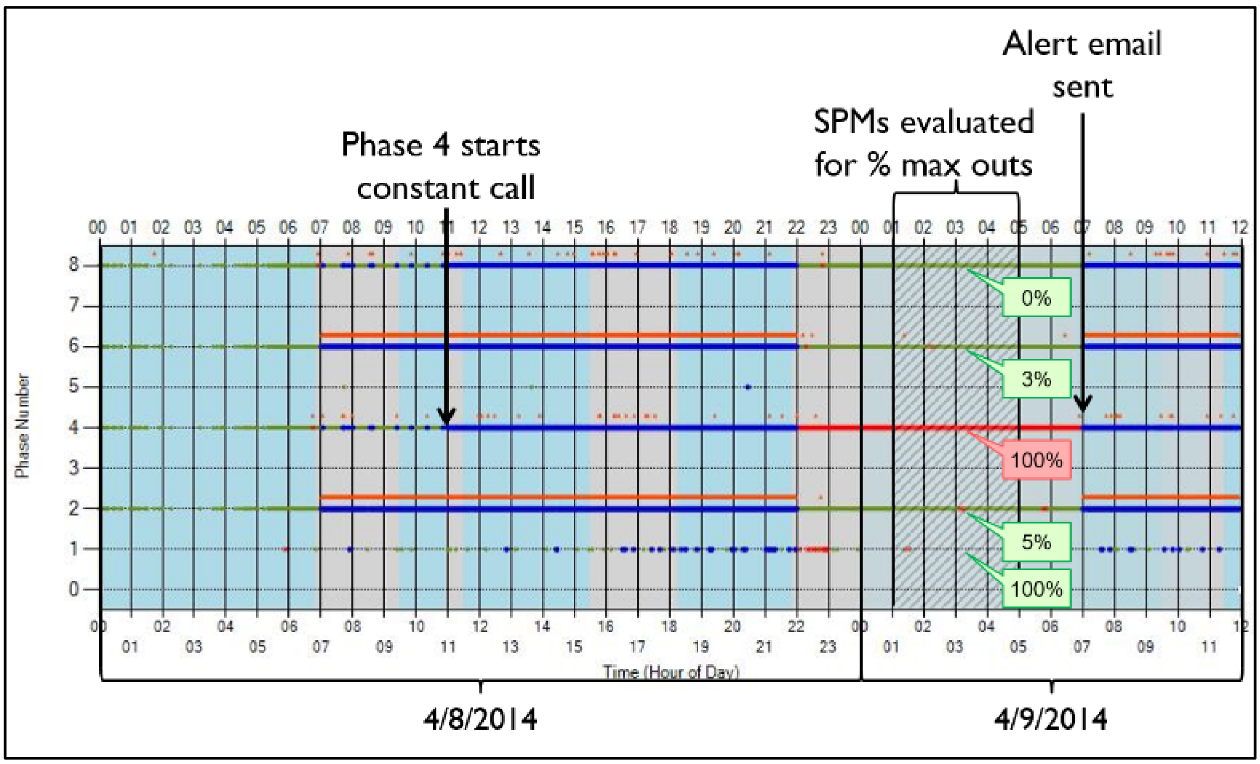


Figure 1.5 ATSPM Evaluations for Too Many Max Out Occurrences

Checking multiple day operations or intersection specific documentation about operations will confirm if the max out is a 'normal' operation or an indication of an operational concern to be addressed. A max out will either be from a MAX recall in the controller tables or a faulting phase detector. Generally, checking the controller configuration ensures that the max out condition is not a desired operation and ensures the need to verify the field detection. Status screens on the controller generally indicate if there is a detection fault or a configuration parameter that is forcing the phase to max out. Follow normal troubleshooting best practices for the detection in use at the individual intersection.

As mentioned in section 1.1.2 Too Many Force Off Occurrences, a faulting pedestrian button can also trigger this alarm. Figure 1.6 shows a situation where the pedestrian clearance time was greater than the Max1 time given to phase 8. Thus, phase 8 was constantly maxing out so that it could service the pedestrian movement every cycle. In these instances, follow the last section, 1.1.5 High Pedestrian Activation Occurrences.

There is also the possibility that a phase min recall will create a max out condition in the ATSPMs. This would occur where the minimum green time is equal to or greater than the MAX 1 time. Operational notes of these cases will assist multiple users troubleshooting the ATSPM Alerts email.

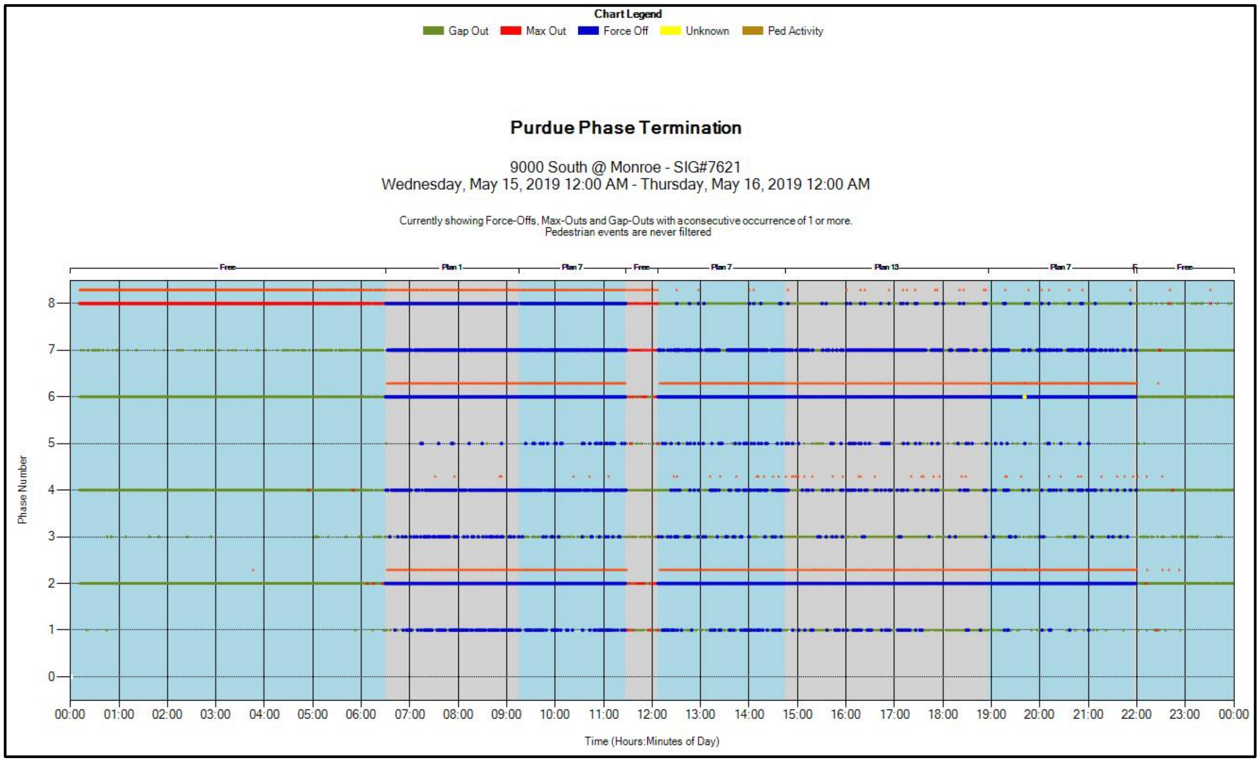


Figure 1.6 Stuck Pedestrian Button Causing Max Outs

1.1.4 Low Advance Detection Counts

This is the fourth sub-section on the ATSPM Alert email. For the UDOT system, the Low Advance Detection Counts section will report intersections where phases are configured with Advance (Dilemma Zone) detectors that have recorded less than 100 vehicles between 5 p.m. and 6 p.m. the previous day. Reference the Automated Traffic Signal Performance Measures Component Details Section 8.6 Watch Dog (Admin Only) for additional details about the configurable parameters of the Watch Dog service.

Figure 1.7 details the process used to evaluate if a sensor has low counts or not. Three main concerns generally contribute to the Low Advance Sensor count alert as described in the following sections.

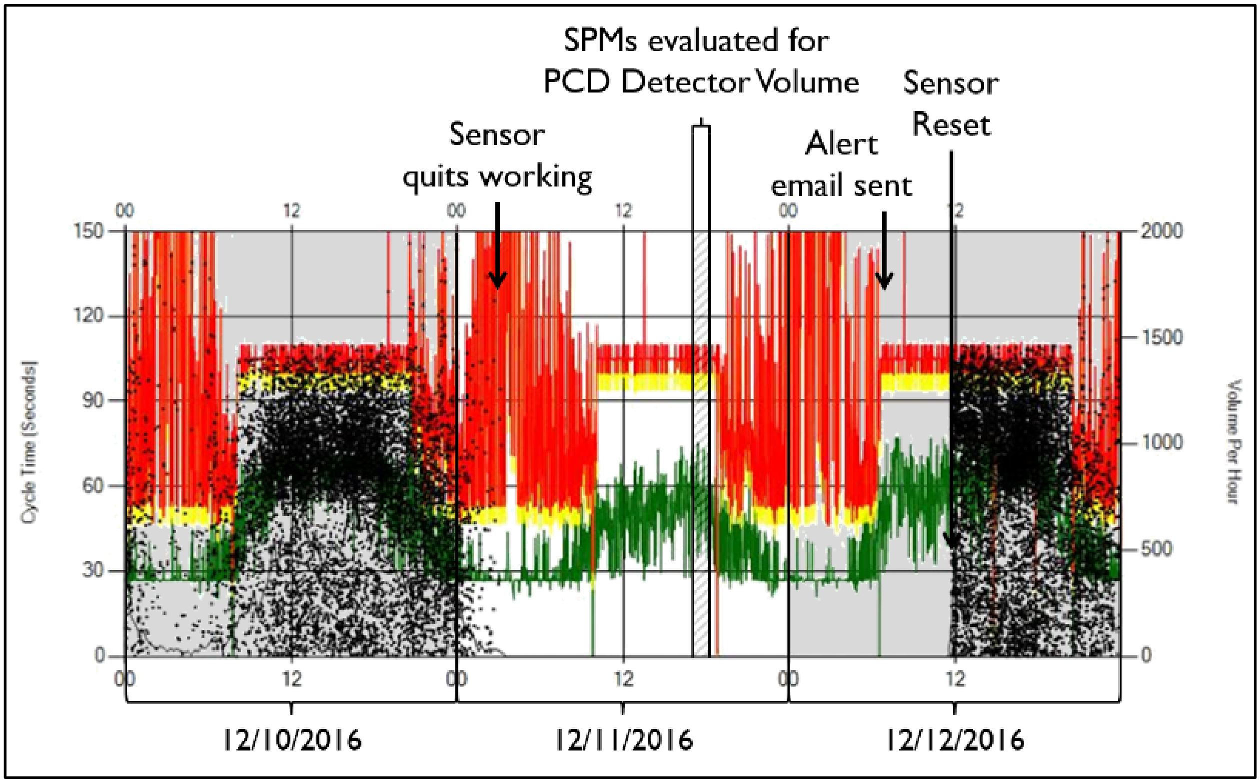


Figure 1.7 ATSPM Evaluation for Low Advance Detection Counts

1.1.4.1 No SPM Data

Once the Purdue Coordination Diagram (PCD) has been created and there are no detector activations or cycle length data, Figure 1.8, the problem resides with the signal controller, not the Advance detector.

The alert will include all phases set up for PCDs at that signal. To troubleshoot a PCD with no ATSPM data, follow the same steps found in section 1.1.1 Too Few Records in the Database as described.

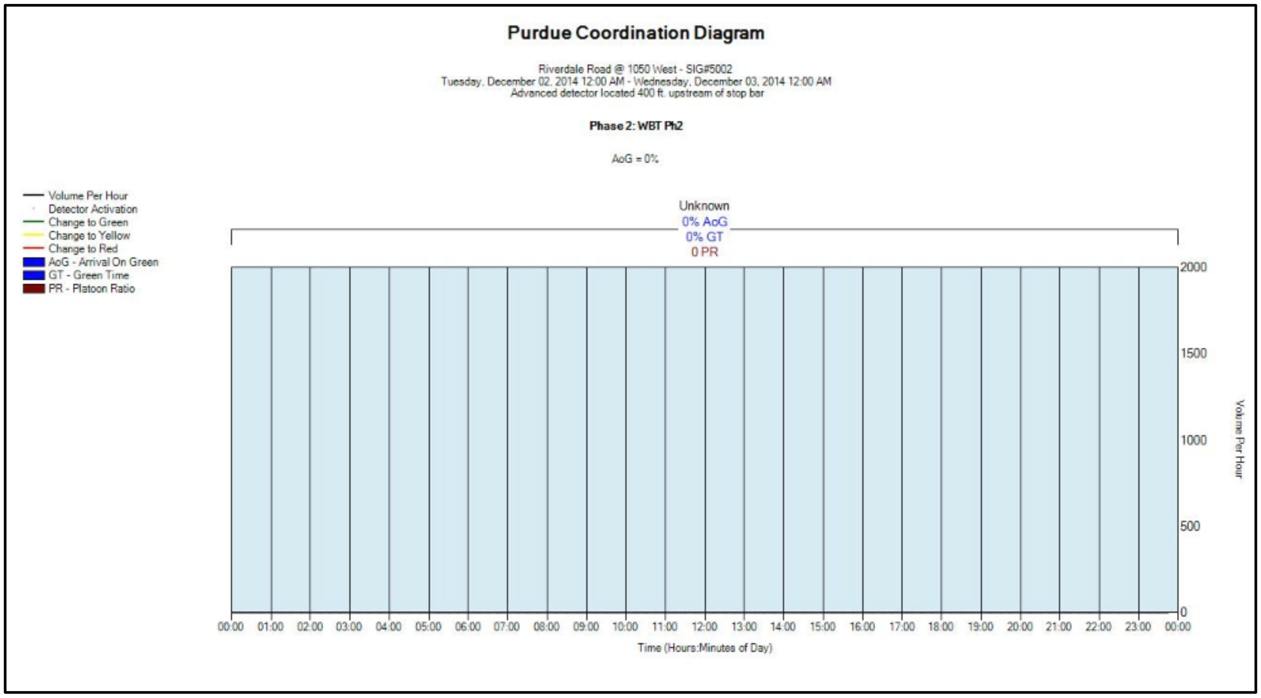


Figure 1.8 PCD with no ATSPM Data

1.1.4.2 No Count Data or Suspiciously Low Counts

In these cases, the number of activations shown for the phase in question could range from 0 to 100. The cycle length data will still be shown on the chart as seen in Figure 1.9. Troubleshooting for this scenario is more involved and includes checks of the Advance (Dilemma Zone) sensor, the controller programming, and the configuration on the ATSPM website.

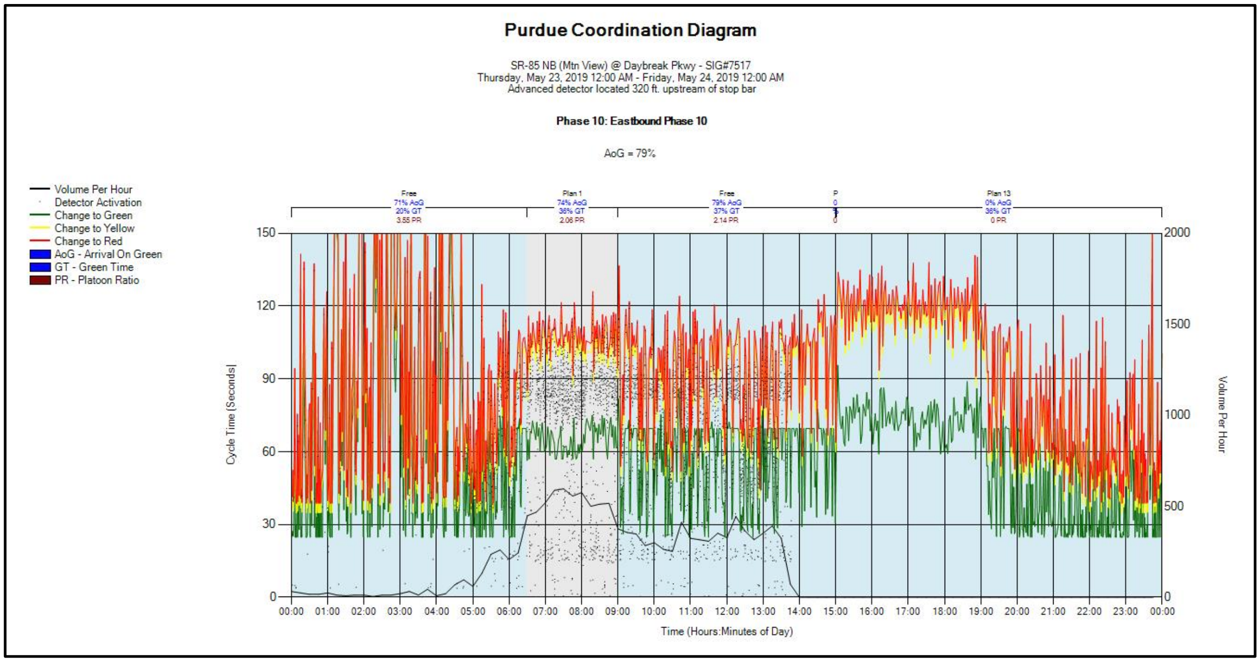


Figure 1.9 PCD with No Counts or Few Counts

1.1.4.2.1 Troubleshooting the Wavetronix Advance Sensor

First, check the connection to the sensor itself. If remote access is not possible, a site visit is required. Once inside the Advance SSM detection software, verify that the sensor is seeing vehicles and tracking them through the count zone. If the SPM alert for a phase has more than 1 activation, most likely the issue will be that the sensor is dropping the calls before and/or after the count zone, therefore not accurately recording the traffic volume data. If this is the case, try rebooting the sensor to restart the algorithm and background processes. Additionally, the SSM can re-learn and adjust the sensor thresholds through an auto-configuration utility. Generally, this needs to be done in a period of relatively steady traffic to help learn the traffic patterns as well as the background scatter to be filtered out. If there is a local CCTV camera at the intersection, these tasks can be completed remotely and verified, otherwise it best to perform these adjustments at the intersection. Additional modifications/aiming may be necessary of the field sensor to ensure that vehicles are being accurately detected and tracked through the sensors field of view.
Note: These are the same steps to follow if the Wavetronix Advance sensor is over-counting in the Purdue Coordination Diagram (PCD)

Please note that the controller must also be getting the sensor detection calls in order to be captured. Monitor the detector status screens on the controller while troubleshooting.

If your troubleshooting has successfully resolved the concern, the PCD should again start populating vehicle arrivals on the next controller log retrieval interval.

1.1.4.2.2 Troubleshooting using the Controller

On the Econolite controller, check to see that the ECPI Log is enabled for the count channel. For the UDOT configuration, the first channel in the Wavetronix Advance sensor will be the dilemma and/or queue zone presence detection, the second channel will be the count zone. The PCD is plotting the count detectors as configured in the approach phase.

There are several cases where the Wavetronix detector rack cards (172, 114, etc.) will lockup and even though the Wavetronix Advance software shows that there are detector calls being placed, they will not make it to the controller. Again, the controller must be receiving the detector calls, so monitoring the Wavetronix Advance software and the controller detector status simultaneously will ensure that there is not an issue with the detector card or detector rack.

1.1.4.2.3 Troubleshooting the ATSPM Configuration

Finally, verify that the count channel is correctly configured on the ATSPM website. The detector assignment in the ATSPM configuration must match the controller detector channel. This is a one to one relationship. If any changes have been made to the detector assignments in the field, ensure that they are also changed on the ATSPM website. It is possible to create a new version of the intersection with new detection layouts setup in the controller and the ATSPM services will correctly translate the changes between the versions and the date changes. *Careful data entry and through quality control on the ATSPM Signal Configuration is essential.* Reference the Automated Traffic Signal Performance Measures Component Details Section 8.1 Signal Configuration (Admin Only) for additional details about the versioning detector layout configurations.

1.1.4.3 No Phase Data

Occasionally when creating the PCD for a signal, a single black line and no phase data will display as shown in Figure 1.10. This is a plot of the volume data only for the approach.

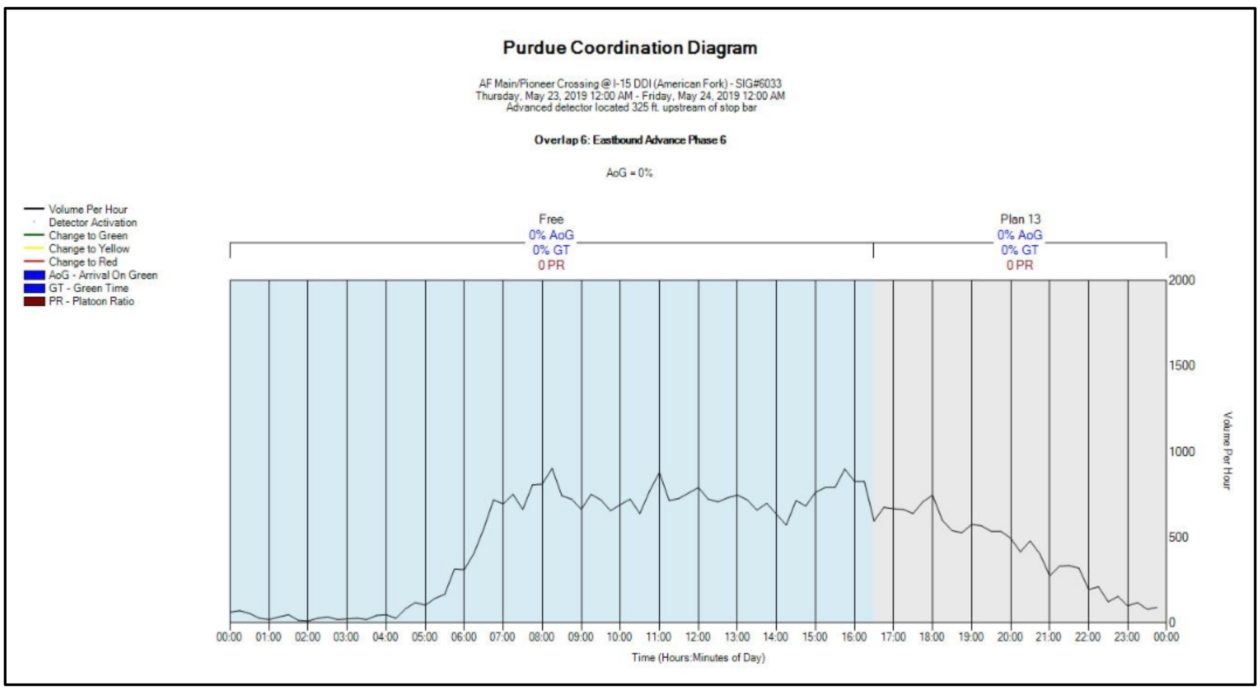


Figure 1.10 PCD with No Phase Data

If the movement in question is truly an overlap and the PCD is desired for review of arrivals – change the ATSPM phase configuration for the overlap setup to the primary parent phase where the advance detection is assigned, Figure 1.11. Some additional interpretation will be needed to capture the entire PCD for the overlap, but this will indicate the arrivals on the primary overlap phase.

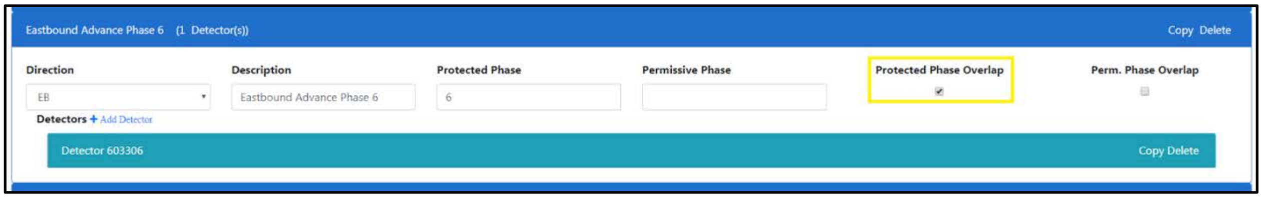


Figure 1.11 Phase Overlap Option Checked

1.1.5 High Pedestrian Activation Occurrences

The ATSPM Alerts will evaluate signals and report phases where the pedestrian activations exceed the thresholds set in the Watchdog Configuration. For the UDOT system, this this is set at 200+ pedestrian activations between 1 a.m. and 5 a.m. the same day. Reference the Automated Traffic Signal Performance Measures Component Details Section 8.6 Watch Dog (Admin Only) for additional details about the configurable parameters of the Watch Dog service.

This is the last section of the ATSPM Alert email used in troubleshooting intersection operations. Figure 1.12 shows how ATSPM evaluates these intersections for the UDOT system.

To troubleshoot this concern remotely, check the controller to see if there is a pedestrian recall. If there is no recall, check the coordination to see if the overnight pattern calls the pedestrian movement. If there is nothing in the pattern or in the recalls, check the phase and call status to see if the pedestrian call is stuck on; a field visit is required if the pedestrian call does not go away after the movement is serviced.

