TRAFFIC SIGNAL PERFORMANCE MEASURES

FINAL REPORT

WSP | PARSONS BRINCKERHOFF

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Executive Summary

This report provides an overview of Traffic Signal Performance Measures (TSPMs), highlighting the potential benefits and challenges that they pose for local traffic control agencies. The authors conducted a literature and peer review of the applications of TSPMs from jurisdictions across the United States in an effort to characterize not just the potential of TSPMs, but the experience that agencies have had with them to date. As part of this effort, the authors consulted academic literature related to the development and implementation of TSPMs, and documentation developed by agencies that have implemented TSPMs. Additionally, interviews were conducted with a number of jurisdictions and academics involved with TSPMs, including:

- Charlie Wetzel, Seminole County Public Works, Florida
- Vik Bhide, City of Tampa, Florida
- Chris Day, Purdue University
- Mark Taylor and Jamie Mackey, Utah Department of Transportation
- Jim Sturdevant, Indiana Department of Transportation
- Aleksandar Stevanovic, Florida Atlantic University
- Alan Davis, Georgia Department of Transportation
- Steve Misgen, Minnesota Department of Transportation
- Shital Patel, Regional Transportation Commission of Southern Nevada

Results from the peer and literature reviews indicate that TSPMs are primed to take on a greater role in signal maintenance and performance as they are deployed more widely among agencies, and as TSPM software and documentation improves. On the whole, agencies see benefits from the implementation of TSPMs in the form of reduced cost and streamlined signal maintenance operations, as well as a public benefit from a reduction in signal-related travel delays, decreases in travel times, and public safety improvements.

From an implementation standpoint, a centralized signal management system is not a requirement for a jurisdiction to implement TSPMs and experience its benefits. However, response to certain TSPMs in making signal timing adjustments in real-time is facilitated by a central system connection. Implementation costs vary, but depending on an agency's existing Intelligent Transportation System (ITS) infrastructure and data storage capacity, implementation costs can be relatively low, especially when compared to the costs associated with the deployment of an adaptive signal system. Of greater concern to prospective jurisdictions is having the in-house technical expertise to carry out TSPM implementation, in addition to the engineering expertise to fully take advantage of the measures.

The following are the key findings that are discussed in more detail in this document:

- Benefits from TSPMs include:
    - System intelligence and remote signal monitoring
    - Travel time savings and reduction in delays
    - Public safety
    - Maintenance cost efficiencies
    - Additional verification of signal performance
    - Public information

  - Low-cost implementation

- Challenges include:
  - IT staff support and system documentation
  - Cultivating an understanding and appreciation of TSPM benefits among on-the-ground engineers and technicians
  - Allocating sufficient staff time for TSPM implementation, monitoring, and making periodic improvements
  - Data storage

- An update to the Utah Department of Transportation (UDOT) TSPM source code is freely available, allowing small agencies to implement TSPMs more easily.

- The number of signal performance measures are increasing, creating additional value to small agencies (reports, etc.)

- TSPMs present an opportunity for traffic signal data to become aggregated with additional transit and transportation metrics to create powerful and effective transportation system improvement tools.

1.0 Introduction to Traffic Signal Performance Measures

The development of Traffic Signal Performance Measures (TSPMs) emerged out of a recognized need for better urban traffic control system performance. Presently, most traffic control jurisdictions in the United States implement traffic signal timing plans based on observed traffic counts and travel time and delay surveys during typical conditions (*10*). The usefulness of a one-time traffic count or survey diminish over time as conditions change, and in most cases do not consider periodic variations in demand. Typically, years go by before signals are re-timed, as signal timing maintenance is labor intensive and driven primarily by driver complaints.

Even as more and more jurisdictions equip signals with communications capabilities and centralized software systems that make signal timing operations more systematic, metrics for evaluating the performance of individual signals or a network of signals has lagged.

The TSPMs reviewed in this report are predominantly those that were developed out of a partnership by Purdue University and Indiana DOT beginning as early as 2002 as part of an effort to evaluate the effectiveness of various vehicle detection devices. Since the initial TSPMs were released at that time, system developers have added additional performance measures and updated the software source code to make it easier and quicker for agencies to install and implement. Most agencies that have deployed TSPMs are now using a software system developed by UDOT and made available for free to any agency. As this review is being conducted, UDOT is poised to release an updated version of their TSPM software, along with documentation to help agencies install and operate it.

The following sections will highlight the benefits obtained through TSPMs, what the system requirements and costs are, as well as the experiences of jurisdictions throughout the country.

What are Traffic Signal Performance Measures?

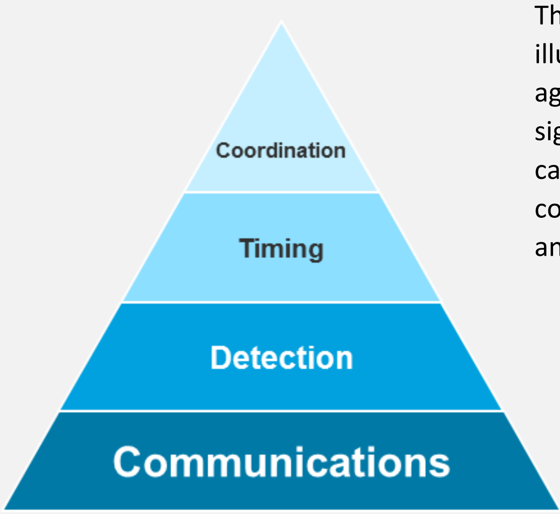
"Automated signal performance metrics show real-time and historical functionality at signalized intersections. This allows traffic engineers to measure what they previously could only model. Accurate decision-making about signal performance and timing helps signal management personnel identify vehicle and pedestrian detector malfunctions. This cost effective solution also measures vehicle delay and the volume, speeds and travel time of vehicles. Your agency can use these metrics to identify operational deficiencies, optimizing mobility and helping manage traffic signal timing and maintenance. Evaluating your traffic signals helps you reduce congestion, save fuel costs and improve safety."