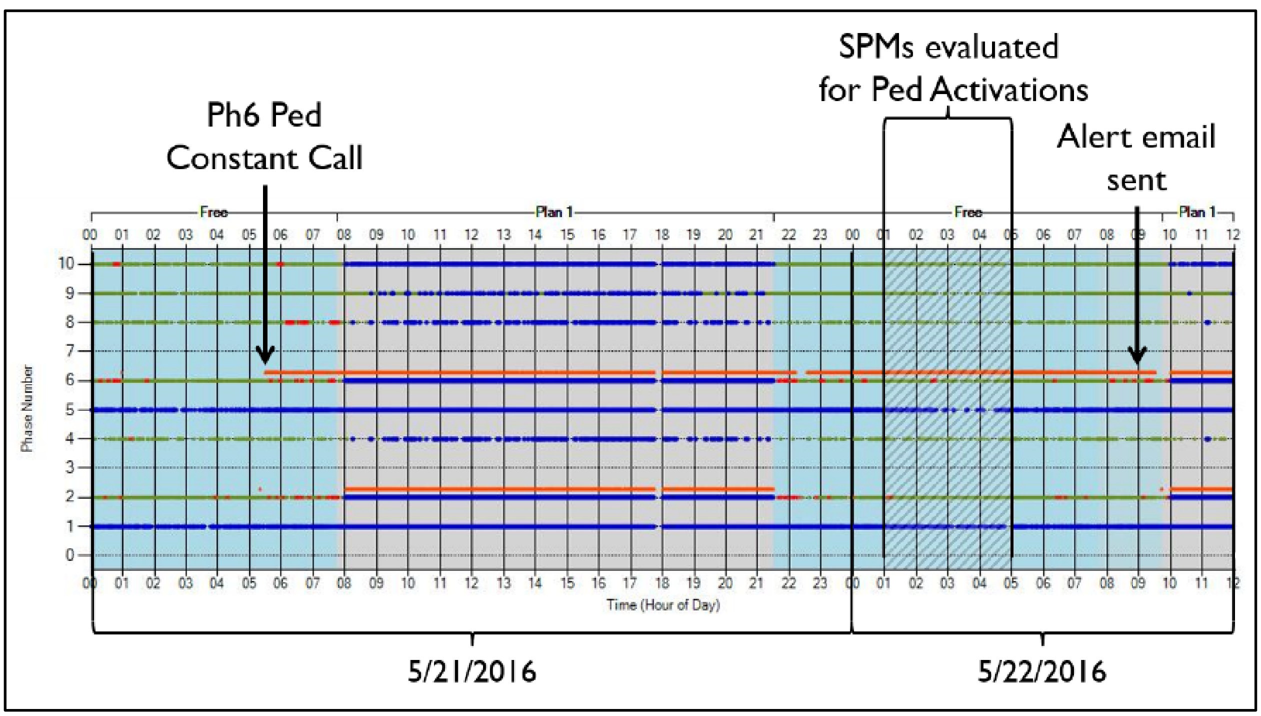


Figure 1.12 ATSPM Evaluation for High Pedestrian Activation Occurrences

1.2 Common Complaints

ATSPMs are a very helpful tool when it comes to confirming and addressing public complaints. This section contains some of the most common complaints with examples of how ATSPMs assist in evaluating the concerns.

1.2.1 Not Enough Green Time

A complaint heard quite often is, "The light doesn't stay green long enough". There are a few different operational conditions that can be evaluated to see if more split time is needed or if there is an issue with the detection.

1.2.1.1 Gap Outs

The Split Monitor chart shows the duration of each phase and the termination type; gap out, max out, or force off. A gap out occurs when the detector doesn't see any more cars and lets the phase end early so extra time can go to other phases as desired and programed by the operating agency. If a phase is showing a lot of gap outs during a time of day where there is typically heavy traffic, check the detection to see if it is dropping calls prematurely.

In one scenario, there were multiple complaints about an intersection saying that the eastbound left turn was not staying green long enough during the AM Peak. The left chart in Figure 1.13 shows that the phase was terminating after an average of 32.7 seconds and had 91.4% gap outs during the AM peak. This movement is very heavy during that time of day and that high gap out percentage did not match expectations. The detection for the eastbound left turn was not seeing vehicles and would frequently drop calls. In this case, the sensor was replaced and reconfigured for the intersection. The chart on the right side of Figure 1.13 indicates the eastbound left had significantly less gap outs (60.3%) and an average split time of 50.4 seconds.

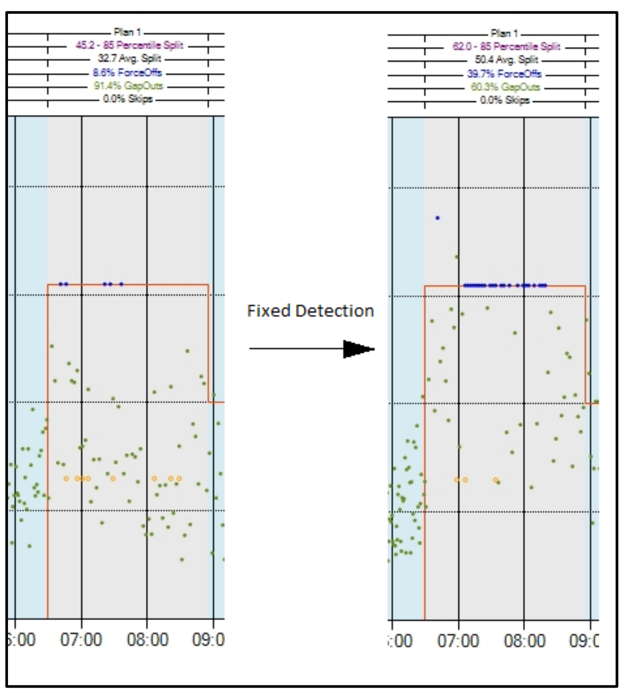


Figure 1.13 Split Monitor with Less Gap Outs

Another scenario to consider would be an analysis of the Split Monitor chart of the other operational phases to see if they are using more than their allotted split time due to oversized pedestrian operations or max out / force off conditions.

1.2.1.2 Oversized Pedestrian Movements

Another issue when troubleshooting a short green light is an oversized pedestrian movement. An oversized pedestrian movement occurs when the split time is less than the needed pedestrian clearance time. For example, a relatively light vehicle phase is allotted a 20 seconds split time; however, the pedestrian clearance time totals 30 seconds requiring 10 seconds be taken from another movement. An oversized pedestrian movement has uses in traffic operations. Using ATSPMs, the frequency of pedestrian actuations and services is measured and the operational benefits can be measured against the impacts.

The split monitor chart is very useful in seeing an oversized pedestrian and how much it affects the impacted movements split time. Figure 1.14 shows two movements at an intersection; phase 1 is a left turn and phase 4 is a thru. Anytime that phase 4 had a pedestrian actuation (yellow dot), phase 1 was shortened to about 10 seconds long. This became an issue because the number of pedestrians increased dramatically since the last intersection retiming project and phase 1 continued to be a heavy left turn movement that needed a longer green.

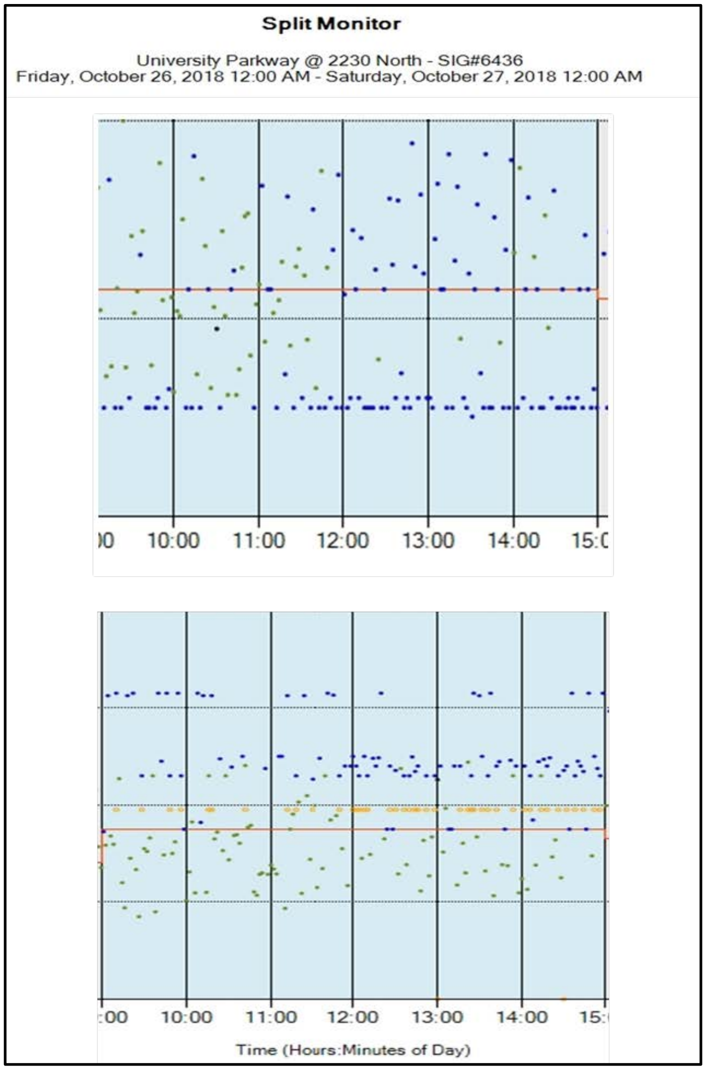


Figure 1.14 Split Monitor Oversized Pedestrian

1.2.1.3 Split Failures

The Purdue Split Failure chart is another useful tool to diagnose if the light needs to stay green longer. The yellow lines on the graph show each time the detector still had a call when the movement terminated. Note: if a detector has a stuck call, it will have split failures every cycle until the call goes away.

In the example illustrated in Figure 1.15, the top chart indicates the westbound left turn failing to clear multiple times throughout the day. After the intersection was re-timed, there were significantly less split failures as indicated in the bottom chart.

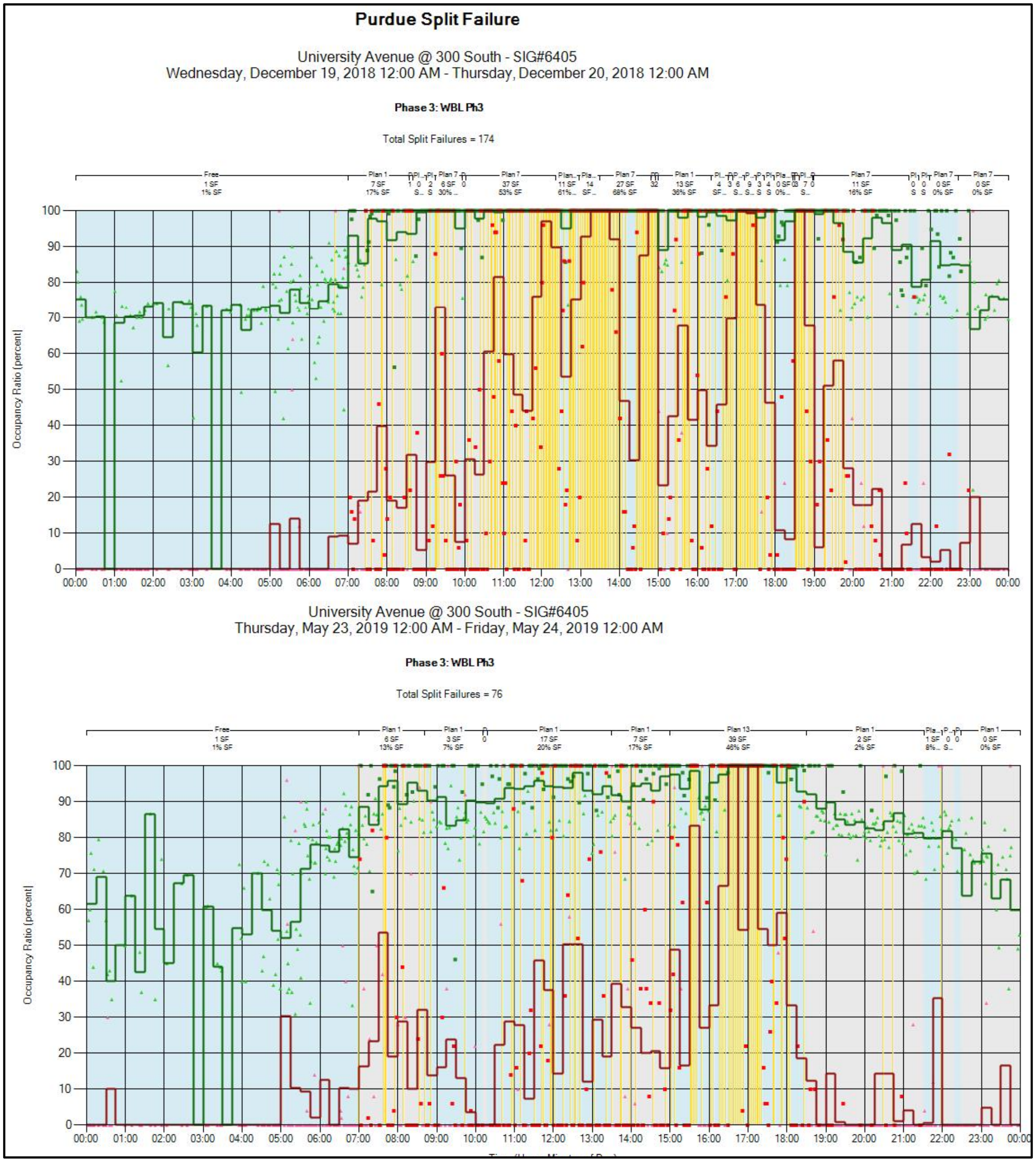


Figure 1.15 Purdue Split Failure Example

1.2.2 Skipped Movement

Another common complaint is, “the light changed green for everyone else except me”. The Split Monitor Chart shows how many skips a movement had during different periods of the day. This is useful, especially when someone says they get skipped a lot during a specific time of day, but not all the time. When a movement is skipped, the biggest culprit is the detection.

In the example illustrated in Figure 1.16, a movement reported skipping 12.2% of the time during the AM peak. After the detection was adjusted, the movement had 0% skips. The ATSPM data is the tool to use in before and after studies of operational changes.

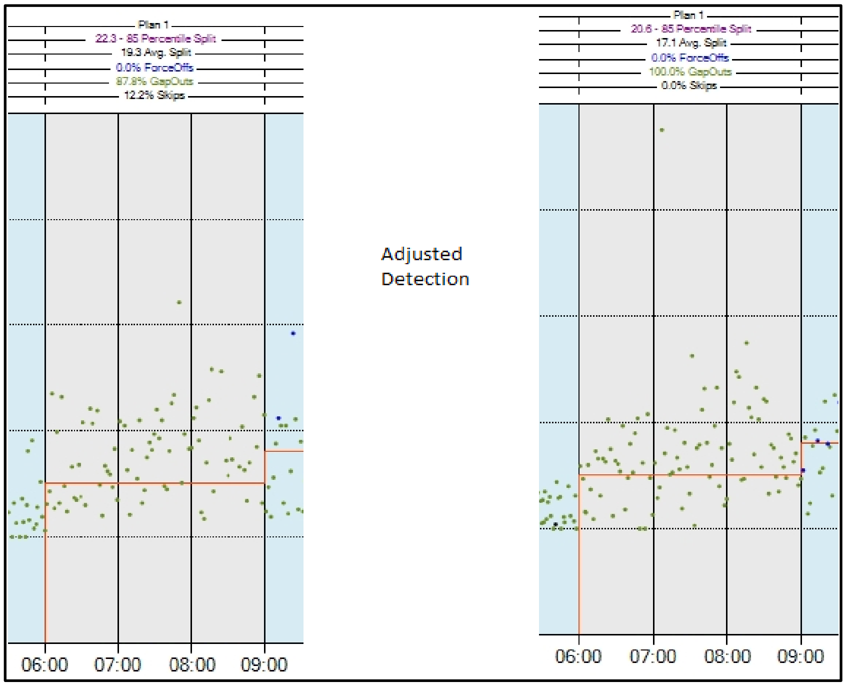


Figure 1.16 Split Monitor Skipping Example

1.2.2.1 Erratic Detection – Sporadic Turning Movement Counts – Georgia Example

The Turning Movement Count chart can also be a good indication of the detection operation of an intersection. Figure 1.17 details the use of this metric using the chart to assist in coordination decisions, but exemplifies the sporadic volume shifts for the approach.

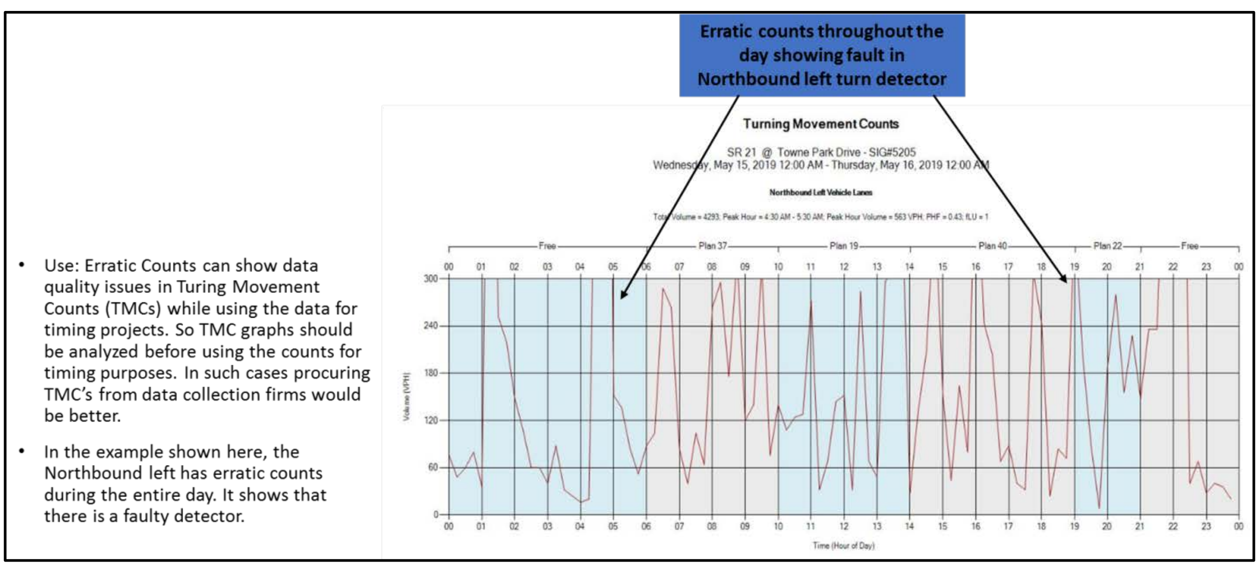


Figure 1.17 Turing Movement Count with Erratic Volumes - GDOT

Figure 1.18 details an approach with more reliable turning movement count data – in turn representing more reliable detection operations.

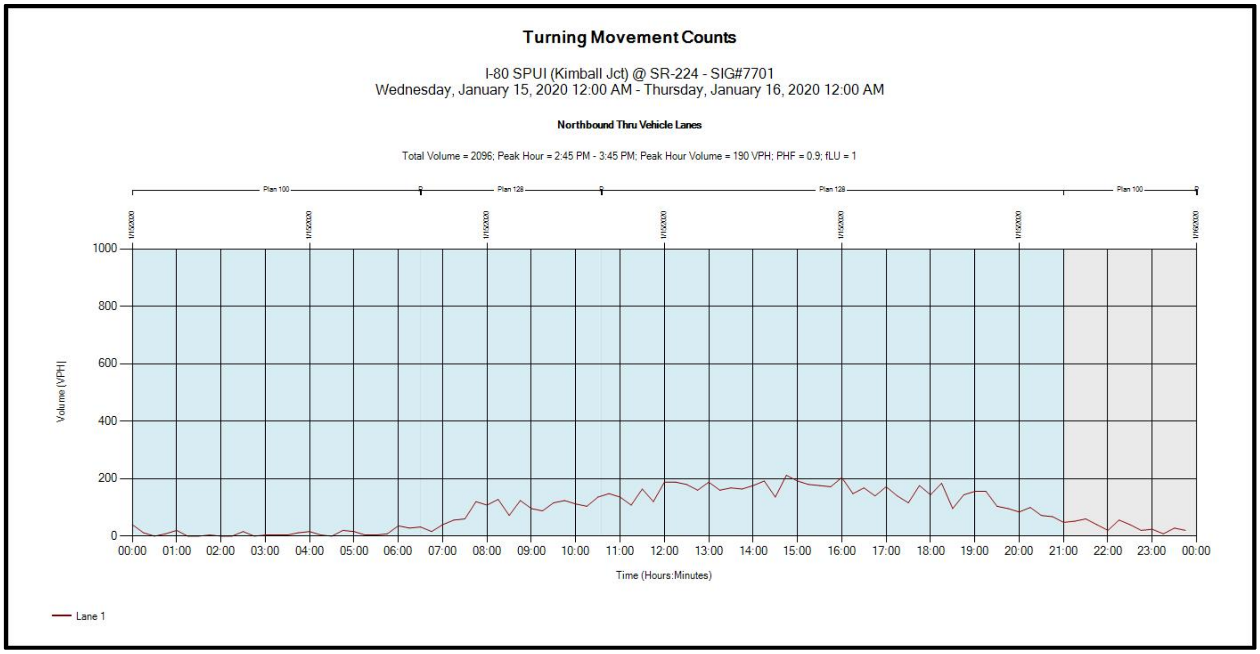


Figure 1.18 Normal Turing Movement Count Volumes

1.2.3 Staying Green and No One is there

Another frequent complaint is, “the light stays green for an opposing movement but no one is there.” ATSPMs can assist in diagnosing this complaint prior to sending a technician to the field to make repairs. Below are some common sources with examples of how ATSPMs can be used to identify the root cause of the complaint.

Section 2 Signal Coordination contains some additional information that can be useful in analyzing the coordination operation. Sizing the coordination window appropriately for the demand at the intersection can aid in improving the overall operation of the intersection.

1.2.3.1 Stuck Detection

Stuck detection might be the easiest to diagnose since it is very obvious on the Purdue Phase Termination diagrams. These will report as either a Max Out (Red indication) or Force Off (Blue indication) for all periods of operation across multiple days, back to the initial fault occurrence.

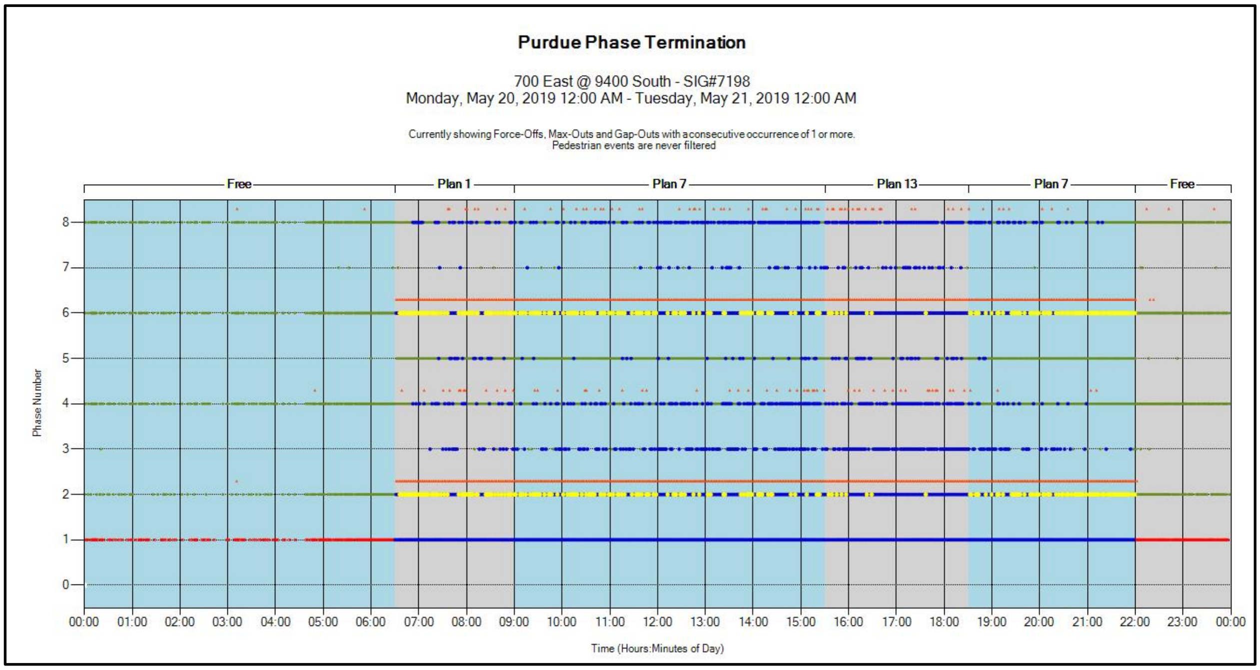


Figure 1.19 Stuck Detector Causing Complaints

Figure 1.19 shows an example of a complaint that the southbound left turn (Phase 1) was constantly coming up but no one was there. The complaint was definitely valid and a field visit was required to fix the detection.

As mentioned in section 1.1.3 Too Many Max Outs, always check for phase recalls first before assuming that it is a stuck detector. The troubleshooting steps in that section apply to this as well.

This has also proved beneficial to track back to when a detector began to fault, helping assign responsibility in making repairs to undocumented detection hits.

It's important to make sure all of the equipment is functioning properly, especially detection equipment. Figure 1.20 shows an example below from Pennsylvania. In this example, we can see a loop on the side street was broken around 7:45 AM because the side street phase started running to the maximum time. Even worse, the max time was programmed at 52 seconds which was very long for a small borough with this two phase intersection.

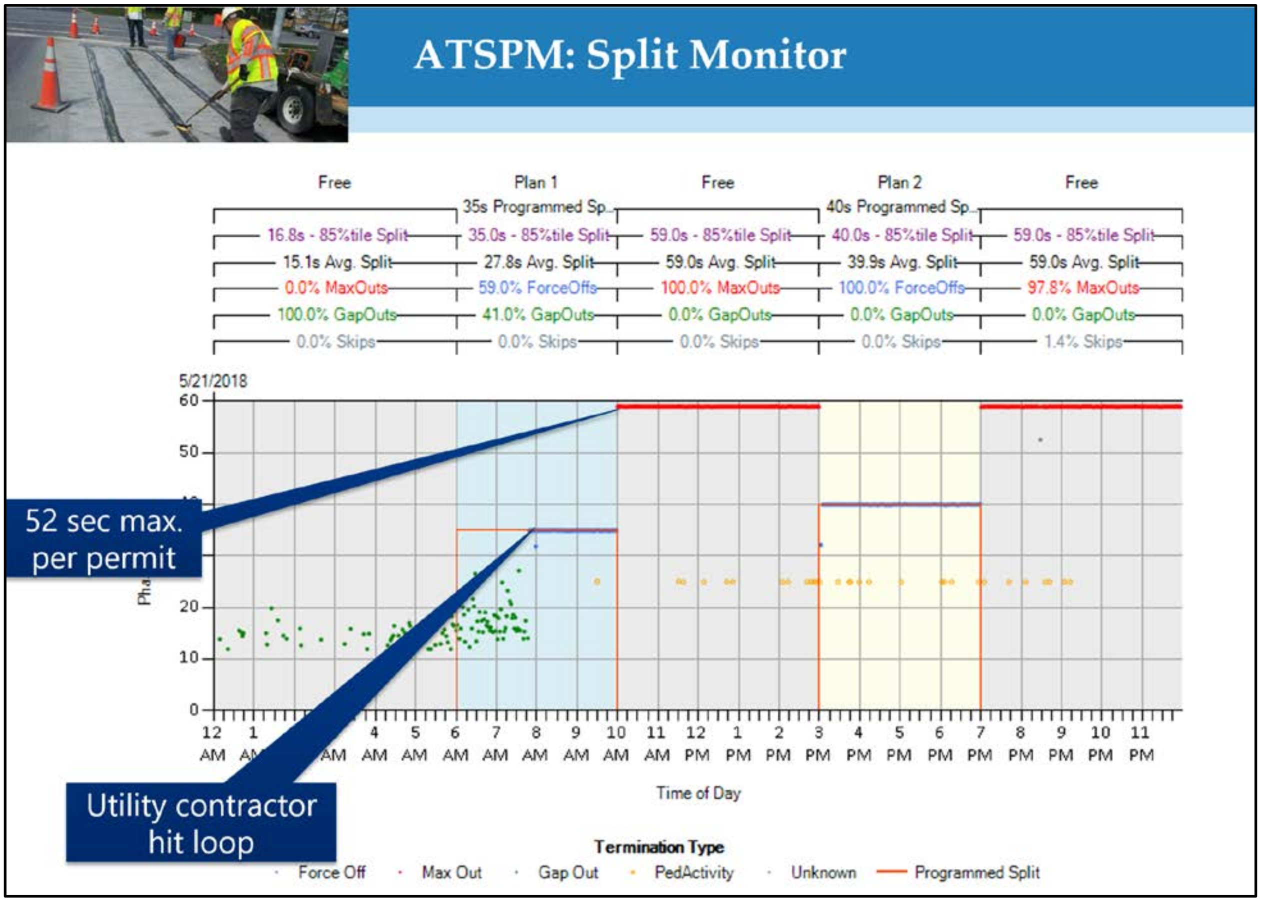


Figure 1.20 Detection Destroyed with Large Maximum Green Time – PennDOT

1.2.3.2 Stuck Pedestrian Button

A common cause of a phase staying green when no one is there is a stuck pedestrian button. With the help of the ATSPM Alert email, a lot of these are avoided since they can be seen with the Too Many Force Offs section, Too Many Max Outs section, and of course the High Pedestrian Counts section.

Notes in the ATSPM charts can also be used to notify users of a pedestrian recall due to a damaged pedestrian pole or construction. Just ensure the notes in the charts remain current.

1.2.3.3 BIU Errors

Figure 1.21 shows all phases maxing until about 10:00am. In this case, all of the movements were on the same source detector BIU device that had failed. Using the controller status in addition to ATSPMs to validate the concern, the root cause was found and repaired. These types of failures almost always require someone to visit the intersection to repair.

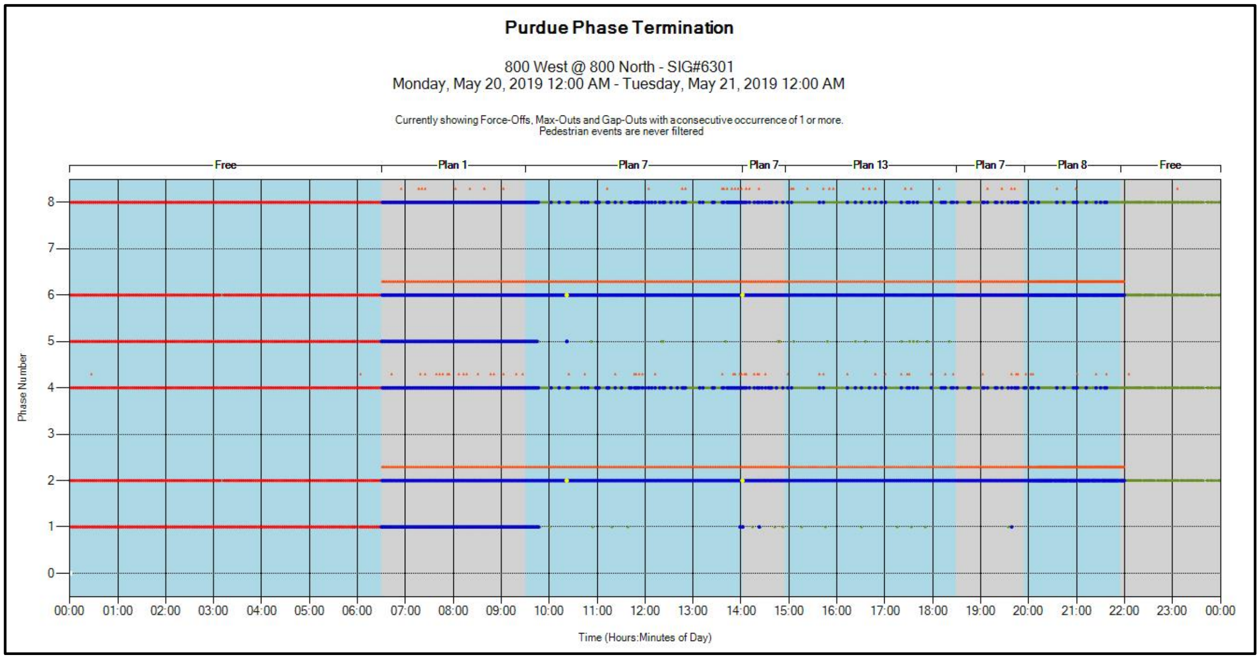


Figure 1.21 Detector BIU Error

1.2.3.4 Advance Sensor Over-counting

If a movement is maxing out in the Purdue Phase Termination diagram and there is no indication of problems in the stop-bar detection, consider looking at the Purdue Coordination Diagram. When an Advance Sensor is over counting, it will place nearly constant calls in the controller when there aren't any vehicles there. Figure 1.22 shows an Advance Sensor that is over counting. This affection "black blob" is causing the approach to max out. After remote troubleshooting of this device around 10:30 a.m. the count data became more realistic and the movement stopped maxing out. See section 1.1.4 -Low Advance Detection Counts to address concerns with issues related to the Wavetronix Advance sensor over-counting.

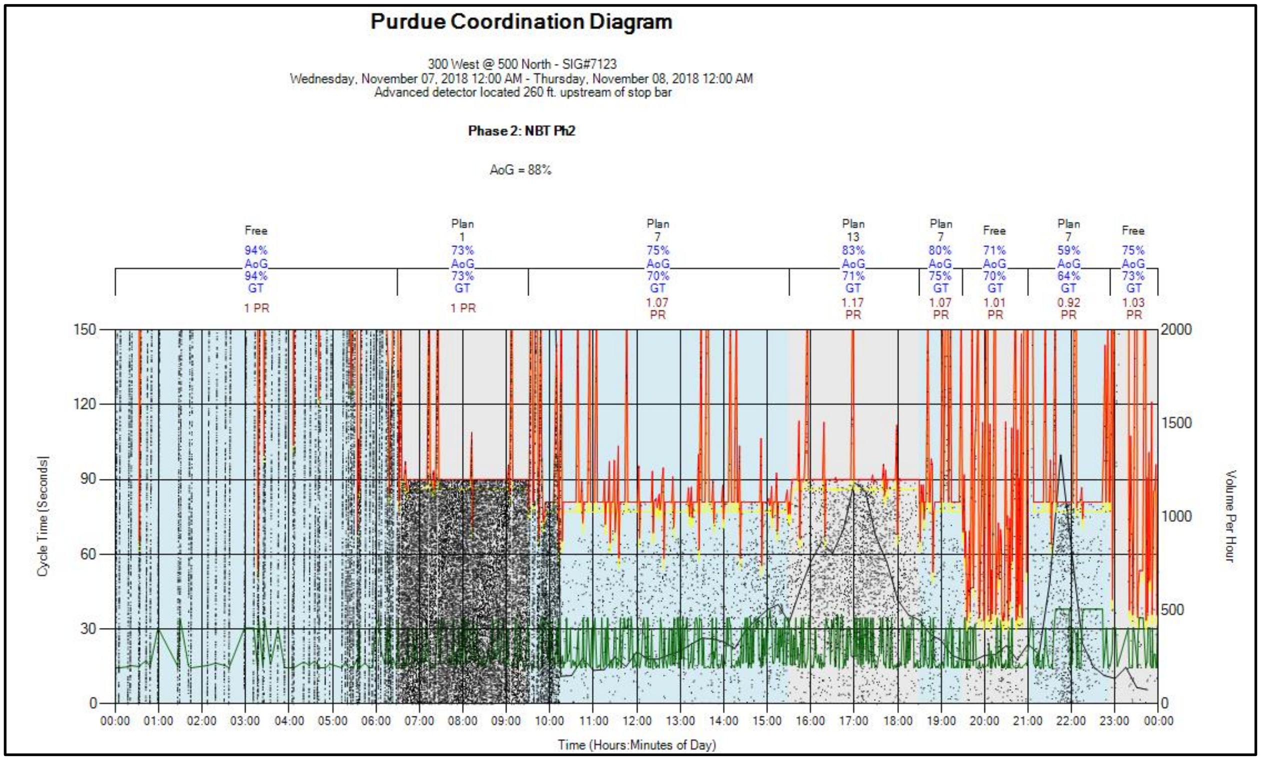


Figure 1.22 Over counting Advance Sensor

1.3 Controller Operational Analytics

1.3.1 Crash Reconstruction

UDOT's strategic goals are zero crashes, injuries and fatalities; optimize mobility; and preserve infrastructure. UDOT is committed to safety, and we won't rest until we achieve zero crashes, zero injuries and zero fatalities. With our goal of improving safety, transportation professionals look for ways to collect data, such as crash data, geometric data, roadway characteristic data, high crash location lists, complaint letters and perform traffic & safety studies. The goal with this and similar data is to look for engineering countermeasures to make the facility or intersection safer. Such countermeasures may include such items as intersection and phasing warrants, installing dilemma zone detection, curve warning signs, advance warning signs, etc.

The ATSPMs record just about every change the traffic signal controller makes to the 1/10th of a second, and as a result have been called "high-resolution data" because they represent controller states at the smallest possible time resolution, in comparison with aggregate measures generated over 20-second or longer intervals. As a result of the high-resolution data that is available and that the hi-resolution will record vehicle and pedestrian detector events with an "on" timestamp and an "off" timestamp, it's now possible to reconstruct some crashes quite accurately; that is dependent on the accuracy and latency of the detectors, the amount of detectors, and if the detectors are on independent channels or not. In addition, the time-of-day can play into it as it can be easier to see the data from the crash during times of day when the traffic signal volume is light. Being able to reconstruct some crashes with signal timing and phasing detail can assist agencies in determining appropriate engineering countermeasures. For example, if red light running is a concern during the first 1-2 seconds of the red, then appropriate countermeasures may include providing more green time so queue failures are minimized, installing dilemma zone detection, identifying locations and times-of-the day where the problem is occurring and requesting local police to step up law enforcement – and/or install tattle-tale red confirmation lights to assist them. If severe red light running is occurring, then appropriate countermeasures may include making the traffic signal heads more conspicuous (yellow transparent tape around backplates, brighter LED's, dual red LED's, additional traffic signal heads) or improving the coordination so drivers stop less on red lights.

Detector Latency

All vehicle detectors have some inherent latency before it gets to the signal controller and gets time-stamped. For example, the Wavetronix Matrix smartsensor in Figure 1.23 Detector call path explaining various points of potential latency below - a vehicle is first detected in the Wavetronix Matrix detector zone. Then, the Matrix detector zone passes the call to the Wavetronix detector cards or Wavetronix Click 650 device, which in turn passed the call to the signal controller where it receives a time-stamp that it turned the zone on. The same process is followed for turning the zone off. UDOT conducted a small study (https://udottraffic.utah.gov/ATSPM/Images/WavetronixMatrixLatencyInformation.pdf) of the Wavetronix Matrix detection latency and found it to vary between 0.89 seconds and 1.82 seconds with a mean latency of 1.24 seconds and a standard deviation of 0.31 seconds. UDOT has not tested other detector technologies (i.e. inductive loops, video, magnetometers, etc.) but would estimate some amount of latency in the system. Bottom line, due to the variableness of latency with detectors (and it's not consistent by approach even with the same technology), caution should be used in using ATSPMs to reconstruct crashes to a resolution less than its maximum latency. For example, ATSPMs may be used to reconstruct crashes for severe (i.e. >4 seconds) red light running but it should not be used in trying to identify if the vehicle exited the detection zone during the last split second of yellow or the very beginning of red.

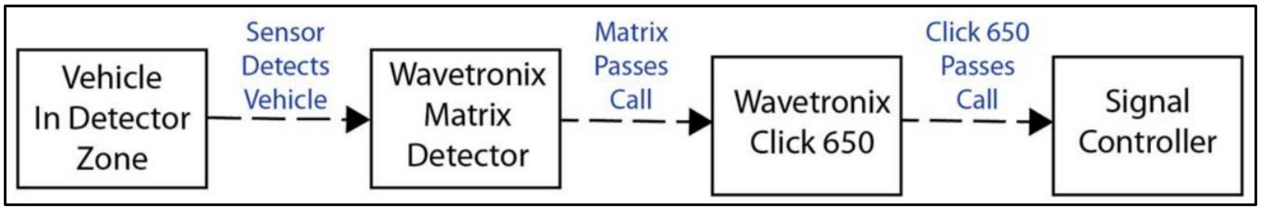


Figure 1.23 Detector call path explaining various points of potential latency

In analyzing crash data, the Timing and Actuation metric is quite beneficial if a 911 call time is known. If not, sometimes the Purdue Phase Termination metric or Split Monitor can be of use to identify the approximate time when phases start to max out. The premise is that when crashes occur, vehicles stop moving through the intersection, and as a result, park over the vehicle detection zones causing the phases to go to maximum green. Most crashes occur before max outs first start to appear, especially during off-peak hours.

It's also helpful to know the type of vehicle detection, placement or location of the detection zones and the detection zone size. In addition, it's important to know if the detector type is presence or pulse. In Utah, the stop bar detectors are presence and the upstream Wavetronix Advance radar sensors are pulse. Vehicles have to be moving for pulse detectors to log data. Presence detectors will remain active (on) during the time the vehicle zone is occupied, regardless if the vehicle is moving or not.

Shown below are a few case examples of using ATSPMs and reconstructing crashes.

Example 1: Vehicle vs Vehicle – March 25, 2018 ≈ 11:32 AM – Signal # 7052 – Bangerter & California

On March 25, 2018 at approximately 11:32 AM, a vehicle was traveling eastbound along California Ave and collided with a northbound vehicle. Several questions were asked:

1) Who ran the red light?
2) How long was the light red?
3) How long was the light green for the other direction?
4) What time did the crash occur?

Evaluating the Timing and Actuation metric on March 25, 2018 between 11:30 AM and 11:40 AM (10-minute window) for phase 2 northbound and phase 4 eastbound, several items are noted.

- Phase 4 eastbound skipped a cycle (i.e. no vehicle demand) around 11:32 AM, and last turned red at ≈ 11:30 AM and then green again at ≈ 11:34 AM. Phase 4 eastbound was red for ≈ 4 minutes.
- Phase 2 northbound did not skip any cycles, and this is due to phase 2 being on minimum recall, which is typical for Utah intersections.
- Phase 4 eastbound had a detector on/off (Note: the black triangle is the detector turning on and the transparent square is the detector turning off) between 11:32:30 AM and 11:33:00 AM from the stop bar presence through lane 1 channel 15 detection zone. At approximately the same time, there is vehicle activity turning on/off the pulse detector zone on phase 2 northbound that is located ≈ 400 feet upstream of the intersection. This is the most likely time of the crash.

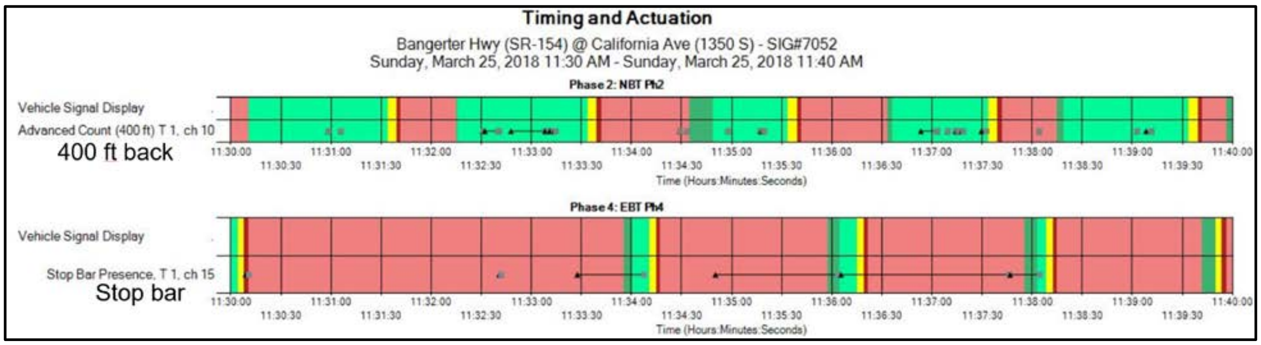


Figure 1.24 Timing and Actuation Metric - 10 minute window of analysis

The timing and actuation metric is designed for detail and is written to analyze things on mesoscopic and microscopic level of analysis. Figure 1.24 is the same information in Figure 1.25, except that the time scale is from 11:32:00 AM to 11:33:00 AM (1-minute window). From this level of detail, the eastbound through vehicle ran the red light turning on the detection zone at ≈ 11:32:41 AM and turning it off at ≈11:32:42 AM. The Eastbound through vehicle ran the red light where it had been red for ≈ 2 minutes and 34 seconds. Northbound through had the green light that turned green ≈ 26 seconds prior to the crash. The crash occurred at ≈ 11:32:42 AM.

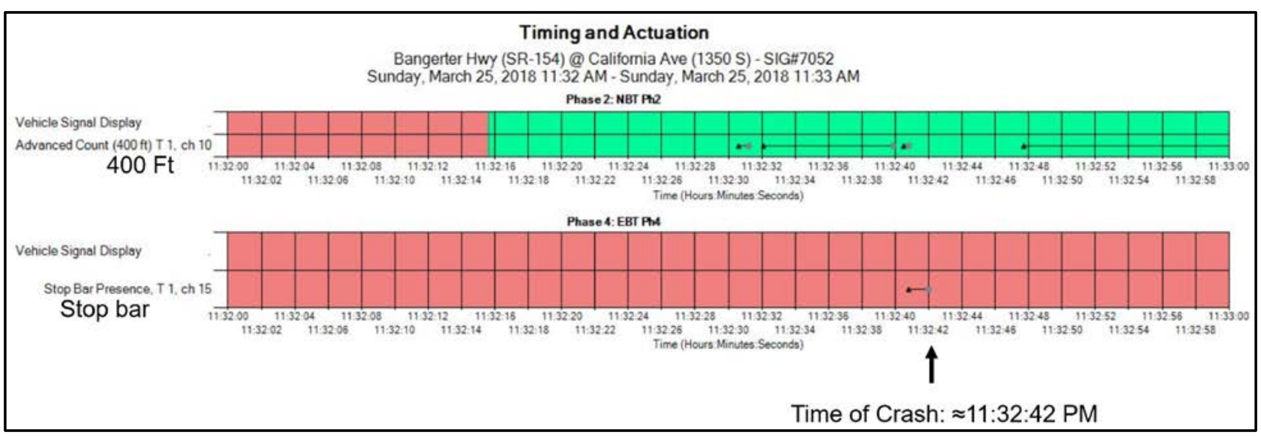


Figure 1.25 Timing and Actuation Metric – Bangerter & California - 1 minute analysis between 11:32 AM and 11:33 AM

Example 2: Vehicle Vs Vehicle – April 24, 2019 ≈ 8:15 PM – Signal #: 7526 - Mountain View & 6200 South

This crash was quite simple to analyze. The 911 call was ≈ 8:15 PM. Evaluating the Timing and Actuation metric between 8:13:30 PM and 8:15:30 PM (2-minute window) for the southbound intersection at Mountain View & 6200 South, it's clear in the data that the westbound through phase 2 ran the red light in the through lane #1 on detector channels 27 & 30 at ≈8:14:32 PM, striking a southbound vehicle also in lane 1 on detector channels 17 & 19. The southbound light was green for ≈ 21 seconds and the westbound light was red for ≈ 24 seconds prior to the crash. The data also shows that there was a witness on the eastbound through phase 6 approach in lane 3 who arrived ≈ 19 seconds before the crash.

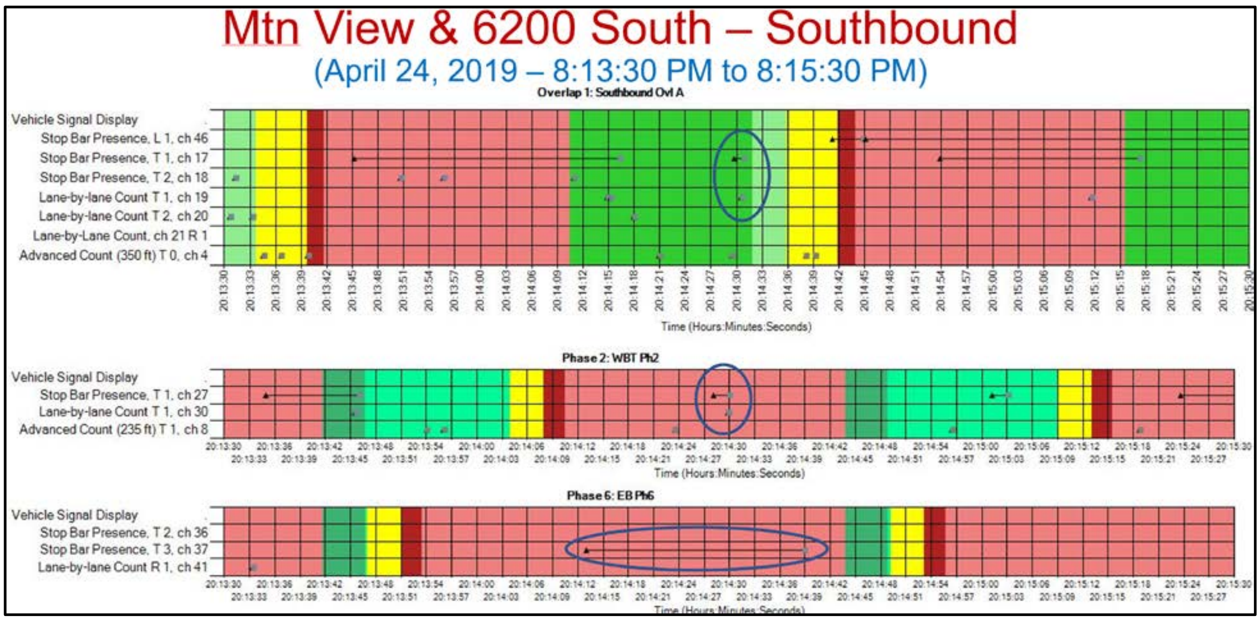


Figure 1.26 Timing and Actuation - Signal #7526 – Time range: 8:13:30 PM to 8:15:30 PM

Example 3: Vehicle vs Pedestrian – Mountain View & Rosecrest – Signal # 7510 – August 23, 2019 ≈ 1:21 PM

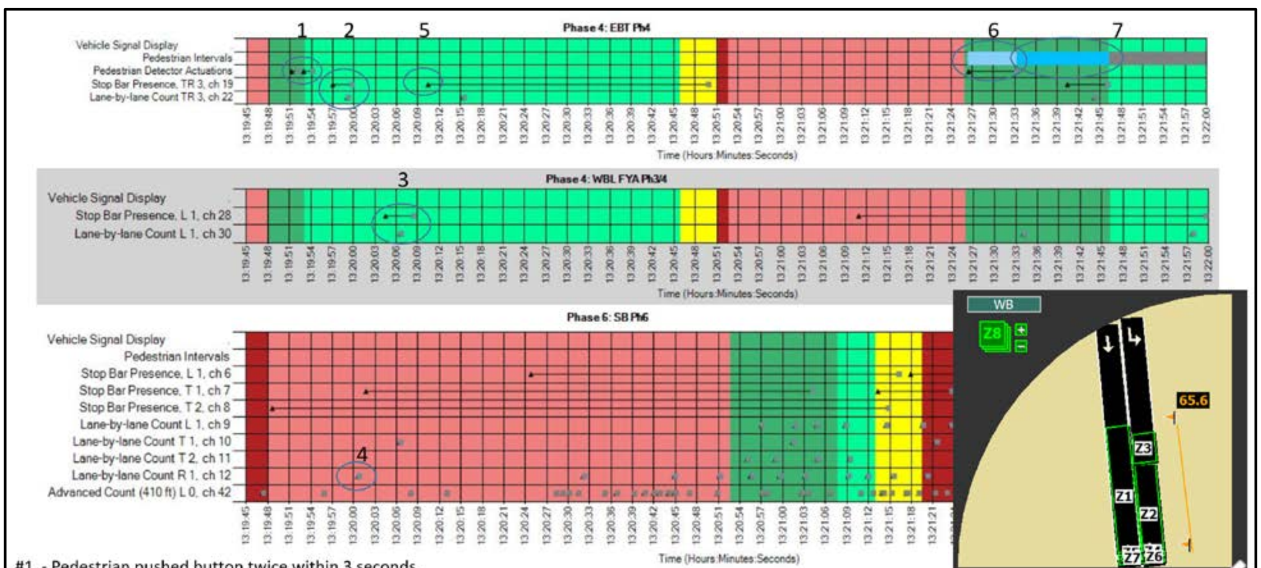
At this signal, a pedestrian was crossing along the south leg crosswalk starting on the southwest corner by the signs and was struck by a vehicle making a westbound to southbound left. Figure 1.27 shows a Google street view of the location. The driver of the vehicle claims that they had a green arrow. The pedestrian stated that the pushbutton was pushed.

Questions to answer:

- Did the pedestrian push the pedestrian button? If so, when?
- Did the left turning vehicle have a green arrow like what was claimed?
- Did the pedestrian cross during the pedestrian phase of the signal?

- What's the location and time of any witnesses at the intersection?

Figure 1.27 Mountain View & Rosecrest Dr - Google Map view looking west



#1 - Pedestrian pushed button twice within 3 seconds.
#2 – EB vehicle in the through right lane. Triangle on ch 19 is when the 70 ft zone was turned on; square when it turned off. Ch 22 is the count zone at the stop bar.
#3 – WB to SB left turn had a flashing yellow arrow and crashes into pedestrian. Ch 28 is the 50 ft zone (Z2) and ch 30 (Z6) is the small count channel at the stop bar.
#4 – Witness who was traveling SB in the right lane witnessed the crash, she made a quick U-turn and activated EB through/right zone (#5).
#5 – Witness who activated the 70 feet EB Through Right Lane zone at 13:20:10.
#6 – When the "walk" turned on for the south leg crosswalk.
#7 - when the countdown turned on for the south leg crosswalk.

Figure 1.28 Timing and Actuation – Signal # 7510 – Time Range: 1:19:45 PM to 1:22:00 PM

From Figure 1.28, the pedestrian did push the button and pushed it twice within 3-seconds between 1:19:51 PM and 1:19:54 PM. However, just a few seconds after the button was pushed, a vehicle was traveling eastbound. The pedestrian most likely waited for this eastbound vehicle (as well as the driver making the westbound to southbound left turn). As soon as the eastbound vehicle cleared, the pedestrian started to cross and the left turning vehicle started to go. The pedestrian was crossing during the appropriate green phase, however, the pedestrian signal indication was a solid don't walk, as the walk indication didn't come on until ≈ 1:21:27 PM. According to police, the witness who saw the crash was traveling in the southbound right turn lane and then flipped a U-turn and parked in the eastbound through /right lane 3 taking the signal timing out to its maximum green. The left turn driver did not have a green arrow but had a flashing yellow arrow.

1.3.2 Controller & MMU Operation Reconstruction

The Timing and Actuation metric is not only beneficial for crash reconstruction, but is also of use in troubleshooting signal phasing and timing problems. For example, at the intersection of Washington Blvd & 4400 South on November 28, 2019 (signal # 5178), we were experiencing a recurring flash event where the MMU would show Yellow+Red Clearance Fault on Channel 1 and 13 (Phase 1 FYA with Flash landed to 13 Green) at 9:13 AM. Evaluating the Purdue Phase Termination metric, it appeared to be operating correctly and detection was working as seen in Figure 1.29.

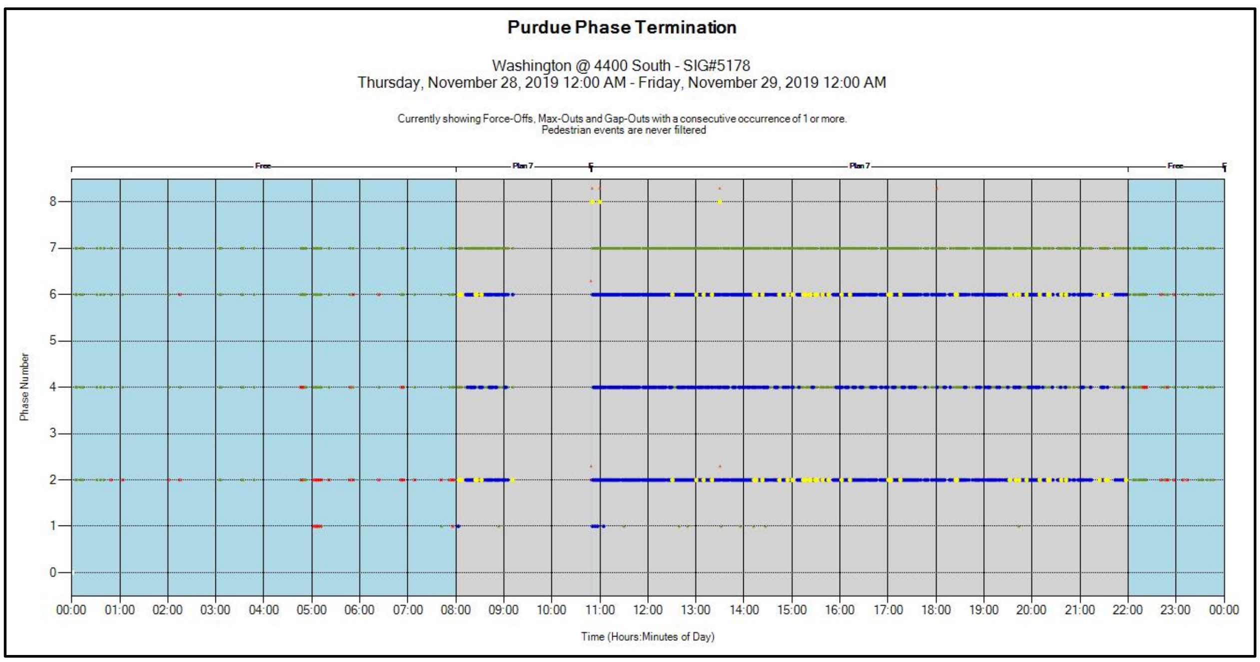


Figure 1.29 Purdue Phase Termination - Signal #5178 – November 29, 2019

Evaluating the Timing and Actuation metric in Figure 1.30 for the 15 minute interval prior to the flash event, we found that at time of the flash event, the signal terminated phase 2 to serve phase 1 demand without going to the side street phase 4. This should not have been a conflict in the operation. Verification was made by pulling smart monitor logs that no conflict existed. Reconfiguring the malfunction management unit resolved the issue.

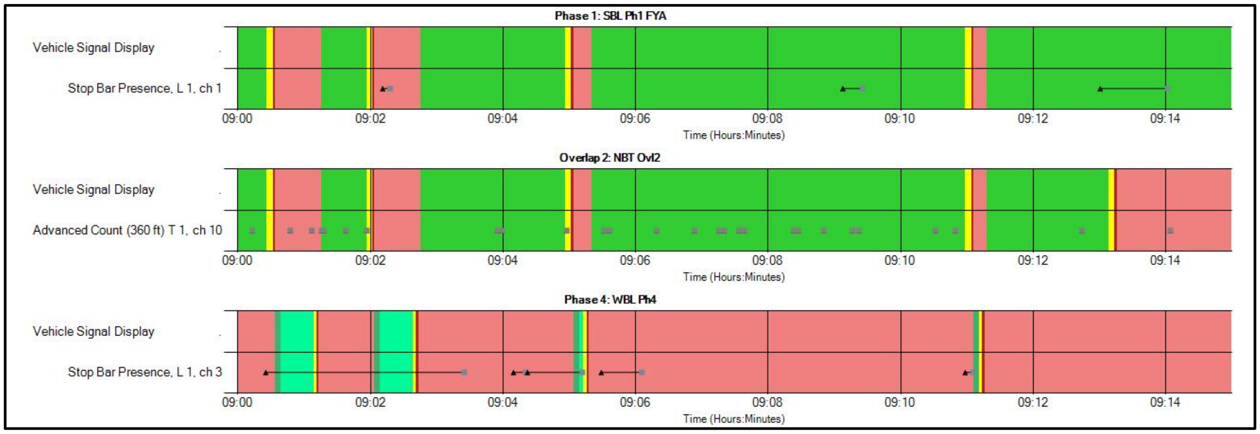


Figure 1.30 Timing and Actuation – Signal #5178 – November 29, 2019 9:00 AM to 9:15 AM

1.3.3 Operational Performance – Salt Lake City Example

Included in the Timing and Actuation metric is the ability to analyze custom codes that are available in the enumerations. This example shows using this metric with a full day of data rather than a small subsection. Salt Lake City transportation professionals recently retimed several intersections and provided some coordination split times that were smaller than the minimum pedestrian intervals with the assumption there were not many pedestrians and the intersection could recover quickly. They found that the intersection was in transition more than desired. By running the Timing and Actuation report and using the code for Coordination cycle state change (code 150), they were able to see that the intersection not only went into transition quite often, but it also took it several cycles to recover, Figure 1.31.

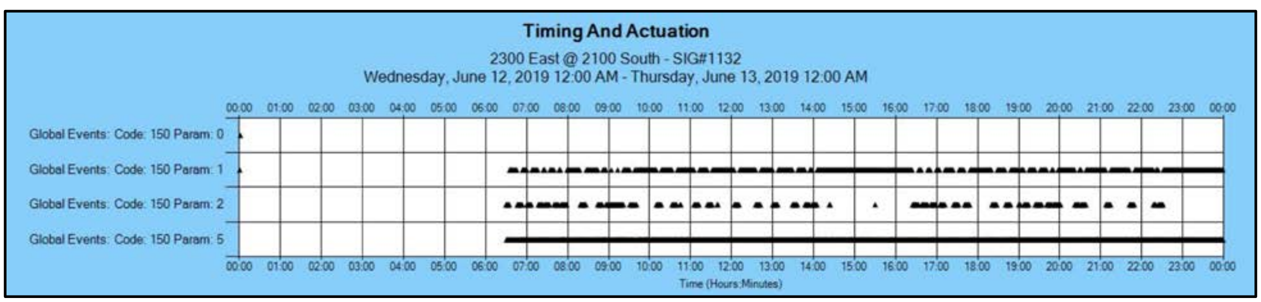


Figure 1.31 Timing and Actuation: Signal 1132 – Wednesday, June 12, 2019 – Salt Lake City

They were able to rework the timings and oversize the pedestrian movement at only one of the crossings. They also did not assign the full cycle to the phases. This allowed the intersection to not only transition less frequently, but to recover quickly as well, Figure 1.32.

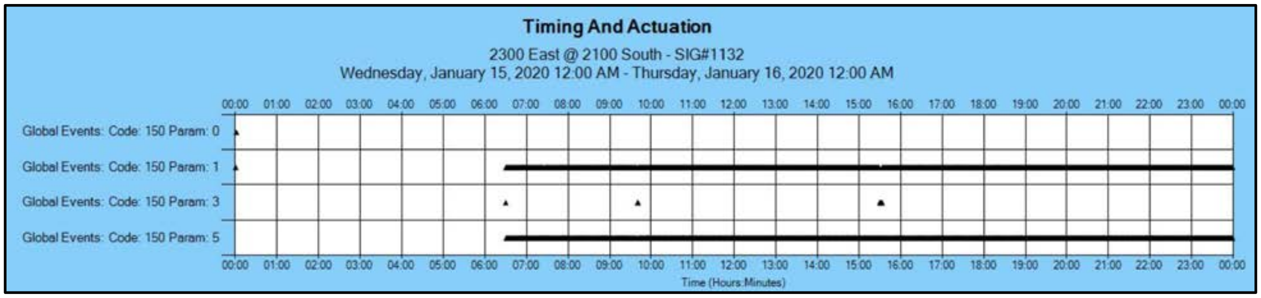


Figure 1.32 Timing and Actuation: Signal 1132 – Wednesday, January 15, 2020 – Salt Lake City

2. Signal Coordination

2.1 Change to the Coordination Optimization Process

ATSPMs allows for an increased focus on field observation than the traditional intensive data collection/modeling. Timing models are now primarily used for their time-space diagrams and not for cycle length or split assessment. Figure 2.1 Change in Coordination Optimization Process

below shows how the signal coordination optimization process has changed with ATSPMs.

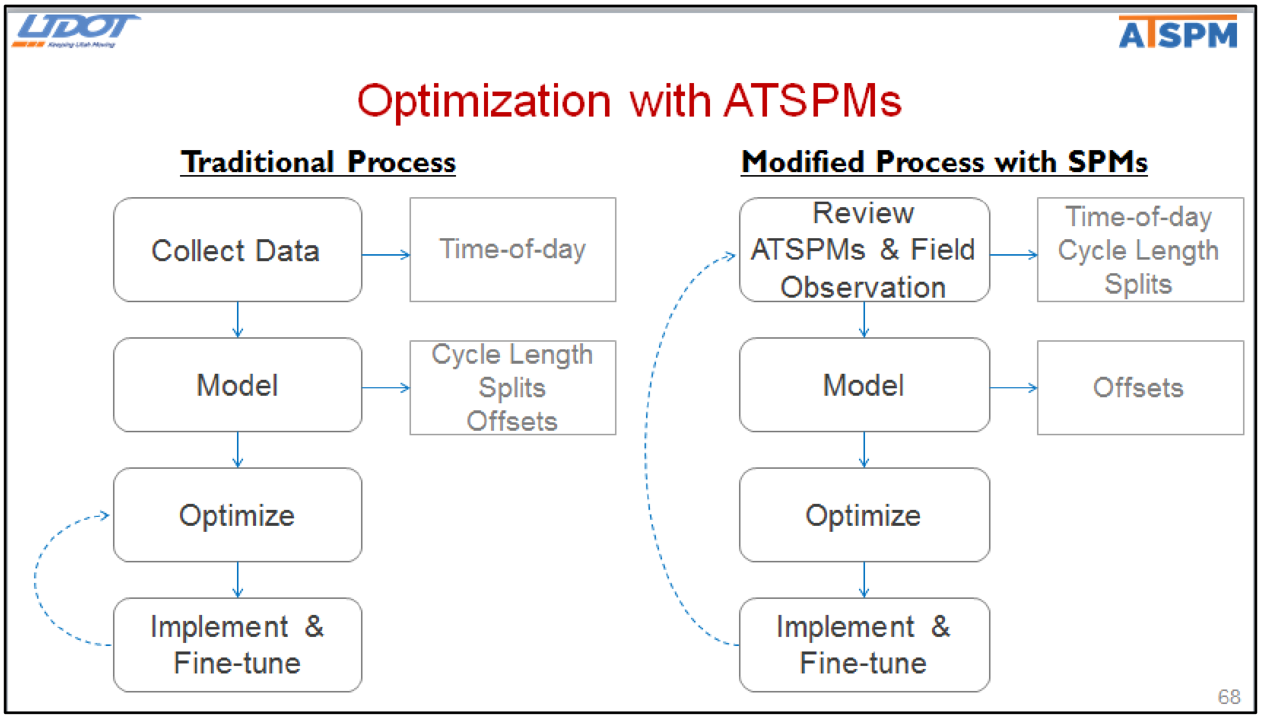


Figure 2.1 Change in Coordination Optimization Process

The most significant change is the elimination of data collection. It is no longer necessary to collect turning movement counts for two reasons: 1) Once configured, ATSPMs are able to collect volume data, and 2) ATSPMs provides phase data which can be used to adjust the split time allocation.

ATSPMs provide numerous benefits to installing and maintaining coordination:

1. The ability to assess progression quality
2. Identifying overcapacity movements
3. Assessing split allocation
4. Identifying oversized cycle lengths
5. Vehicle counts for TOD schedule and progression balance
6. Near real time review of operations during re-timing projects

2.2 Evaluating Split Times

There are three metric charts useful for evaluating split times / max times based on the operational mode if the signal.

1. Purdue Phase Termination
2. Split Monitor
3. Purdue Split Failure

These not only ensure that there is enough time to clear each movement but also to distribute delay equally among the movements. For, example if the westbound-left turn is forcing off at 80% and the eastbound through is forcing off 30% then it may make sense to move split time from the eastbound through to the westbound left turn. A similar analysis can be completed using the Purdue Split Failure metric. Each of these metrics is described in the following sections.

2.2.1 Purdue Phase Termination

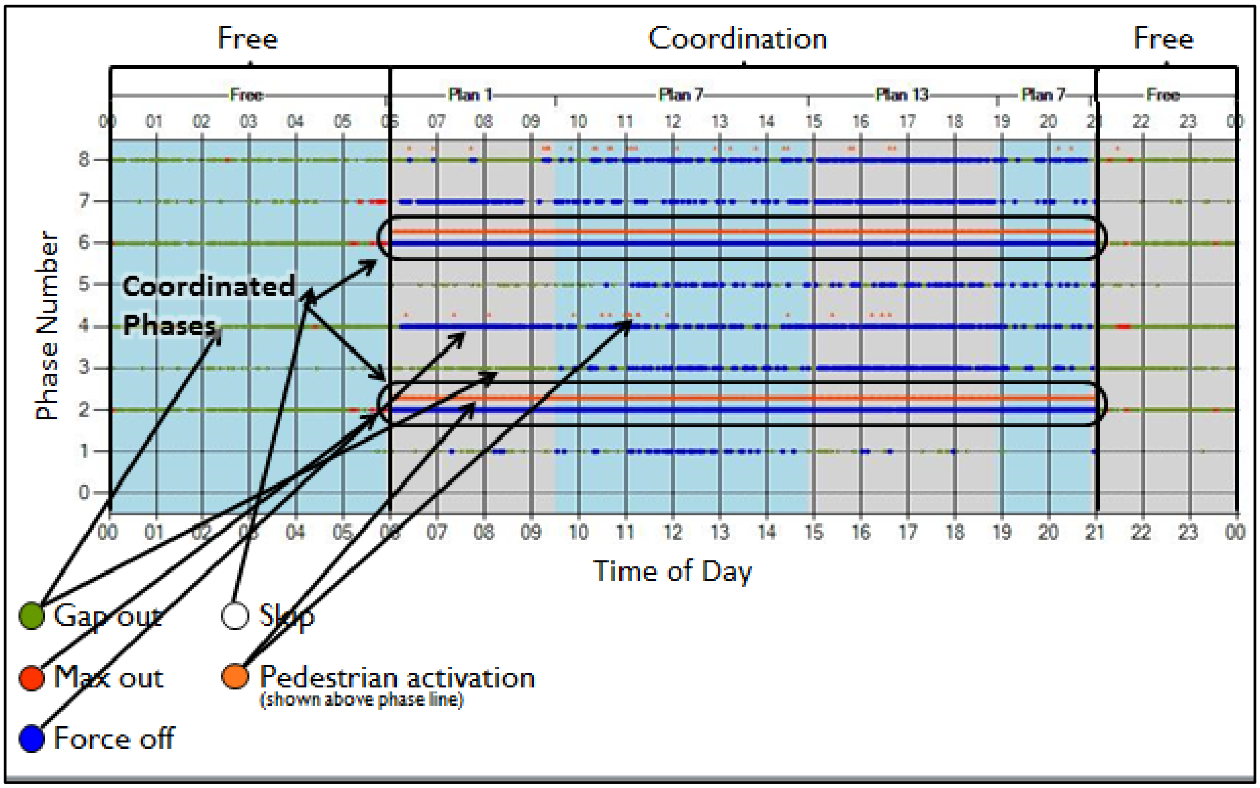


Figure 2.2 Purdue Phase Termination

The Purdue Phase Termination chart, show in Figure 2.2 Purdue Phase Termination

above, is helpful for quickly evaluating coordination plans. A glance at this chart provides information to help determine if the current split times are adequate for the demand on each movement. A high concentration of force offs indicate that the phase could use additional split time. On the other hand, a high concentration of gap outs indicate the phase could give split time.

While the Purdue Phase Termination chart is helpful for a quick assessment, more information is needed. The Split Monitor metric provides the Phase Termination information as well as additional detail for every phase in an individual chart per phase.

2.2.2 Split Monitor – Georgia Example

Although the Purdue Phase Termination chart can be useful, the Split Monitor chart reports significantly more data, including the length of time the phase actually serves. An example of the Split Monitor chart can be seen Figure 2.3.

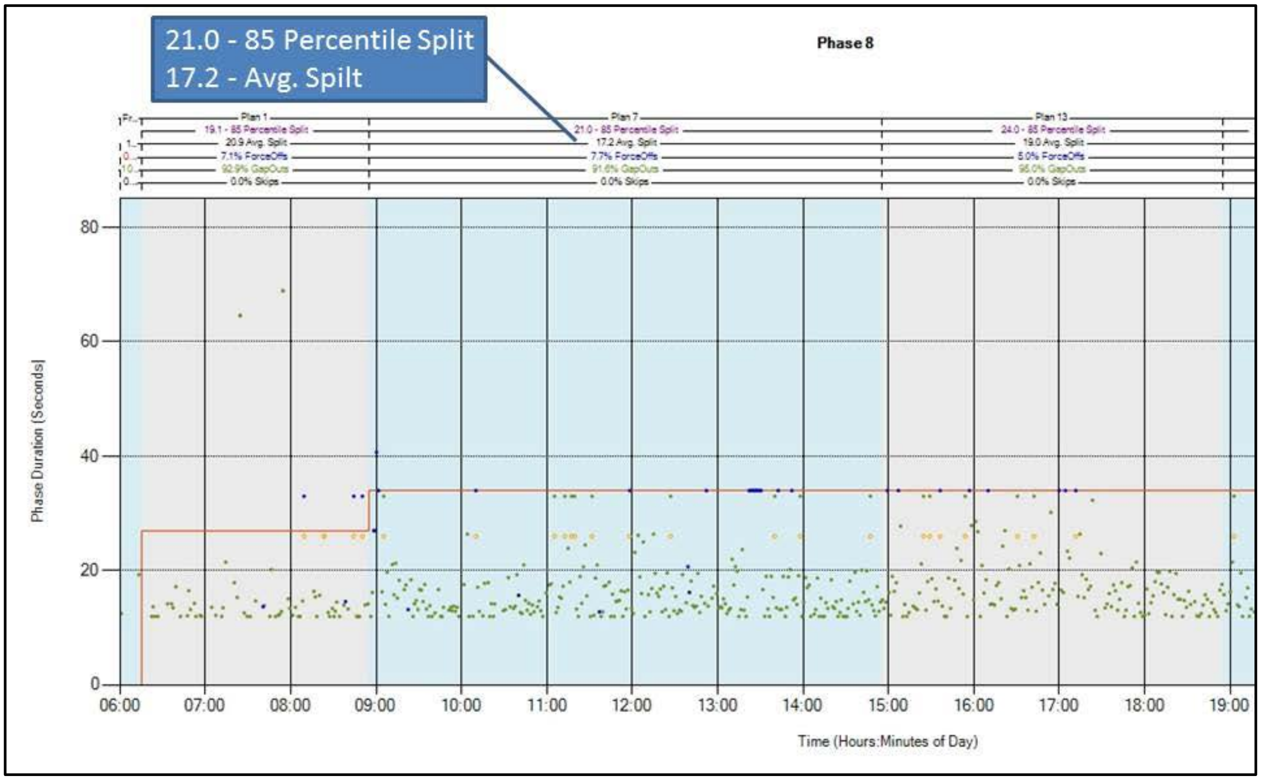


Figure 2.3 Phase 8 Split Monitor Results- GDOT

Table 2.1 Programed Split Times

Phase	**Programed Split Times in Each Coordination Plan**		
	Plan 1	*Plan 7*	*Plan 13*
Ø6	33	38	54
Ø8	27	34	34

Figure 2.3 indicates the Split Monitor results for phase 8. Table 2.1 contains the split information programmed into the controller. Phase 8 in Plan 7 has a programed split of 34 seconds but the Split Monitor chart shows its 85th percentile split as 21.0 seconds with the average at 17.2 seconds. It could be stated that for 85% of the time phase 8 doesn't use more than 21 seconds. This indicates that the split time could be reduced from 34 to 21 seconds and almost all of the time it would enough to clear traffic. However, in this case the split time was left at 34 seconds to provide enough time for the pedestrian crossing times. Evaluating when it is okay to oversize pedestrian time is discussed further in section 2.5 Pedestrian Analysis.

Figure 2.6 contains the Split Monitor result for phase 6 from the same signal as shown above in Table 2.1. Phase 6 in Plan 7 has a programed split of 38 seconds. However, the 85th percentile split is 74.5 seconds and the average split is 66.5 seconds which is well over the programed split. This shows how much extra time the coordinated phase is getting from other phases ending early.

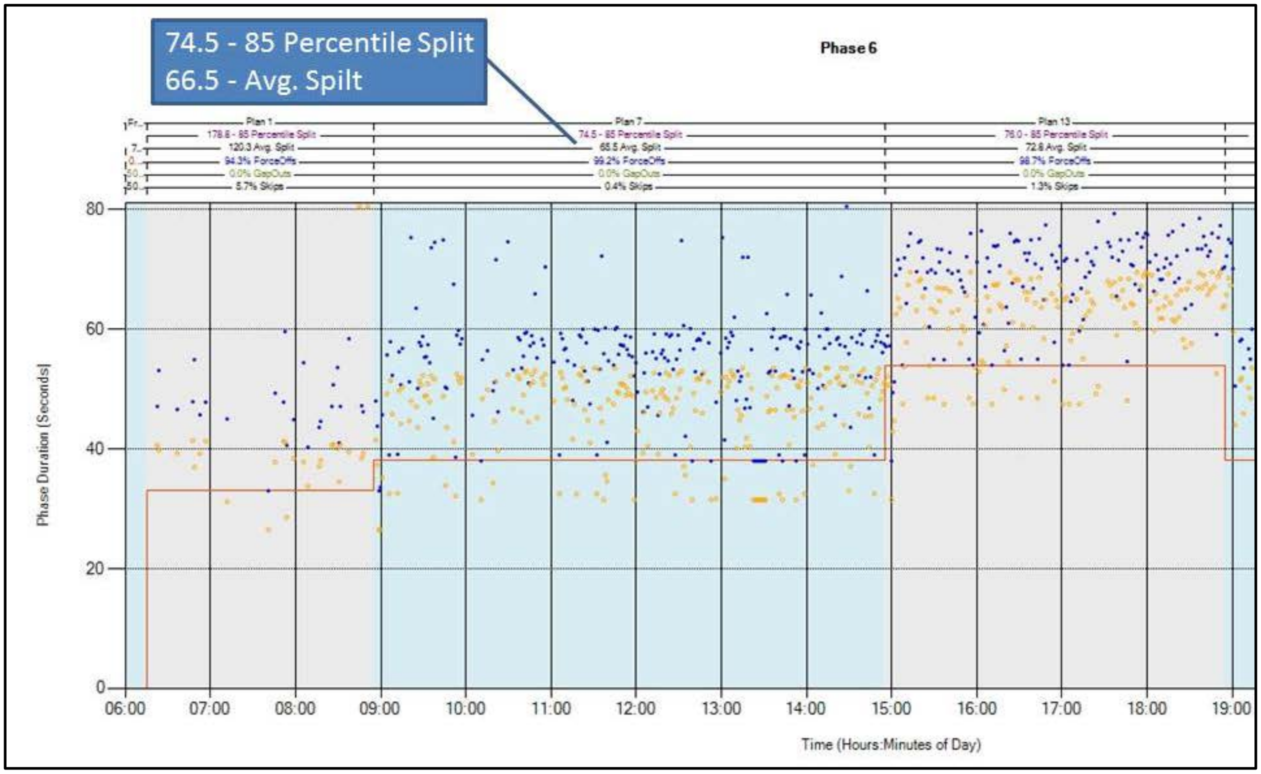


Figure 2.4 Phase 6 Split Monitor Results - GDOT

2.2.2.1 Split Monitor – Short Split Time – Pennsylvania Example

Just looking at the phase termination status can tell a lot about whether the timing is sufficient. Figure 2.5 is an example where Plan 2 is active from 9:15 AM to 11:30 AM. It had an 8 second programmed split for a left turn phase, and the phase would force off time every time it was called, and it never gapped out. That's logical since it's hard to gap out with only a maximum 3 second green time possible.

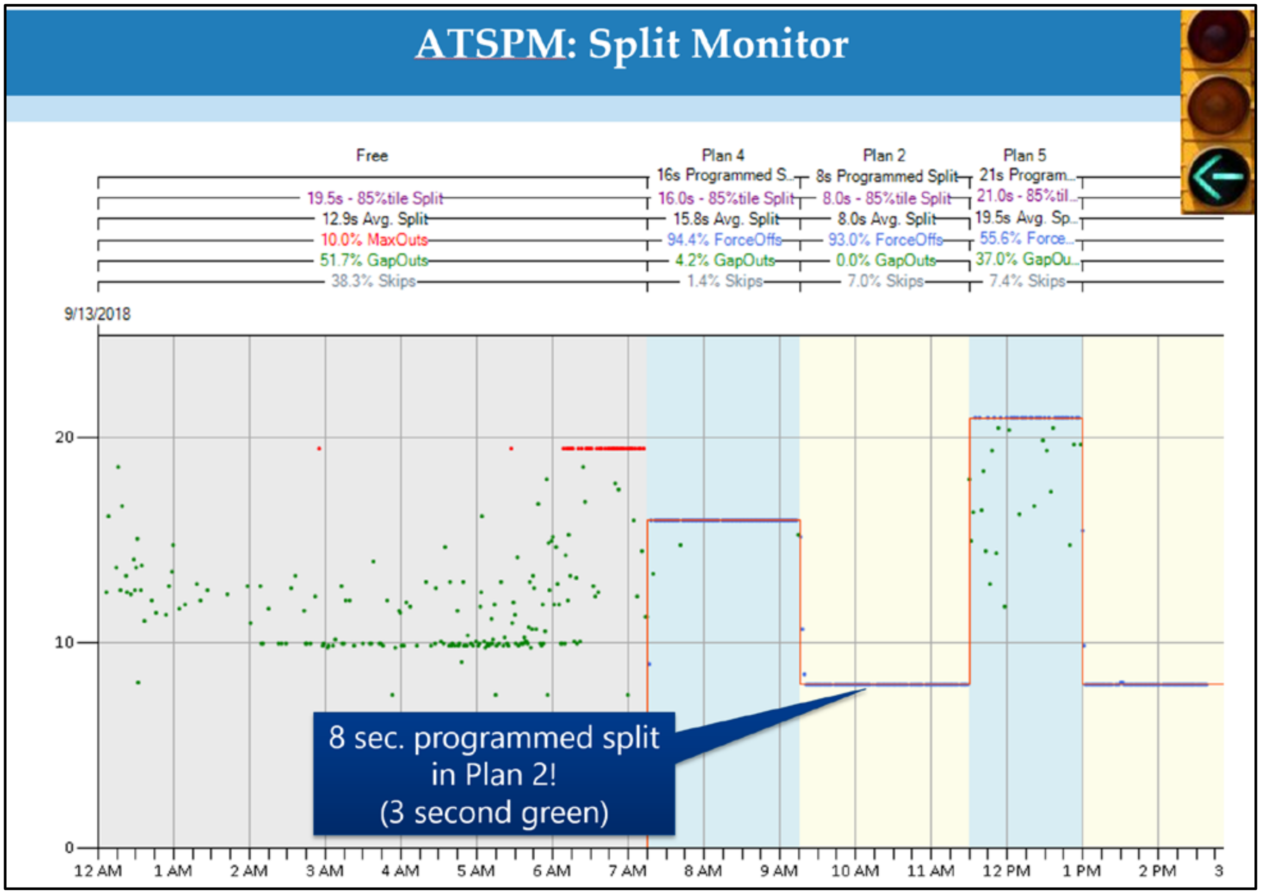


Figure 2.5 Short Split Time Example – PennDOT

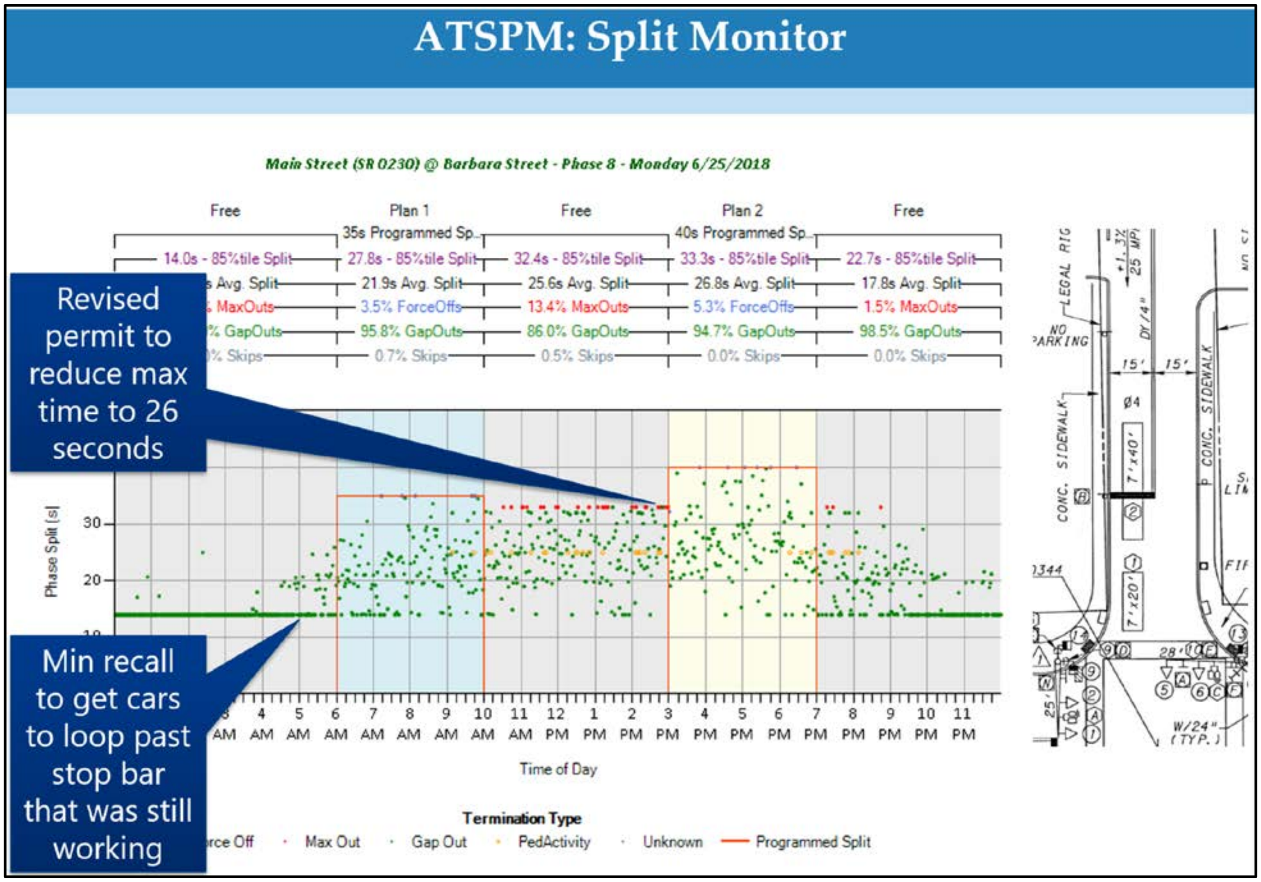


Figure 2.6 Split Monitor Example of Revising Permit with too much green time – PennDOT

Another example from Pennsylvania is analyzing high resolution data for an entire year. In Figure 2.6 PennDOT was able to determine that a max time of 26 seconds was sufficient to accommodate 85% of the cycles for the whole year. Without running a Synchro analysis, they could comfortably change the split time knowing from the ATSPM data that it wasn't used.

Even further, ATSPMs helped address a concern where the detection was faulting. For this location there were two loops in the lane. The one at the stop bar failed, but there was one past the stop bar was still working. The faulting loop was removed from the detection assignments; a minimum recall was placed with an increased passage time to ensure that the queue could reach and extend the phase from the front loop.

2.2.3 Purdue Split Failure – Georgia Example

Both the Purdue Phase Termination and the Split Monitor charts can make it difficult to assess the split time given to a coordinated phase. Also, a force off on a non-coordinated phase doesn't necessarily indicate that the time is inadequate; the queue may actually clear just at the last moment. The Purdue Split Failure metric helps to overcome these issues.

An ATSPM split fail occurs when there is a call on the stop bar detector within a user defined time frame after the phase has turned red. This parameter is called "First Seconds of Red" and can be set in the ATSPM configurations. Research has indicated that the default value of 5 seconds provides the most accurate results. Cycles with a split fail are indicated with a vertical yellow line.

Figure 2.7 shows the split fails at a busy left turn during two differing coordination plans. Between 9:00 am and 7:00 pm there were 97 total split failures. After determining that other phases could give time to this phase, the split time was increased by 7 seconds in Plan 7 and 5 seconds in Plan 13. The split fail chart from the day after these changes were made is provided in Figure 2.8. Split fails decreased significantly in both plans for a 43% reduction in split fails.

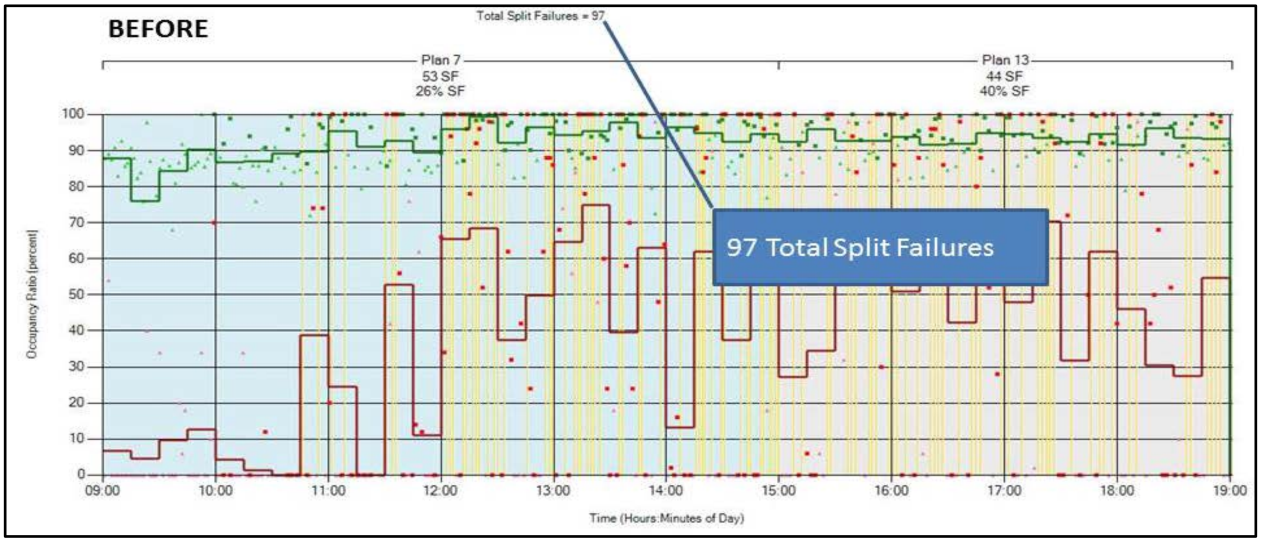


Figure 2.7 Purdue Split Fail – (BEFORE) – GDOT

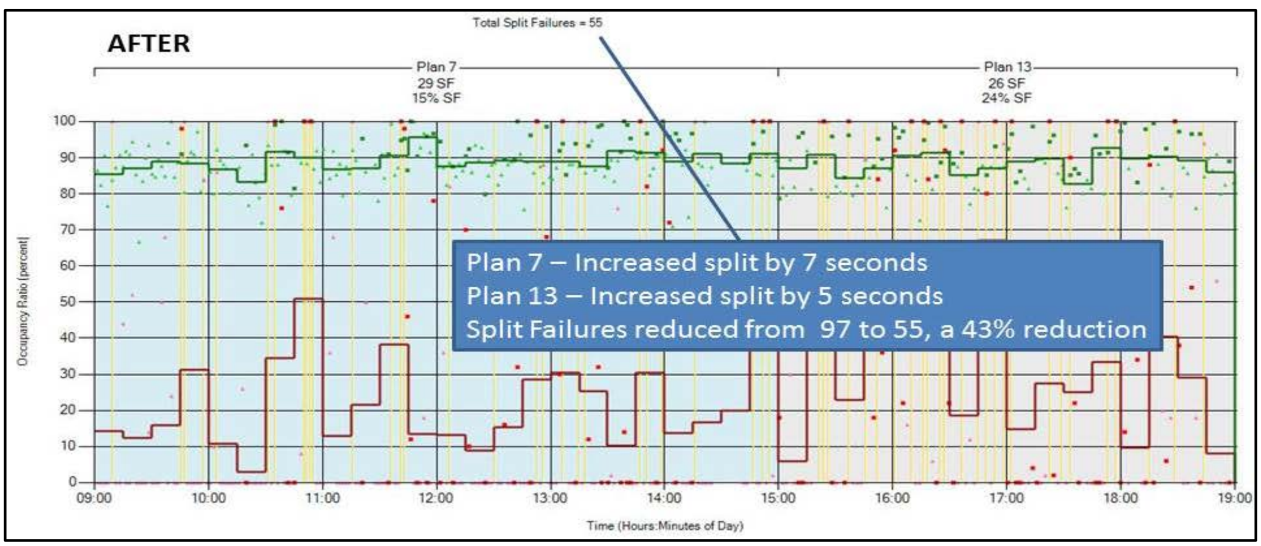


Figure 2.8 Purdue Split Fail – (AFTER) - GDOT

2.2.3.1 Phasing Change Analysis – Pennsylvania Example

Figure 2.9 presented Pennsylvania DOT with another opportunity for ATSPM analysis. Understanding that a traditional capacity analysis wouldn't provide significant insight without split changes and the fixed arrival and saturation flow rates, ATSPMs became a tool for further analysis.

Figure 2.9 Purdue Split Fail Analysis - Sequence Change Potential – PennDOT

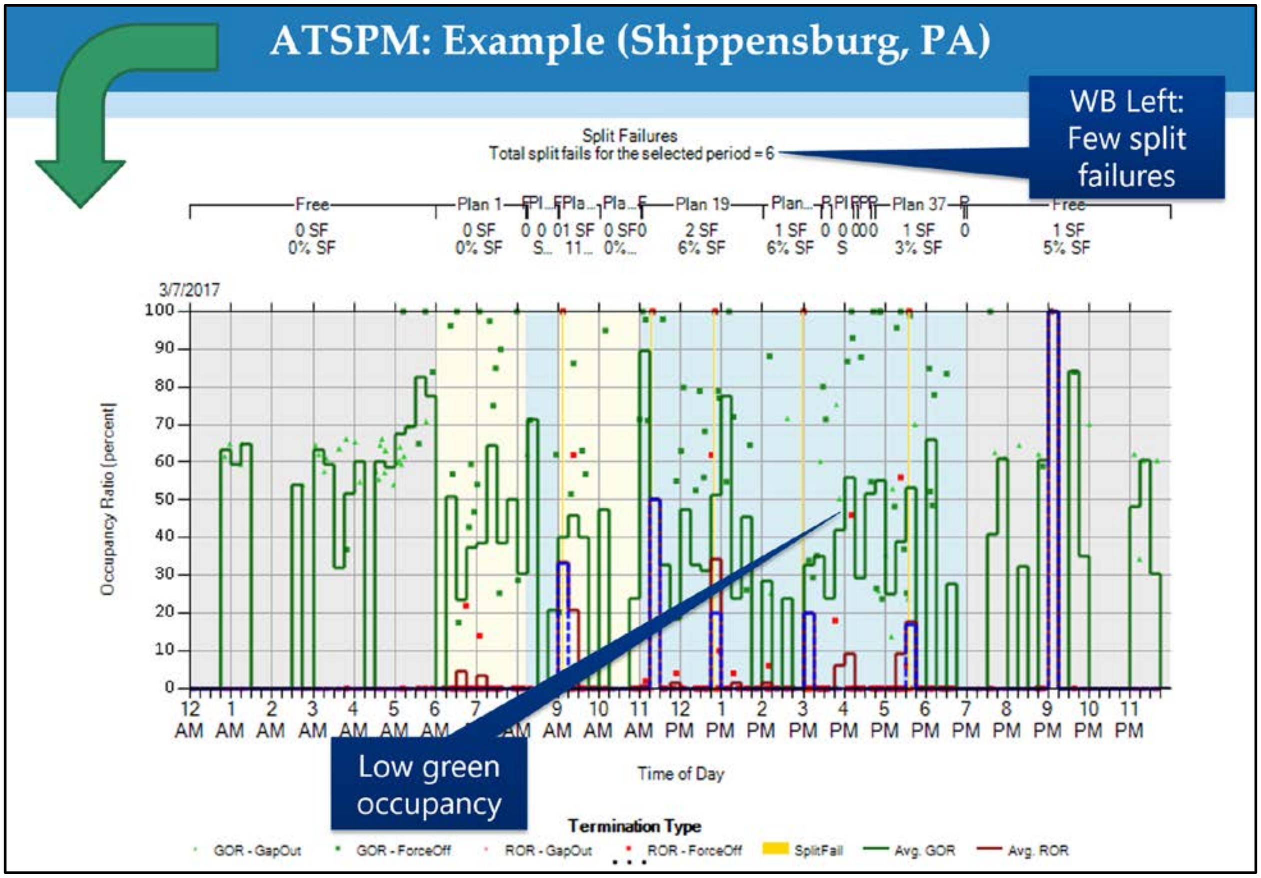


Figure 2.10 Purdue Split Fail Sequence Change Analysis (WB Left) - PennDOT

Figure 2.10 indicates that the westbound left turn phase had few split failures, and the green occupancy was low. This chart indicates that the vast majority of the vehicles are served during the permissive phase instead of needing the lagged protected period. However, because the westbound left had to come up with the eastbound left to prevent a yellow trap issue, it served frequently, with no demand.

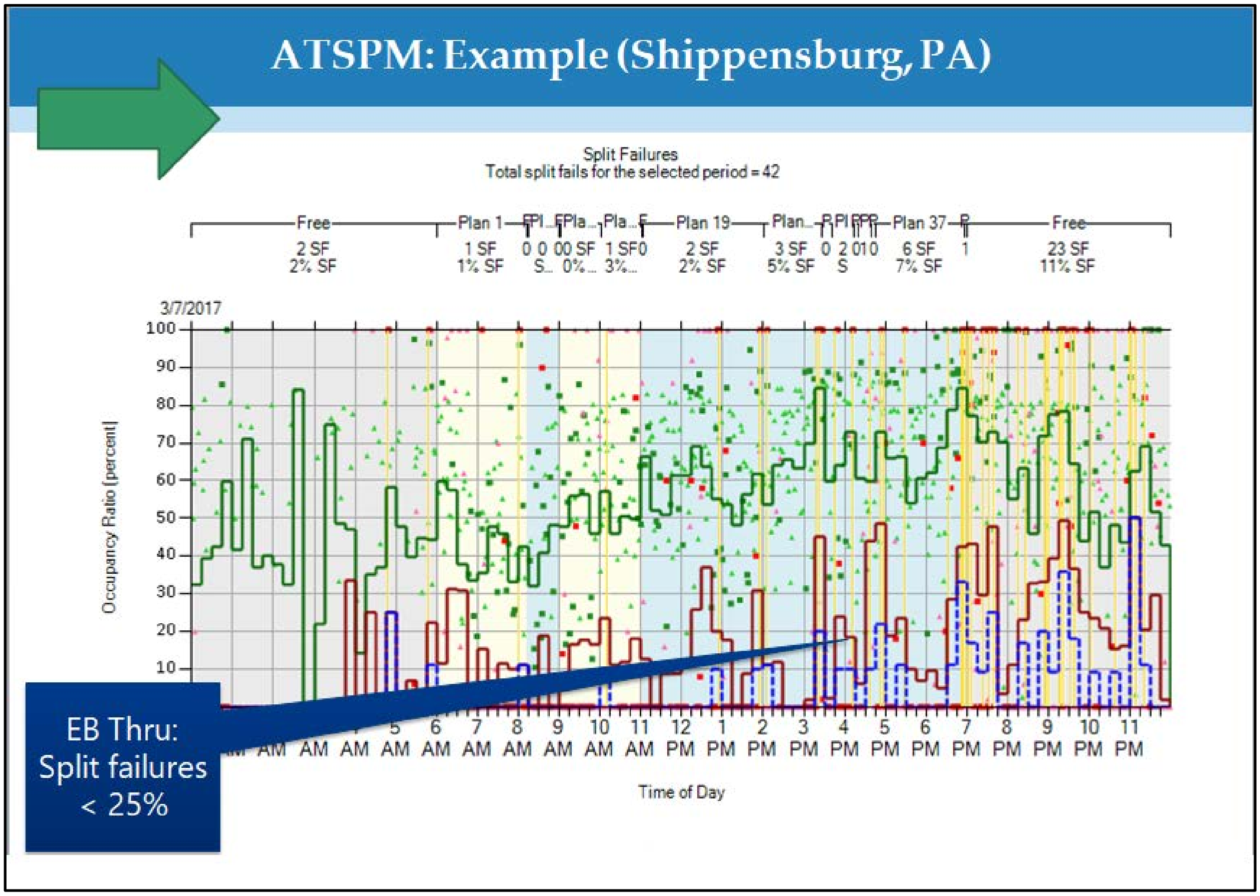


Figure 2.11 Purdue Split Fail Sequence Change Analysis (EB Thru) - PennDOT

Figure 2.11 indicates that the eastbound thru phase also didn't have many split failures, which indicates that westbound left turns would likely have sufficient gaps without the left turn phase being served.

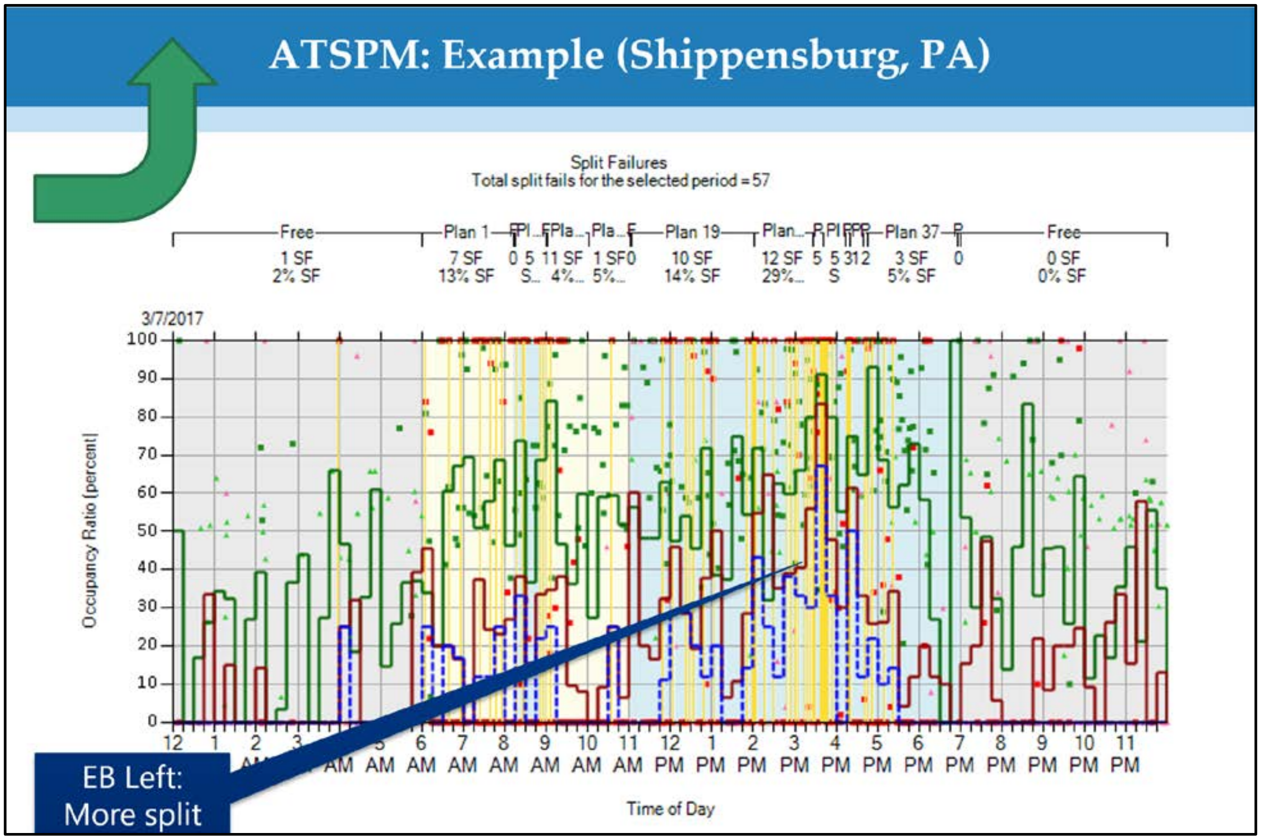


Figure 2.12 Purdue Split Fail Sequence Change Analysis (EB Left) - PennDOT

Figure 2.12 details he eastbound left turn which is a very different story. There is a significant spike in split failures during the PM peak.

Ultimately, the solution for this intersection was to eliminate the westbound left turn phase entirely since it was underutilized. To avoid the yellow trap, the eastbound left turn was changed to a leading phase. The timings were implemented and positive feedback has been received from the Borough.

2.2.3.2 Time of Day Schedule Analysis – Pennsylvania Example

Figure 2.13 is another example from PennDOT using ATSPMs to augment engineering judgment. Split failures are a good way to measure delay for conflicting movements. If the side street traffic is fully served each cycle, we are balancing the needs of side street users with mainline progression goals. There may still be room for improvement, and prior to ATSPMs, intersections had to be monitored over the course of multiple periods and multiple days.

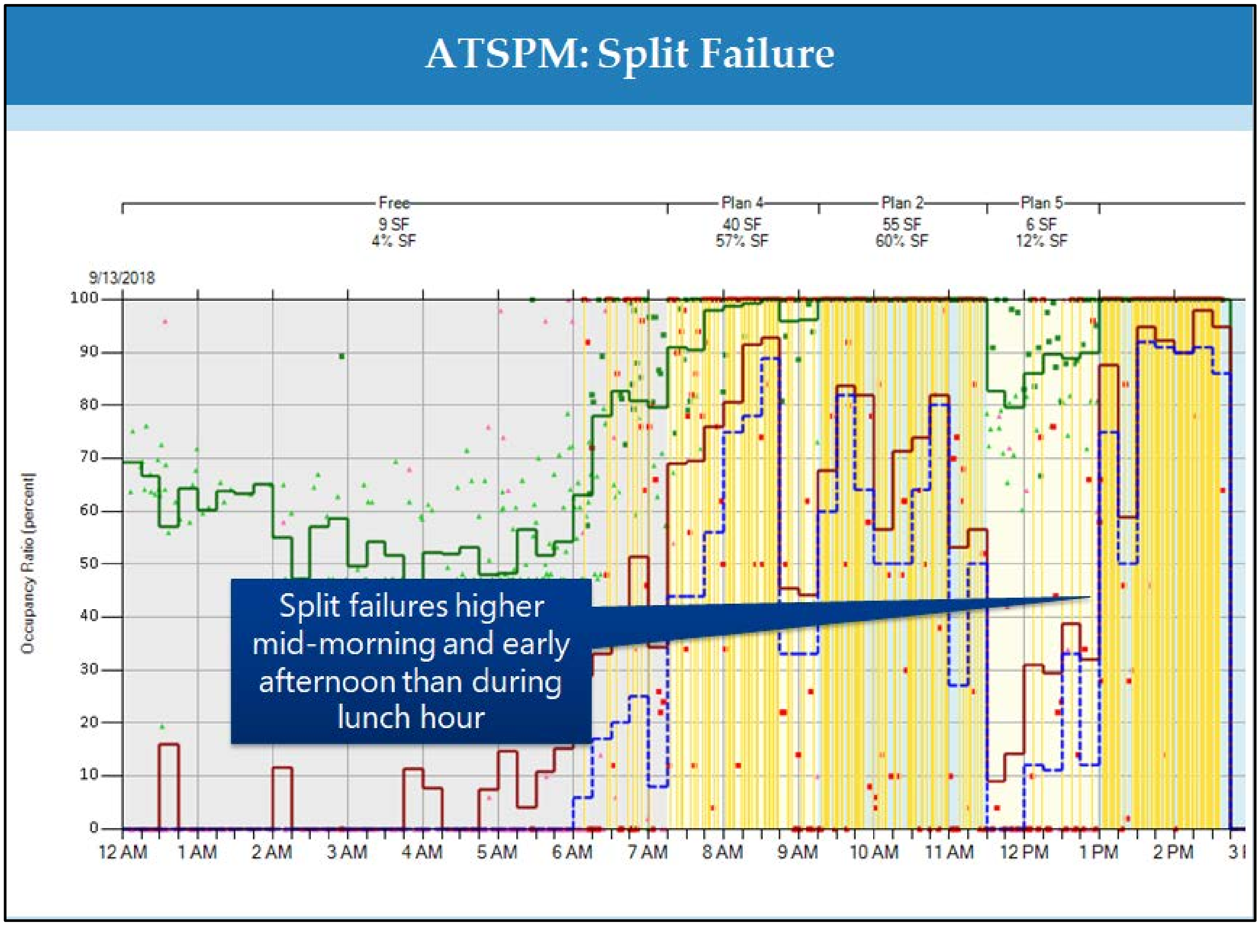


Figure 2.13 Purdue Split Fail Analysis - PennDOT

Figure 2.14 shows a lot of split failures occurring before the signal changes from free to Plan 4 at 7:15 AM. This can be a sign that queues will continue to grow and could eventually block the mainline lanes. Using ATSPMs we can make a decision to start the plan earlier to assist the coordination operation.

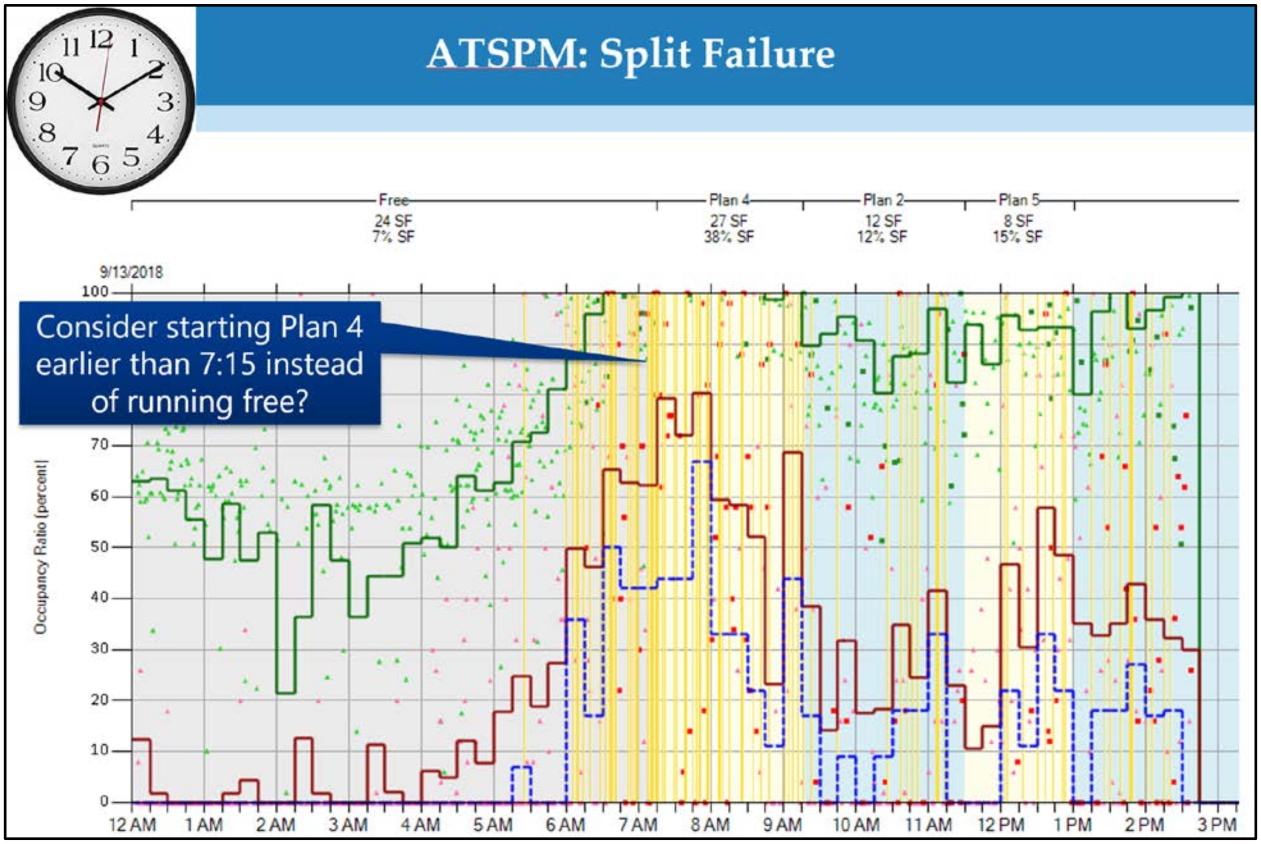


Figure 2.14 Purdue Split Fail Time of Day Analysis - PennDOT

2.2.4 Approach Delay – Georgia Example

The Approach Delay chart displays the time between approach activation during the red phase and when the phase turns green (Note, it doesn't account for startup delay, deceleration, or queue length that exceeds the detection zone). This can be useful to determine if a movement is waiting a long time for a green light, and is especially helpful in areas where there might not be detection on a side road and max times are used.

Figure 2.15 indicates high delays in the AM and PM peak for the southbound movement at a particular intersection. Complaints were made that the southbound was waiting 20 seconds or more during peak times and occasionally there was only a single right-turning vehicle on the side street causing the delay. Figure 2.16 documents the improvements of operational changes to address the excessive delay.

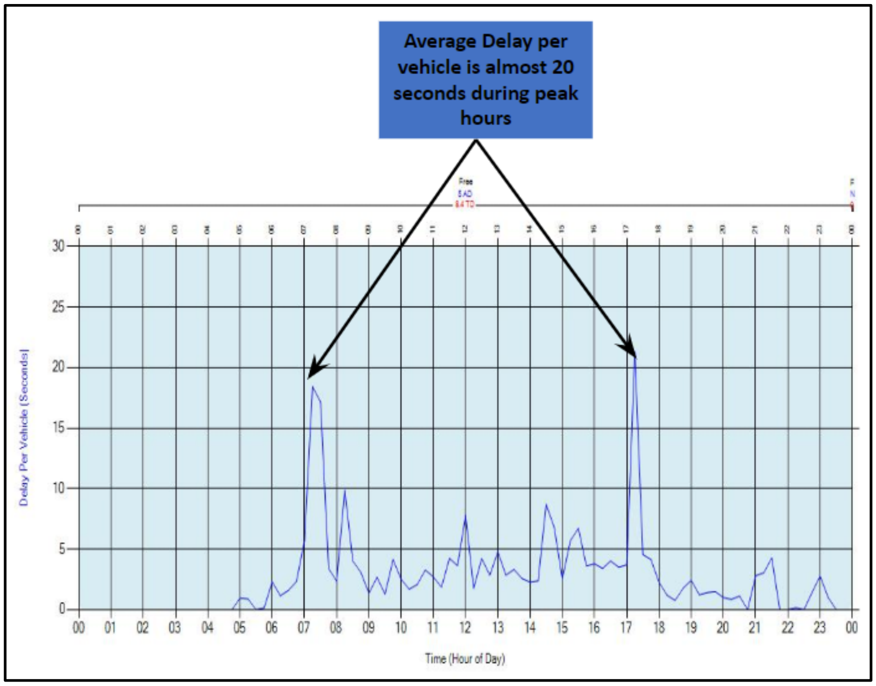


Figure 2.15 High Approach Delay Observed - GDOT

The side street MAX time was reduced and a delay was added for the right, which resulted in the 13 seconds reduction for the southbound approach during the AM peak and 6 seconds during the PM peak.

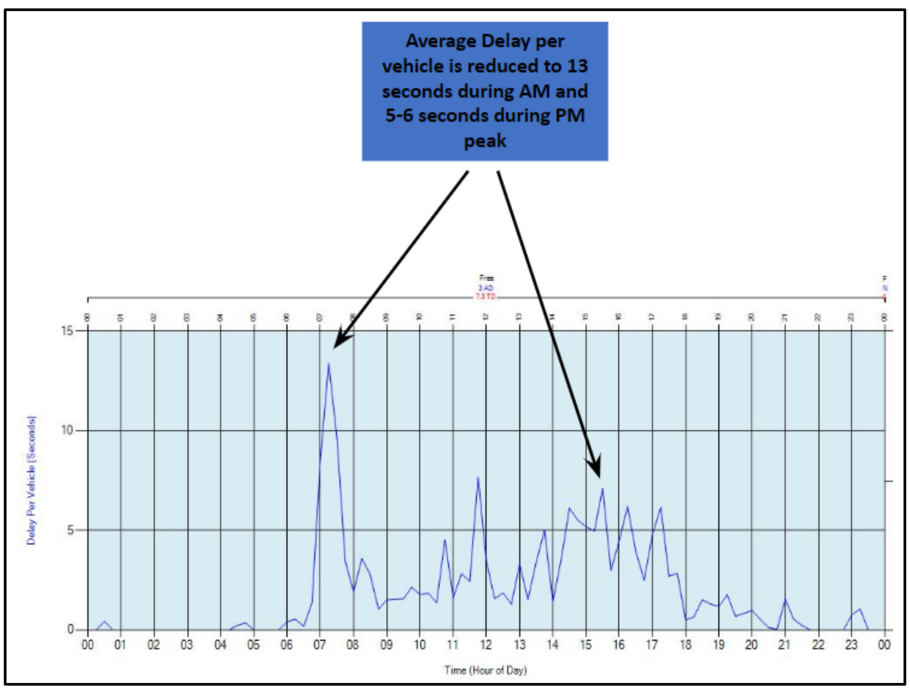


Figure 2.16 Approach Delay Chart after Changes - GDOT

2.3 Sequence Change Analysis

Changes to the sequence of a pattern can allow a movement that is constantly forcing off to get time from a phase that frequently gaps out. The Split Monitor metric can evaluate the benefit of making the change. Figure 2.17 shows the Split Monitor data both before and after of a sequence change. Before, while running a typical sequence, phase 3 forces off constantly with an 18-second average split. After the sequence change, the average phase 3 split increased to 24.5-seconds, which helped the westbound left turn to get more time.

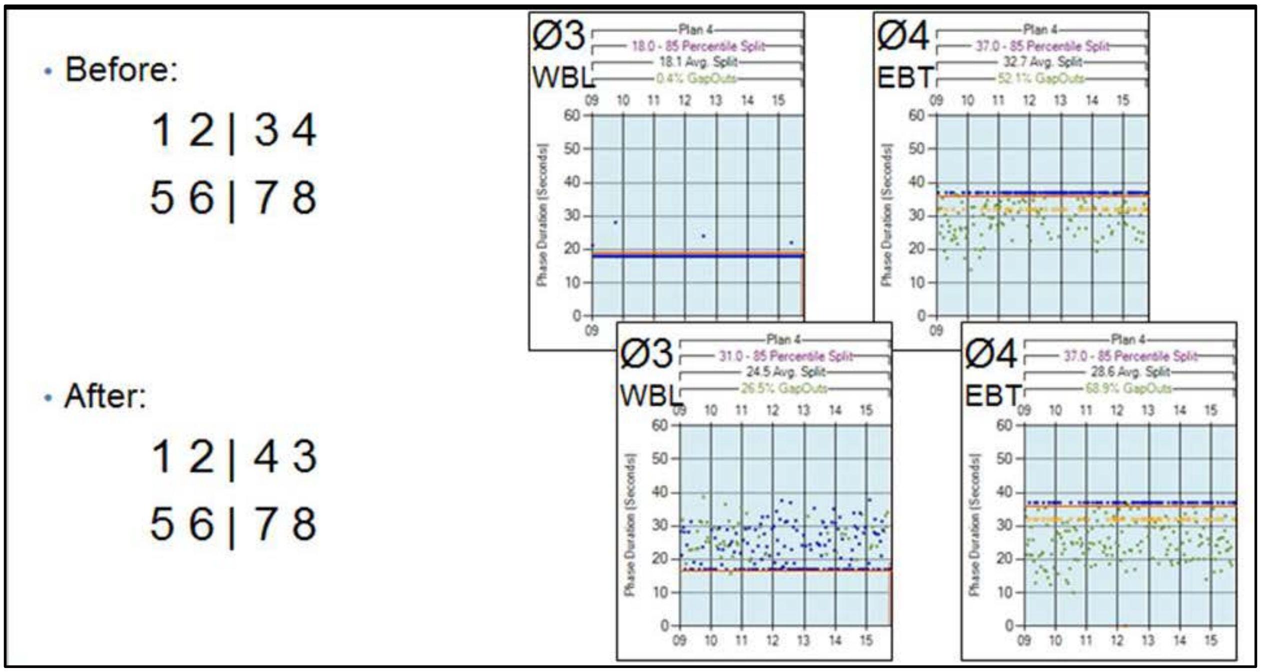


Figure 2.17 Evaluating a Sequence Change

It is important to realize that the extra time from phase 4 gaping out used to go to another phase or even the coordinated phase. Thus, the sequence change may also require an offset change or additional split changes.

2.4 Cycle Length Analysis – Georgia Example

When considering adding coordination at a signal that has historically run free, a summation of the average and 85th percentile splits provided in the Split Monitor metric can provide a sense of what the natural cycle length is. The natural cycle length is defined as the cycle length at which the intersection would run in an isolated mode. Setting the coordination plan cycle length near the natural cycle length will ensure there will be enough time for each movement and motorists are less likely to notice a negative effect resulting from the change from free to coordination. Figure 2.18 is an example of determining an appropriate cycle length based on the FREE operations of the intersection. In this case the average splits from active ring 2 phases led to a 120 second cycle being selected.

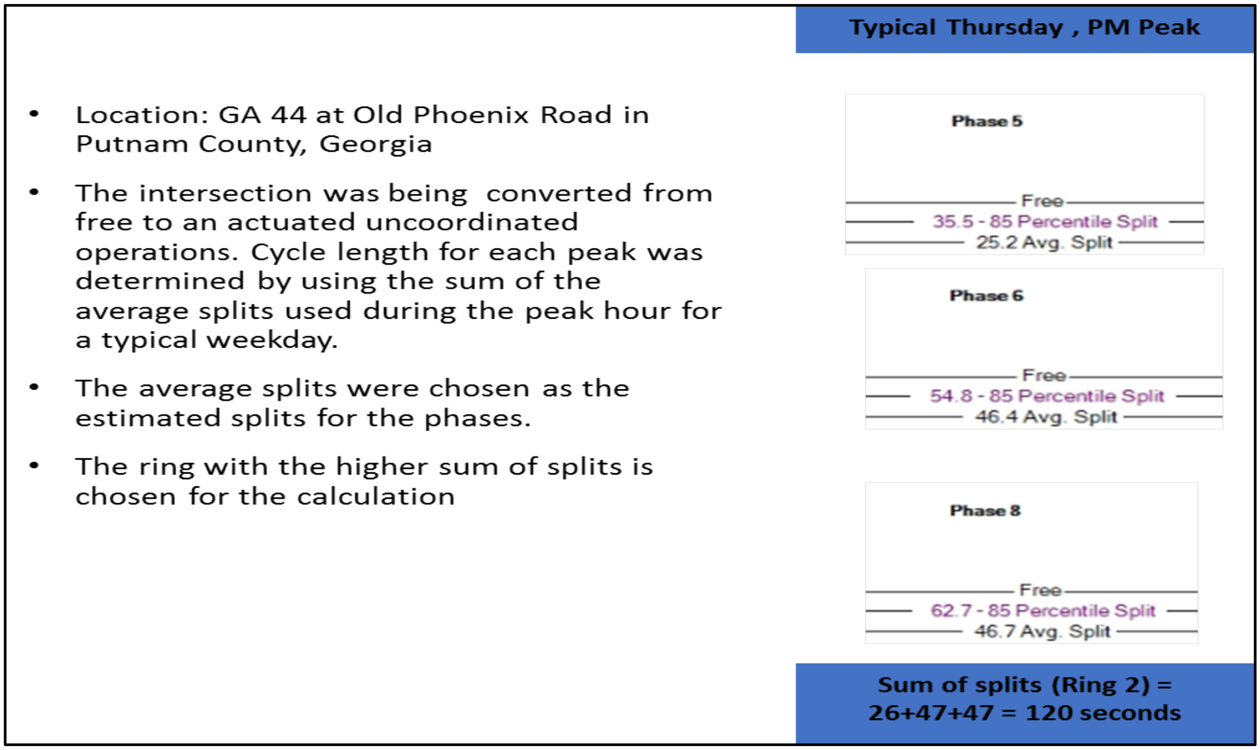


Figure 2.18 Coordination Cycle Length Analysis - GDOT

A couple of ATSPM charts can be helpful in evaluating existing coordination plan cycle lengths. First, the Purdue Phase Termination chart showing a high number of force-offs on all phases can indicate the need for a larger cycle length, as shown in Figure 2.19 below.

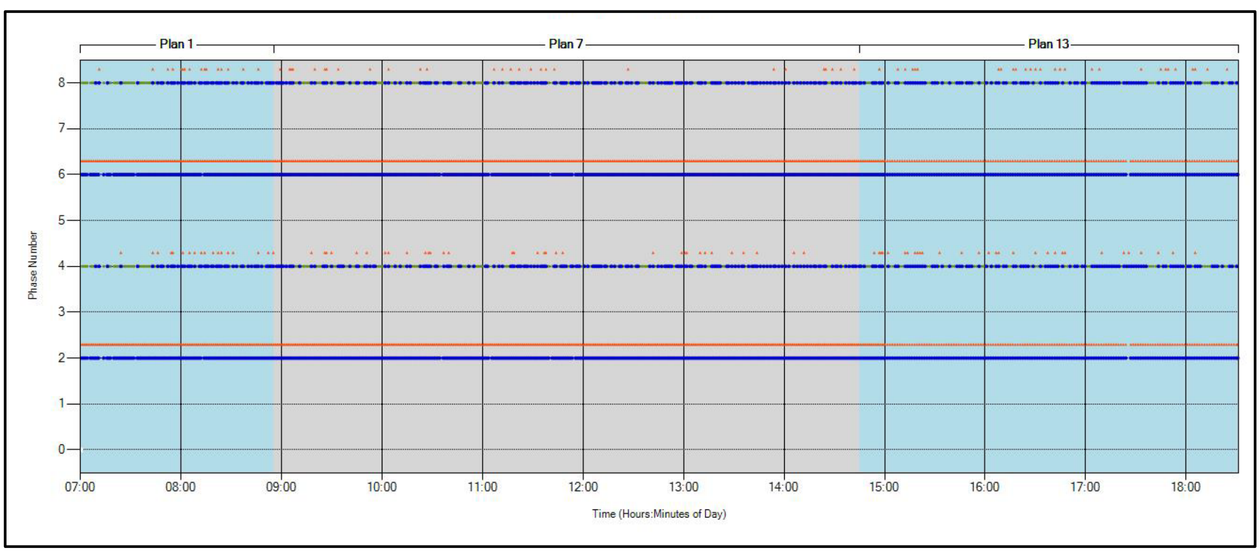


Figure 2.19 High Force Offs Indicate Need for Higher Cycle Length

However, since coordinated phases always force off, the PCD provides additional valuable data. Figure 2.20 Figure 2.20 PCD Indicates Need for Lower Cycle Length - GDOT

has a PCD that indicates there are approximately 20 seconds of wasted time at the end of the coordinated phase in Plan 7 which runs in the middle of the day and late evening. Reducing the cycle length from 110 seconds to 90 seconds would eliminate the time that the side street traffic waits for no one. Conversely, Plan 13 that runs during the PM peak, indicates that this coordinated phase needs all the time it's given. There is no wasted time.

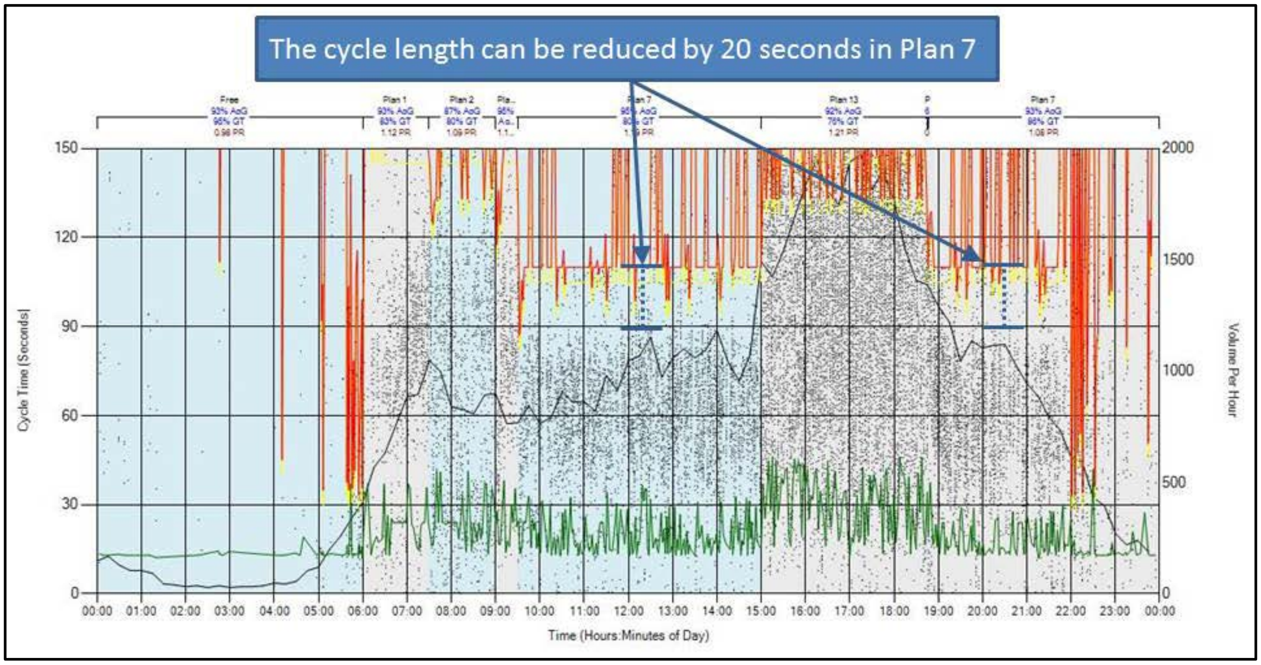


Figure 2.20 PCD Indicates Need for Lower Cycle Length - GDOT

2.4.1 Incorrect Cycle Length Running in Signal Controller – Pennsylvania Example

Ensuring the signal is operating properly and as intended is another key use of ATSPMs. Figure 2.21 is an example where ATSPMs can help visualize programming errors in the controller operation. In this case using the split monitor, an unusually high split of 209 seconds is routinely observed during Plan 1 operation. In the case of this intersection, according to ATSPMs this phase had a 209 second split with a 254 second cycle.

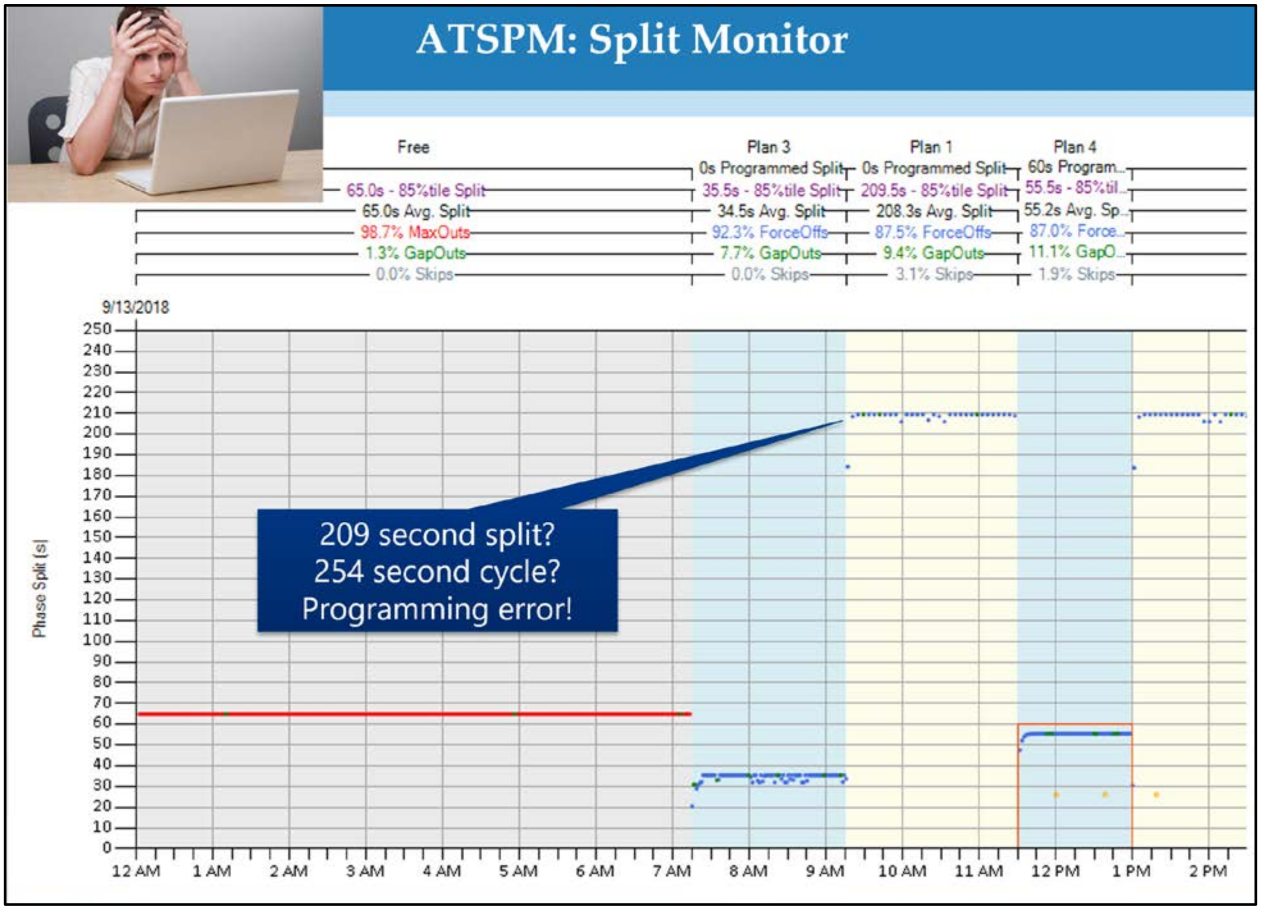


Figure 2.21 Incorrect Cycle Length Example - PennDOT

2.5 Pedestrian Analysis

Pedestrians are also significant when evaluating or updating coordination plans. Coordination can make pedestrians wait longer than they are accustomed. The Pedestrian Delay metric is helpful for analyzing changes in delay.

For instance, Figure 2.22 shows a signal, which is a HAWK, where it was decided to tie it into the coordinated network. There is dilemma zone detection installed. We wanted to look at the results that signal coordination had on pedestrian delay. The chart on the left is when the intersection was uncoordinated and running free. The chart on the right is when we tied it into signal coordination. With coordination the delay varies; and the maximum delay did increase as would be expected.

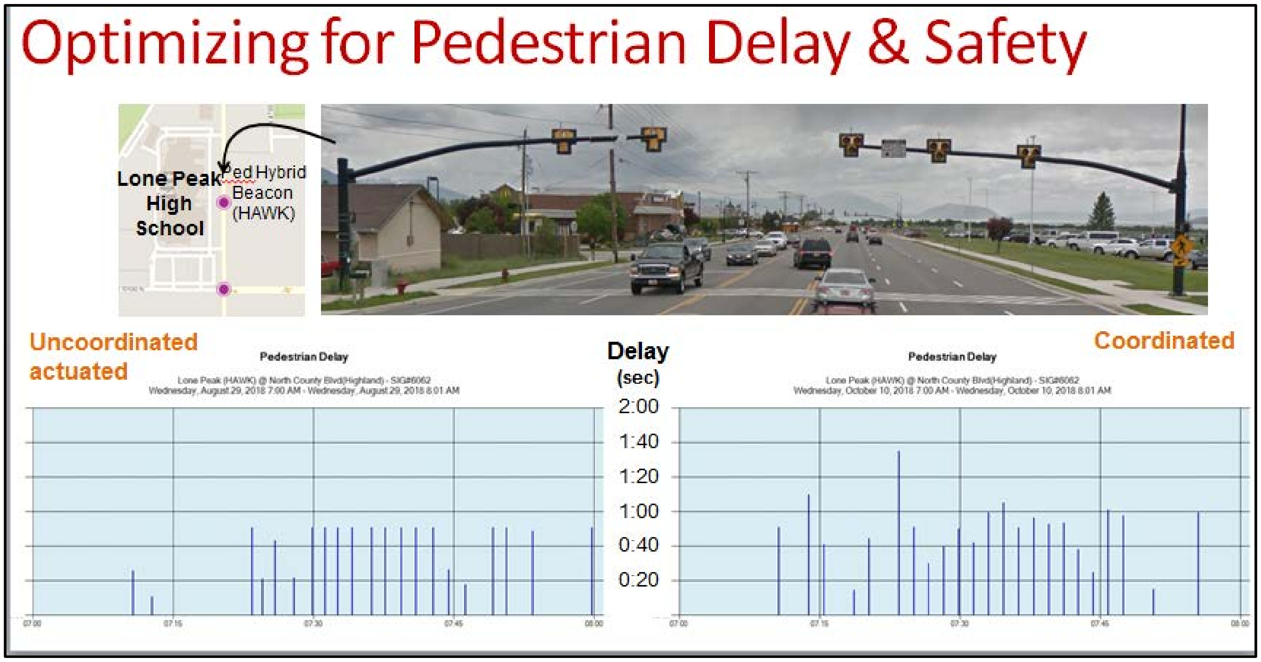


Figure 2.22 Changes in Pedestrian Delay When Adding Coordination

However, analyzing the data further using ATSPMs, while the max delay did go up with signal coordination, the average delay stayed about the same. We did use the actuated-coordinated feature to help bring the maximum pedestrian delay down, which helped.

Often, wide roadways mean that the pedestrian time is larger than what is needed for the vehicles on the same phase. This leads to the practice of "oversizing the pedestrian time". This is when split time is not large enough to serve the pedestrian walk and all red times. If the pedestrian phase is called, the signal will be pushed out of coordination and into transition.

In the past, manual field counts, assumptions or engineering judgment were used to estimate pedestrian usage. With ATSPMs accurate count data of actuations can be collected, often surpassing original thoughts on pedestrian activity.

Figure 2.23Figure 2.23 Evaluating if Pedestrian Times Can be Over-sized

shows Purdue Phase Termination charts at two different signals. The left chart shows the Phase 4 and 8 pedestrian movements being called almost every cycle. If oversized pedestrians were used here, the signal would be in transition constantly. The chart on the right only has a few calls on the Phase 4 pedestrian and none on Phase 8. The impact on coordination from oversized pedestrians here would be minimal.

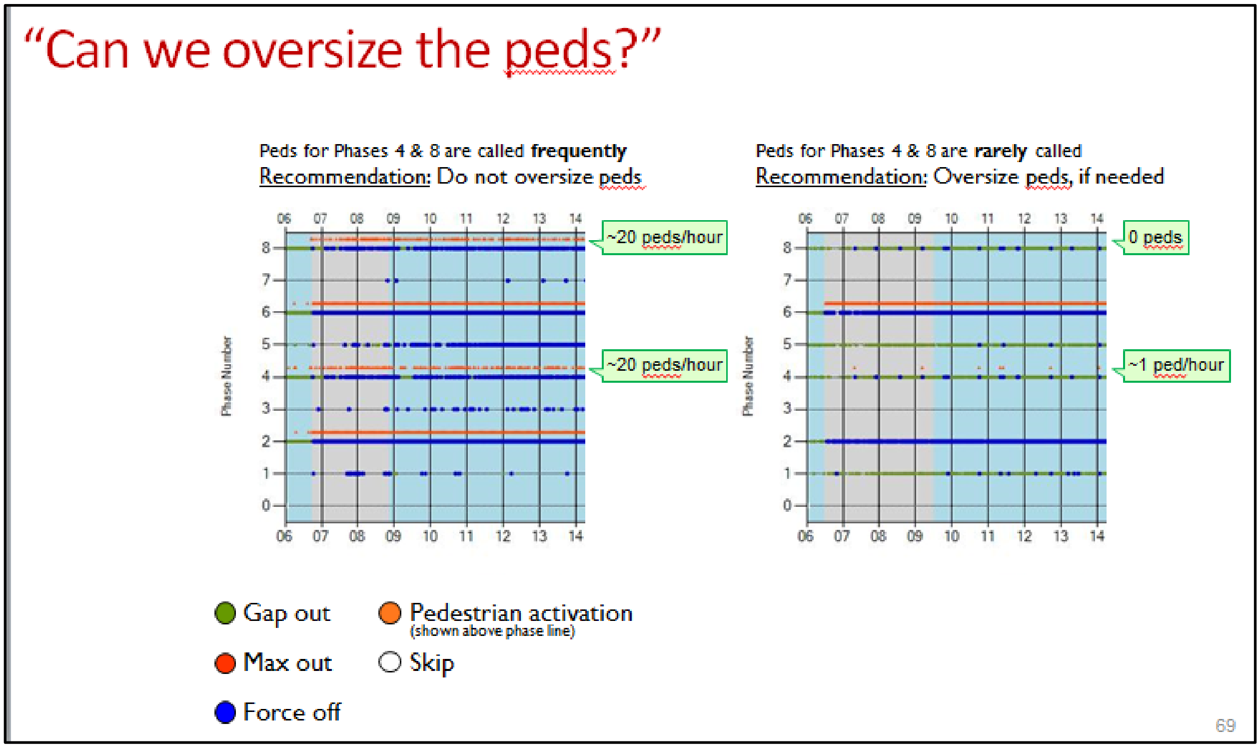


Figure 2.23 Evaluating if Pedestrian Times Can be Over-sized

The Split Monitor metric is great for phases that are not coordinated. However, coordinated phases bring the pedestrian phase on every cycle. In this case the Pedestrian Delay metric is helpful as shown in Figure 2.24. Despite the phase 6 pedestrian phase coming on each cycle, the Pedestrian Delay metric shows the associated pedestrian buttons were only pushed 5 times between 9:00 and 13:00.

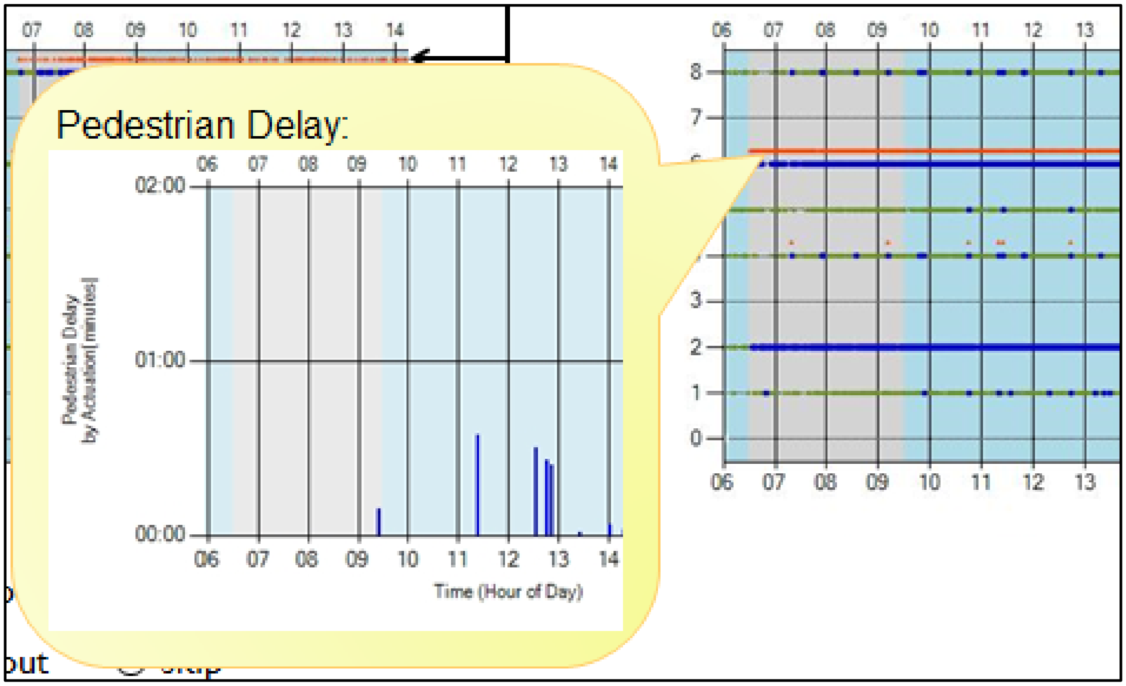


Figure 2.24 Pedestrian Delay Shows Pedestrian Actuations on Coordinated Phases

2.5.1 Long Pedestrian Delay – Pennsylvania Example

For pedestrians, we can measure the time between when the push button is pressed and when the walk signal is displayed. Realistically, a pedestrian is going to assume the push button is broken if the wait is too long, and is likely to make unsafe choices to cross the road without the walk signal. The pedestrian delay chart not only lets us make sure we aren't creating a situation where pedestrians will make bad choices, but it can also flag push button issues or controller programming issues. Figure 2.25 details what this may appear like for a pedestrian delay chart.

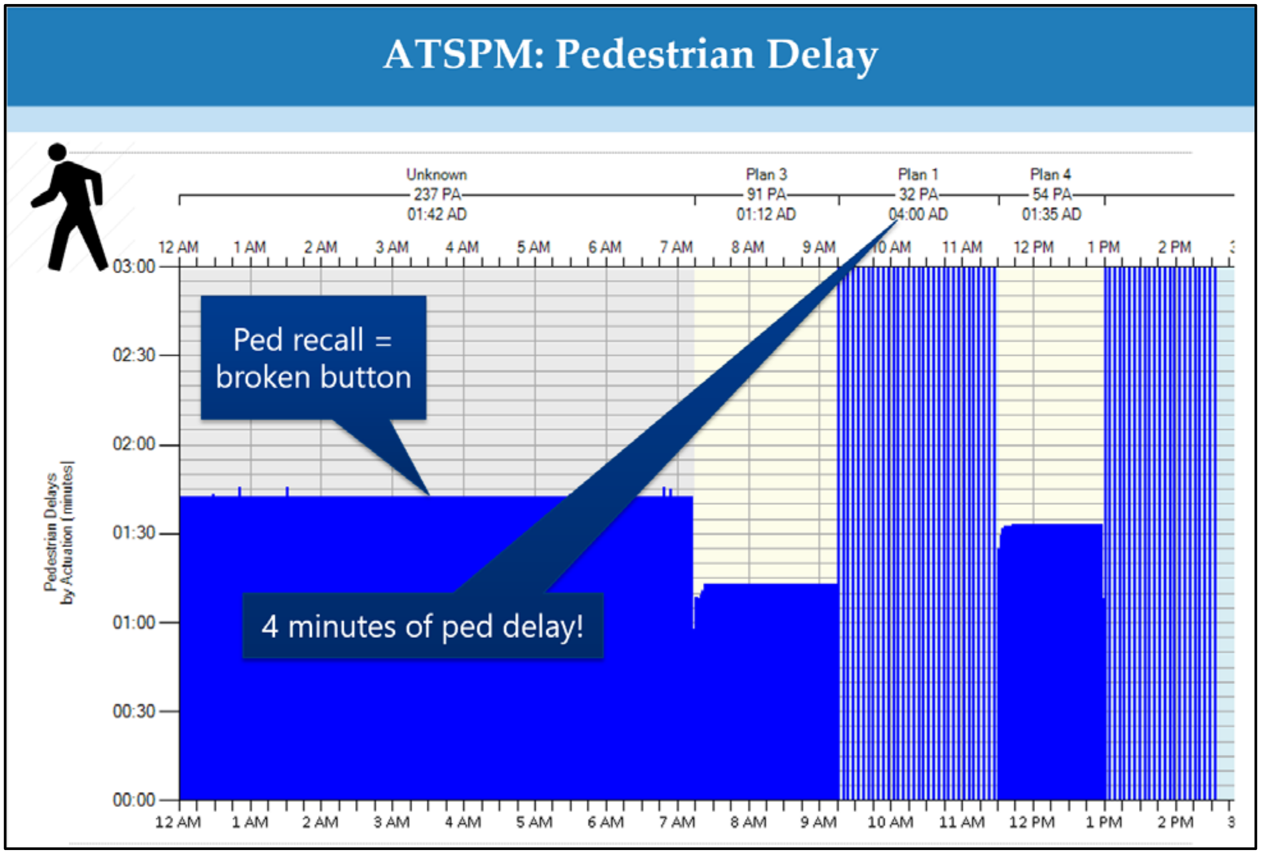


Figure 2.25 Pedestrian Delay Shows Pedestrian Actuations on Coordinated Phases - PennDOT

2.6 Progression Analysis

There are three important uses of the PCD data. First, is making adjustments by looking at each PCD. Second, is using the Link Pivot tool that analyzes all of the PCD data on the corridor and makes offset recommendations. Finally, tracking AOG degradation over time to know when a corridor's coordination plans need to be reevaluated.

2.6.1 Purdue Coordination Diagram

The PCD data shows at which point in the cycle each vehicle arrives. The PCD in Figure 2.26 details how quickly observations and adjustments can be made from the PCD diagram. In this example, new signal coordination plans were installed along a major highway. While field staff were fine-tuning along the corridor, a signal engineer noticed at one of the key intersections almost all of the vehicles were arriving on red in the PCD. A new signal controller brand was in use at this particular intersection and the offset reference point was not set correctly. At about 11:45 the offset was corrected and most motorists began arriving on green.

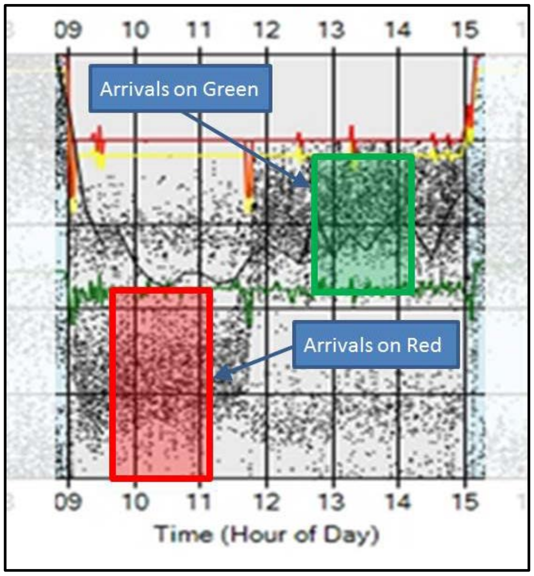


Figure 2.26 PCD Where Offset was corrected at 11:45

Checking PCDs during the process of coordination optimization is useful for both: 1) confirming changes made during field fine-tuning and 2) identifying issues that may have been missed by field staff.

PCDs are also useful as an MOE by showing the change in AOG as a result of the optimization effort. Figure 2.28 shows the results of a signal retiming study on a busy corridor. Overall, the percent of vehicles arriving on green improved by 19%. This before and after data was all collected with ATSPMs and is real measured data. No field visits or manual data collection was needed.

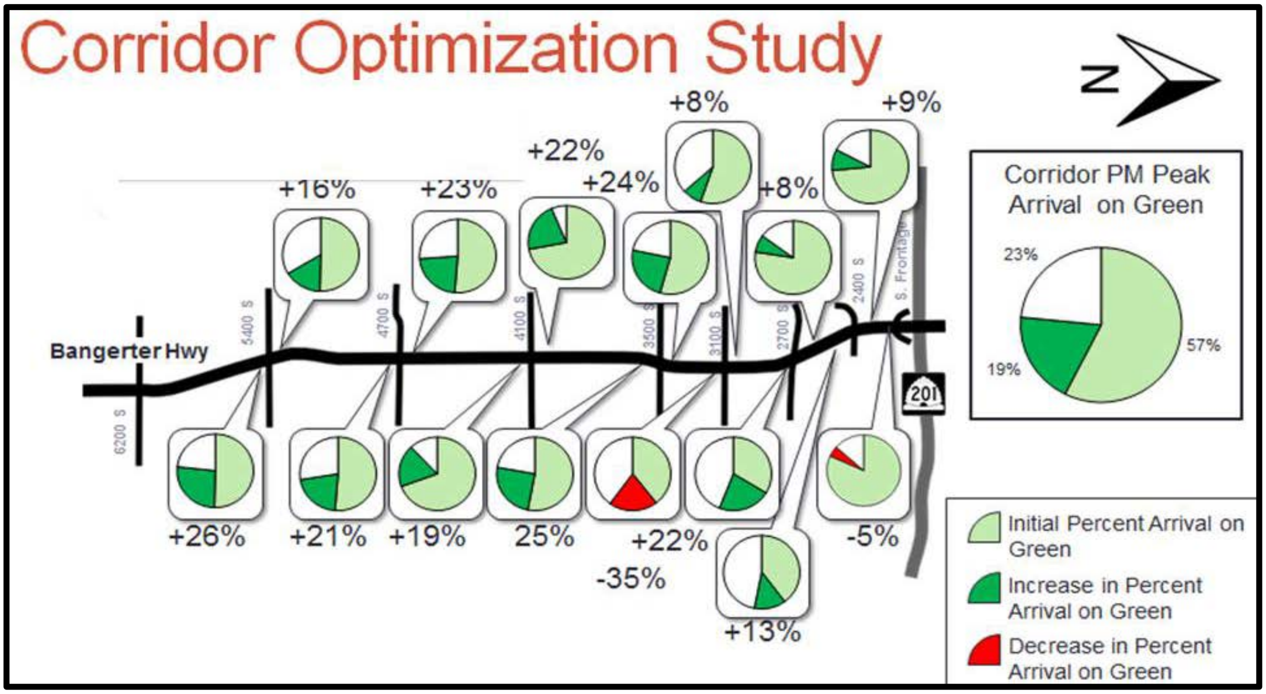


Figure 2.27 Changes in AOG used as an MOE

2.6.1.2 Analysis of incorrect offsets – Pennsylvania Example

PennDOT uses Purdue Coordination Diagrams to accomplish a key goal of improving progression on critical corridors. Figure 2.28 and Figure 2.29 detail a case example where the offset was incorrectly set and the intersection was experiencing poor arrivals.

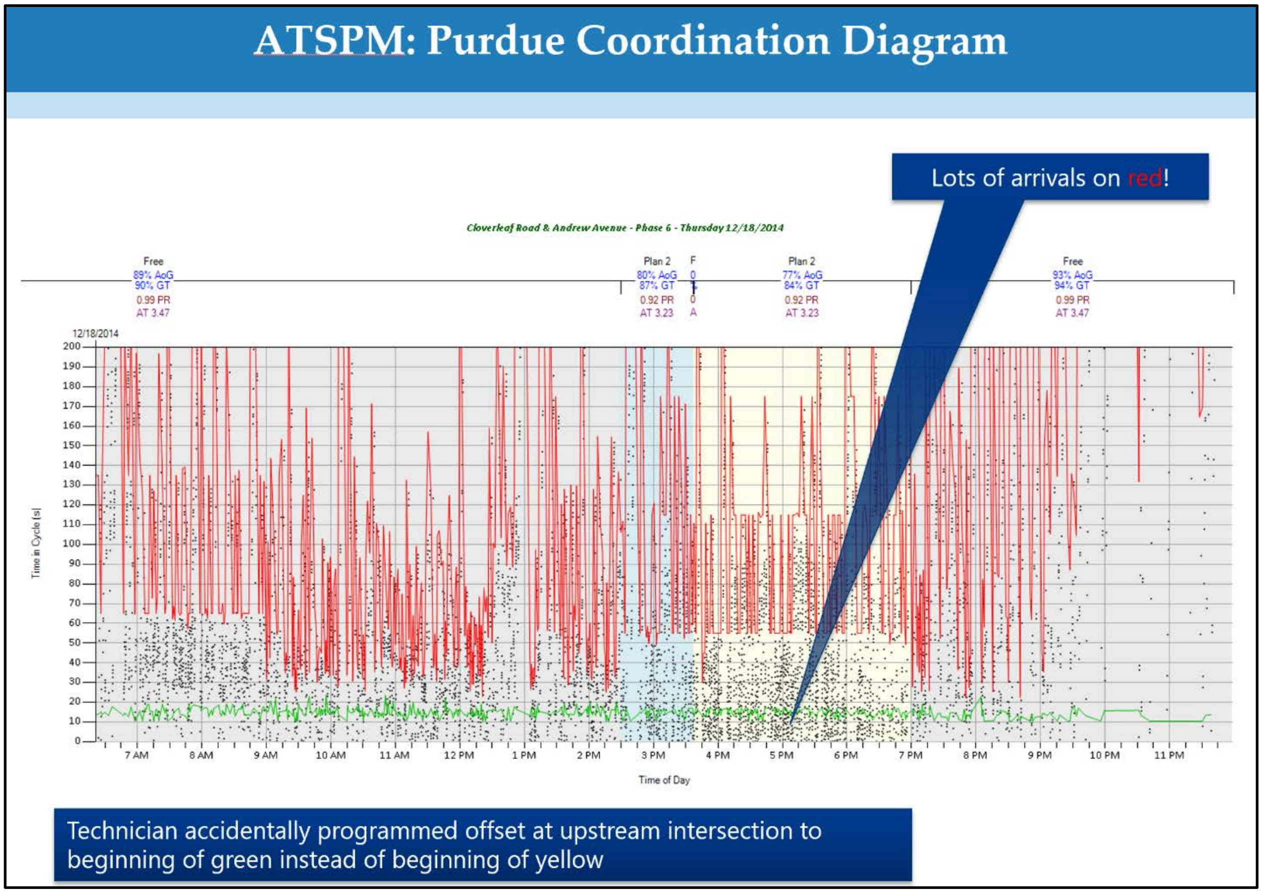


Figure 2.28 PCD Used to Identify Offset Concern (BEFORE) - PennDOT

The vertical axis is time in the cycle, and the signal turns green for the subject line at the green line and is green going up until the yellow line is reached. Each black dot is one vehicle arriving. The goal is to get the black dots arriving on green. This can be further expanded to show an entire day with different timing plans all in one chart.

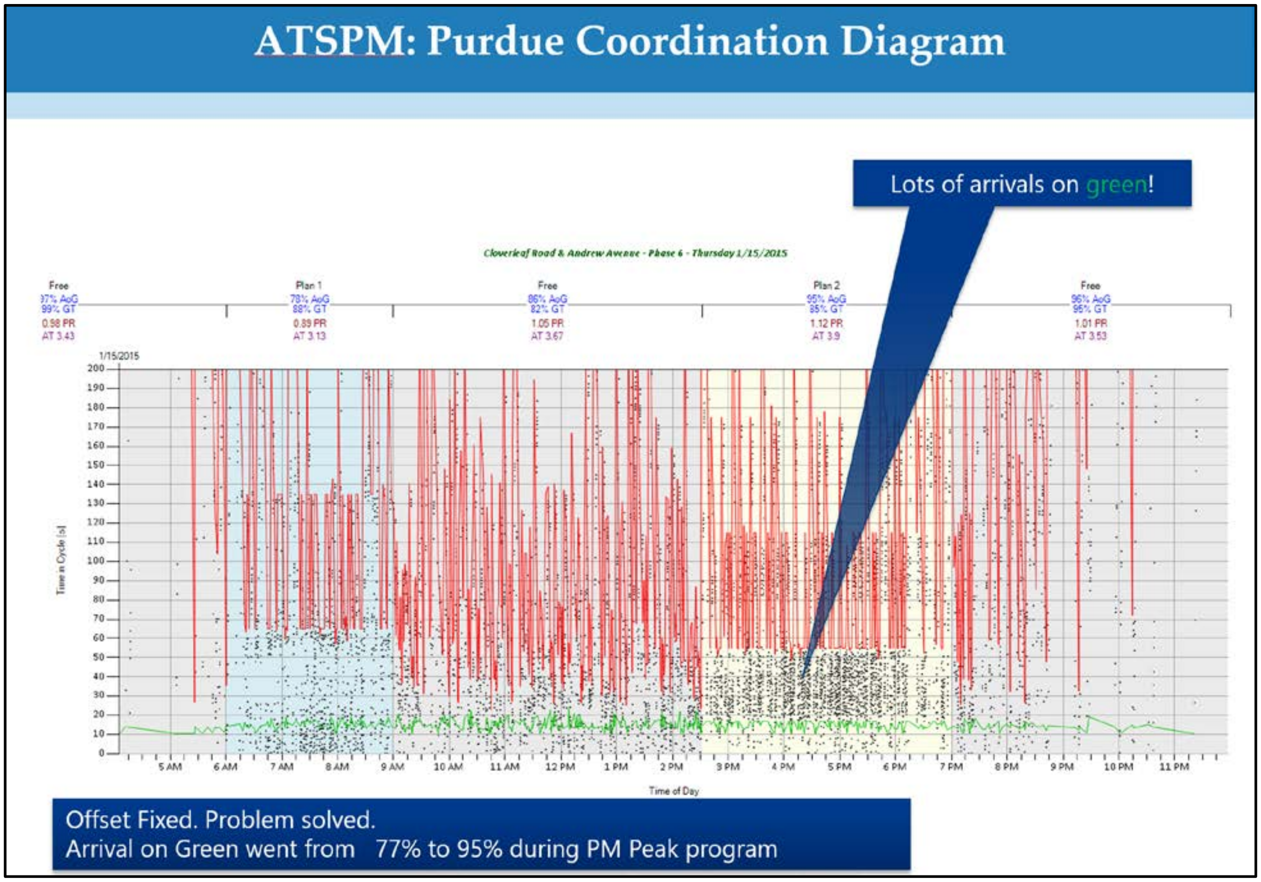


Figure 2.29 PCD Used to Identify Offset Concern (AFTER) - PennDOT

2.6.2 Executive Reporting

Executive leaders and public officials are interested in program-wide signal performance and trends. They want to know if signal operations are getting worse, getting better, or staying the same and by how much. They also want to know how an agency most effectively prioritizes resources and workload. PCD data enables us to better respond to those questions.

Figure 2.30 shows an example of a statewide executive report. It shows 30% of vehicles are arriving on red. This is measured data from approximately 400 intersections and 800 approaches and is averaged over the 24 hours of each day throughout the various months. ATSPMs now have an Aggregate Data feature that makes producing these types of reports easier. In addition, it is possible to further drill down and access this same information for various areas, corridors and intersections statewide. This helps prioritize resources to focus signal timing improvements on the corridors of greatest need.

Executive Reports & Prioritizing:

Statewide Summary 24 hours / day

Month	Arrival on Red		Volume	Intersections	
Month	Percent	Platoon Ratio	Daily Average Per Approach	Total	Number of Approaches
Aug 2014	30%	1.16	10,740	414	843
July 2014	30%	1.30	9,467	410	837
June 2014	30%	2.73	6,201	405	827
May 2014	30%	1.40	9,628	377	774
April 2014	30%	1.12	10,383	368	752

- Region, corridor, and intersection summaries also available.
  - Prioritize coordination projects where they're needed the most.
- Software project to modify breakdown by time-of-day instead of 24/7.

Figure 2.30 Executive Reports Example

2.6.3 Link Pivot

Purdue Link Pivot is an ATSPM tool that generates recommended offsets for coordinated operations along predefined routes of consecutive signals with PCDs configured along the route. Table 2.2 outlines a number of steps for offset optimization.

Table 2.2 Link Pivot Offset Optimization Steps

Determine Scope	• Check the following: a. Advance detector health (See System Monitoring section) b. ATSPMs configuration. (See System Monitoring section) c. Communication status for each signal. d. Day plan transition time congruity along the corridor. e. Cycle length congruity along the corridor. f. Time periods where queues reach beyond advance sensor count zone making it unable to see true arrival times. If it only queues beyond count zone for 15 mins consider moving zone location back.
Determine Start and End Times	• Start with day plan change times but exclude the first 15 to 30 mins so that arrivals while the signal is in transition are not included the report. • Exclude time periods where long queues make it impossible for sensors to see true arrival times. For when it queues beyond the count zone from more than 15 mins and moving the zone back is not likely to help. In PCDs it

	will look as if the platoon is arriving late (See discussion and illustration below).
Determine Starting Point	• Start from the signal where it is desirable to hold its offset unchanged for cross-coordination or for coordination with non-link-pivot signals on the corridor. • Ensure Link Pivot tool is set up appropriately for the chosen starting point.
Changing Offsets	• Avoid making offset changes based on the offset adjustment recommendations of a single day. Compare a minimum of 3 or days and use the recommendations that agree across all the days or at least 2 of them. • No need to change all offsets each time but change the 2 or 3 offsets that will make the largest predicted improvement in AOG. • If there are special relationships between signals, closely spaced or interchange signals, which by field knowledge should not be changed be sure that offsets at both signals are changed by the same amount.
Do Not Use	• Monday or Friday recommendations. They differ significantly from those provided on Tuesday, Wednesday, and Thursday. • Also, only use midday recommendations for off-peak patterns not late off-peak recommendations.
Modify All Day Plan Patterns Simultaneously	• Only requires a few hours of work a week.

Determining when queues are reaching past the advance sensor count zone will primarily have to be done in the field or via camera. A portion of a PCD from a signal on corridor heavily used by university students and faculty traveling to and from campus is shown in Figure 2.31. Arrivals at the beginning of the period, from 6:30 to 7:30, look good arriving just as the phase turns green. However, after 7:30 it begins to look as if the platoon is arriving late but in reality the queue is reaching beyond the count zone. This is caused by the fact that it takes a while after the light turns green for the queue to get moving back where the count zone is. Link Pivot results from periods when this occurs should not be used.

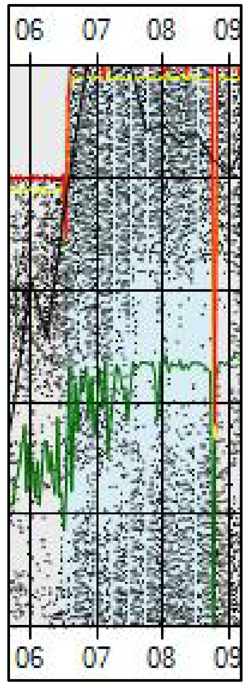


Figure 2.31 PCD Example of Queuing Past the Count Zone

2.6.4 Identifying Need for Retiming

Figure 2.32 shows the percent of vehicles arriving on green tracked monthly over 1.5 years along a corridor. The AOGs degrade over time. The signal coordination was optimized again in October 2014.

Tracking changes in AOG helps indicate when the coordination needs to be revisited. Historically, every 3 years coordination plans were checked and redone. However, with this tool, optimization can wait unit degradation in AOG can actually be observed.

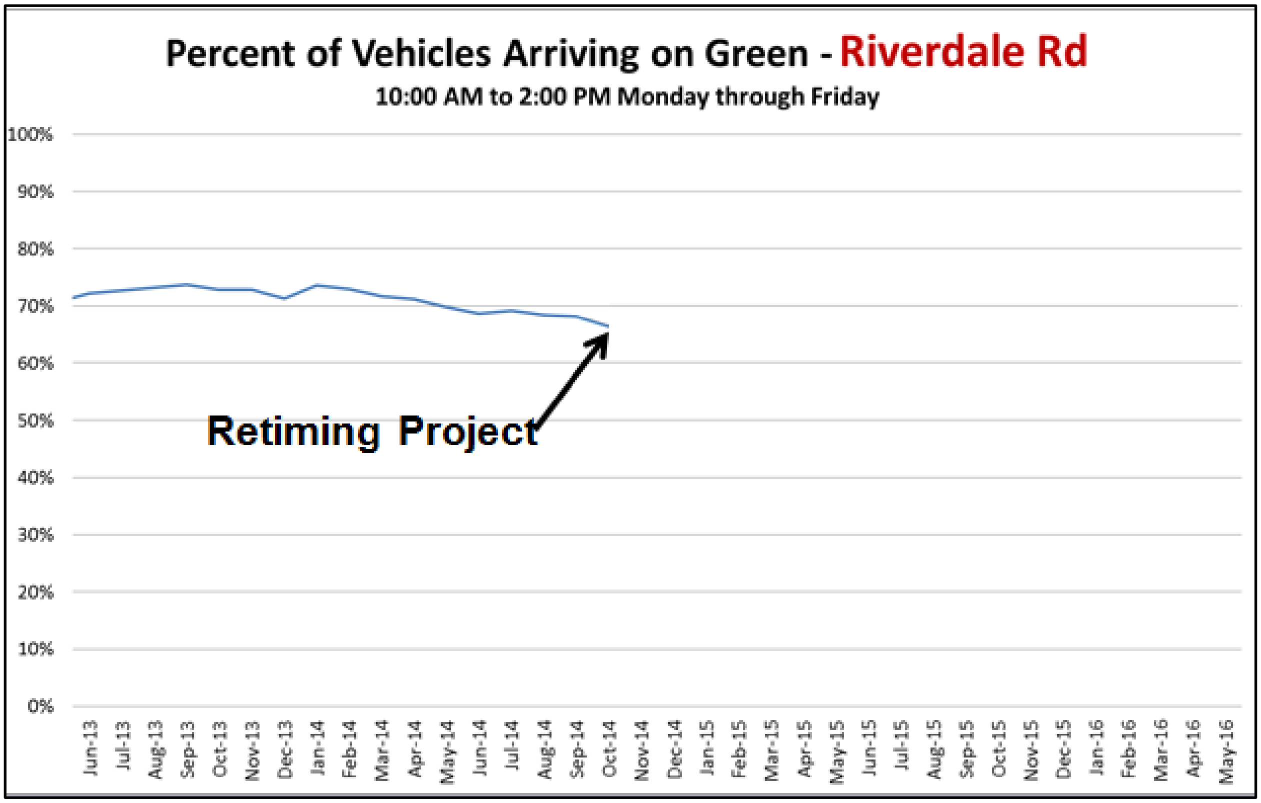


Figure 2.32 Degradation of AOG Triggers Coordination Optimization

2.7 Throughput Analysis – Pennsylvania Example

If demand exceeds capacity at an intersection, there will be a queue. Traffic signals can reduce capacity, but they can't increase it. The goal is to allow for the highest volume of thru traffic on as many approaches as possible to ensure maximum efficiency of the intersection.

Figure 2.33 is an indication that the throughput volume has plateaued for this movement. Every possible second of green is being used to serve thru traffic at the intersection. Looking at this intersection Purdue Split Failures it became evident that other movements had excess time that could be given to the peak movement. Figure 2.34 is an indication of the additional throughput that was gained in through this analysis and the redistribution of split time.

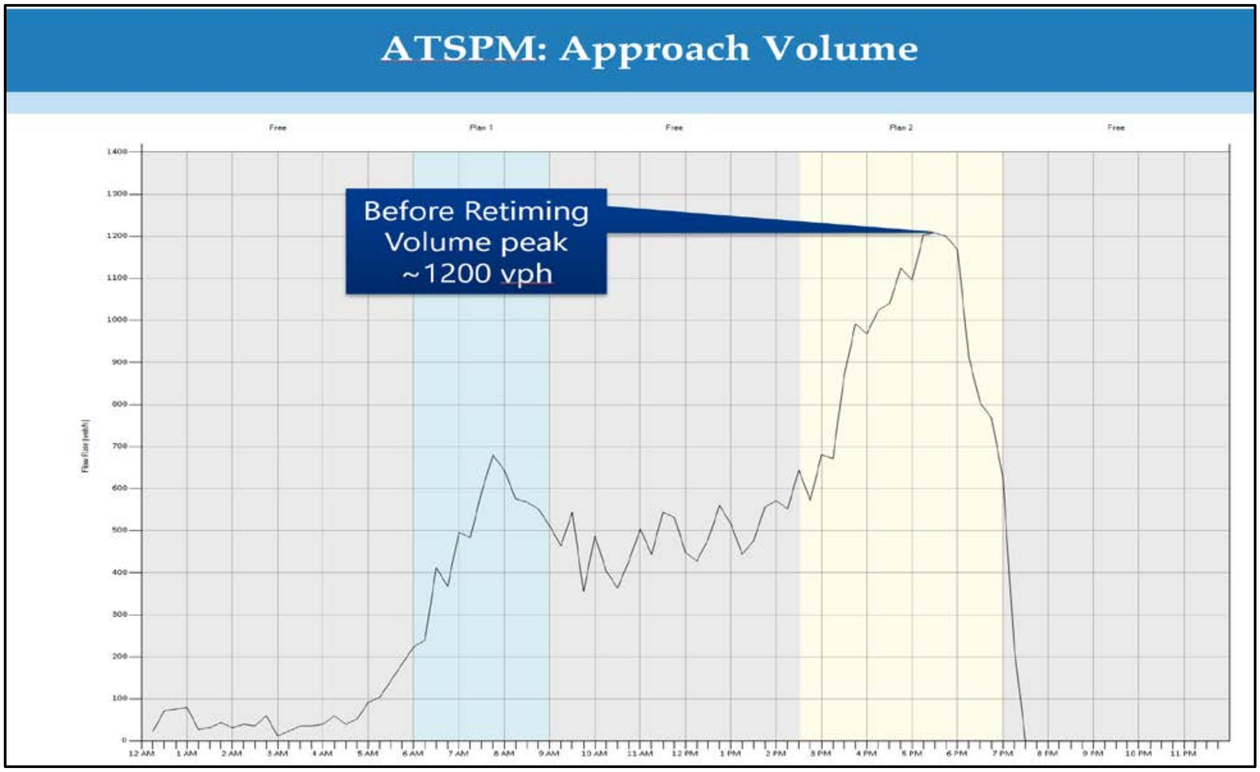


Figure 2.33 Throughput Analysis (BEFORE) - PennDOT

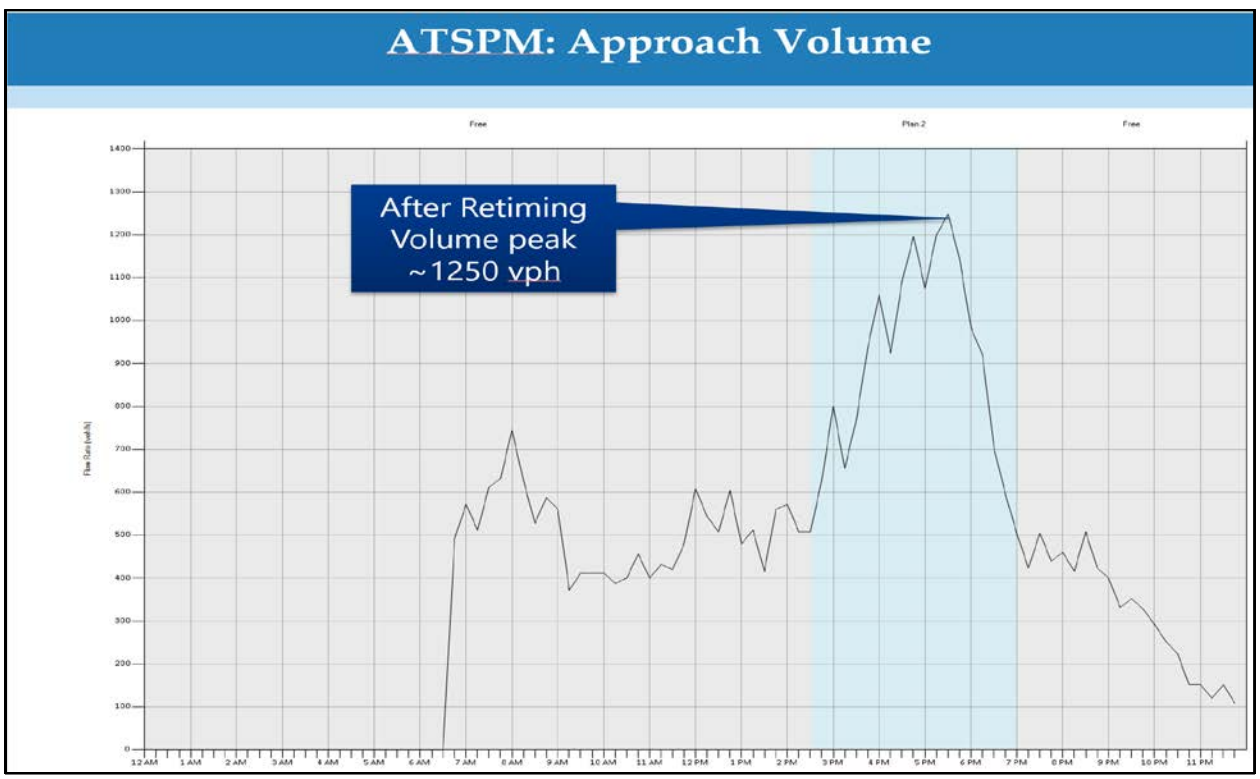


Figure 2.34 Throughput Analysis (AFTER) - PennDOT

2.7 Determining Coordination Speeds (Link Speeds)

Travel speed is critical data for any signal coordination project. The link speed used in a signal coordination model dramatically changes the resulting offsets. Historically, the speed limit has been used but real travel speeds are regularly below or above the speed limit. Correcting the issue can take a significant effort in the midst of field fine-tuning. The ATSPM Approach Speed metric provides this value data.

Figure 2.35 shows and example of an approach speed chart. Between 16:00 and 17:00 the average speed drops from 40 mph to 17 mph. Progression designed for 40 or 45 mph is not likely to work well during this time period. This metric is helpful for planning for the real speed conditions.

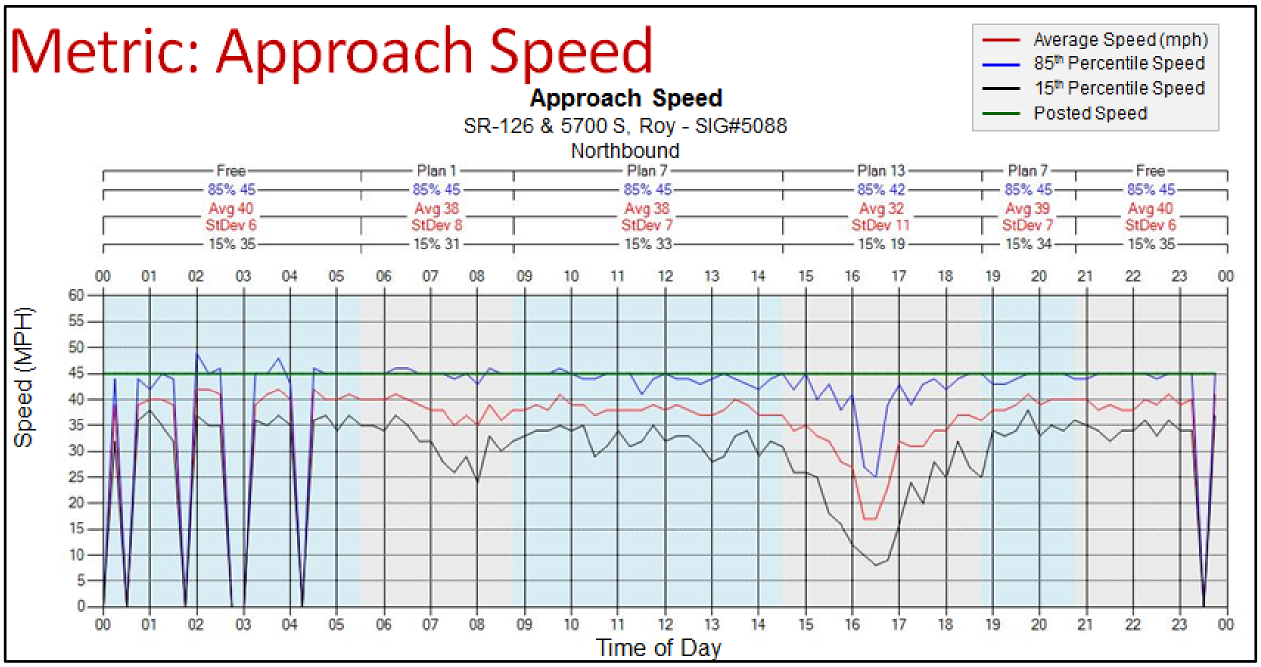


Figure 2.35 Approach Speed Metric

2.8 Determining TOD Schedule

Another task associated with signal coordination is determining the time periods when coordination plans should run in addition to when the signals should be set free overnight. The Approach Volume metric is helpful for this. Figure 2.36 illustrates the volume peaks that can be associated with the AM and PM periods as well as the lower volumes period when an off-peak plan could be scheduled.

Figure 2.36 Defining TOD Schedule Using Approach Volumes

Historically, determining these transition times required field observations or pneumatic tube counts. While field observations is still a good idea, once there is a sense of what field volume levels look like compared to the approach volume data, it is easier to make decisions about when other transitions should occur, like on weekends.

Approach volumes also help in determining progression priorities. For example, in Figure 2.36, if there is a choice to have a northbound stop or a southbound stop in the AM peak progression the data shows that northbound volumes are over twice that of southbound. The progression should favor northbound and if there has to be a stop, it should be southbound that stops.

2.9 Coordination Complaints Resolved Using ATSPMs

A critical part of maintaining a system of coordinated signals is receiving complaints from the motoring public. Signal staff can't watch everything all the time. ATSPMs can help by either confirming or refuting what is reported by the public. ATSPMs are also helpful for confirming that this issue is fully addressed after a change has been made.