-AASHTO Innovation Initiative (*1*)

2.0 Overview of Traffic Signal Performance Measures

There are more than a dozen traffic signal performance measures in use by various agencies. Some of these measures are standard ones developed by Purdue researchers or part of UDOT's widely-available TSPM software package. Other measures have been custom-tailored by agencies for specific purposes and may become more widely available. This section will discuss some of the key measures in detail, along with relevant illustrations.

Performance Measure Pyramid



The "Performance Measure Pyramid," shown here, illustrates the hierarchy of considerations that local agencies must make to efficiently manage their traffic signal networks. In interpreting the pyramid, agencies can ask themselves the following questions, which correspond to each step. Implementing TSPMs can help an agency advance to higher steps along the pyramid.

1. *Communications*: Is communication working?
2. *Detection*: Are detectors working?
3. *Timing*: Is there adequate green time on each phase?
4. *Coordination*: Are most vehicles arriving on green?

Figure 1: Example of Performance Measure Pyramid (2).

The detection devices that operate at a given intersection dictate the number of performance measures that can be obtained from that location. Table 1 lists key traffic signal performance measures, organized by the relevant detection devices required to obtain them.

Table 1: Common Performance Measures and Detection Needs

Detection Type Required	**Common Performance Measure**
High-resolution controller only (*No Additional Detection Needed*)	Purdue Phase Termination
	Split Monitor
	Pedestrian Actuation / Delay
	Preempt Duration
Advanced Count Detection (400 feet behind stop bar)	Purdue Coordination Diagram
	Approach Volume
	Volume-to-Capacity Ratio
	Purdue Link Pivot
	Platoon Ratio
	Arrivals on Red
	Approach Delay
	Executive Summary Reports
Advanced Detection with Speed	Approach Speed
Lane-by-lane Count Detection	Turning Movement Counts
	Red / Yellow Actuation
Lane-by-lane Presence Detection	Split Failure (future)
Probe Travel Time Data	Purdue Travel Time Diagram

The following are key traffic signal performance measures used most commonly by the agencies interviewed for this report.

Purdue Phase Termination

Additional Detection Requirements	None
Purpose	Displays the reason for phase termination in a conventional controller.
Benefits	Generally useful for visualizing which of the possible reasons for phase termination occurred at a given time. The chart has most often aided agencies in investigating public complaints of long wait times during overnight hours, as shown in Figure 2, below.

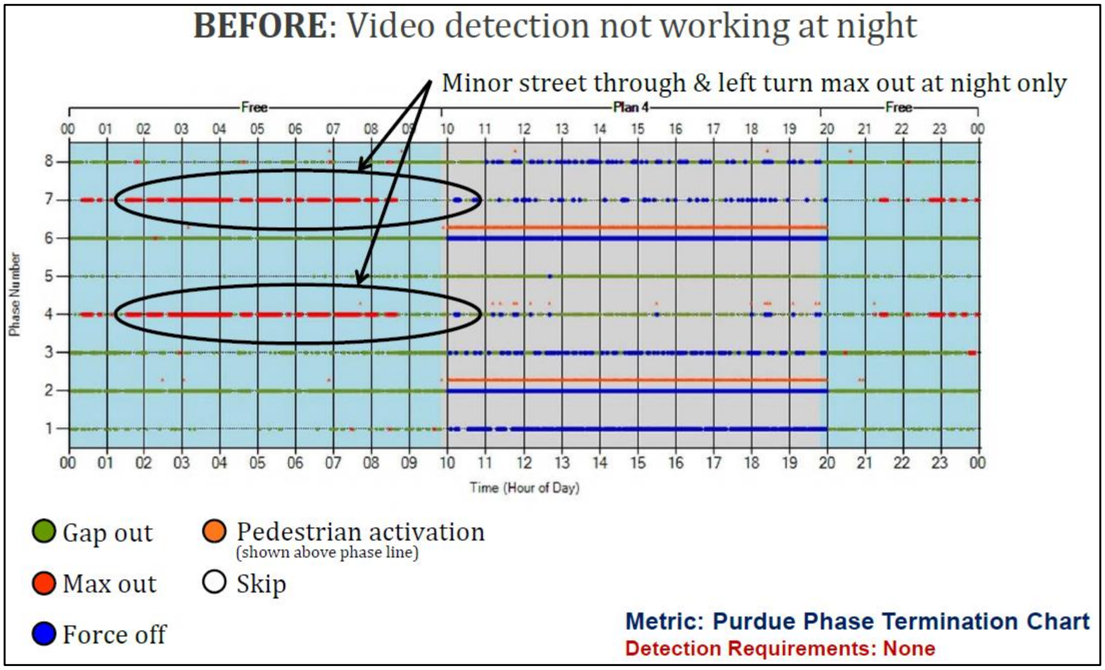


Figure 2: Example of Phase Termination Chart (3)

Purdue Coordination Diagram

Additional Detection Requirements	Advanced Count Detection
Purpose	Shows the volume of vehicles that arrive at various traffic signal phases over the course of a specific time period (usually one day).
Benefits	The Purdue Coordination Diagram is considered to be one of the most instructive of the TSPMs. The chart allows the one to quickly indicate if the majority of vehicles during a particular time period are arriving at a signal during the green or red phases and can re-time the signal if necessary.

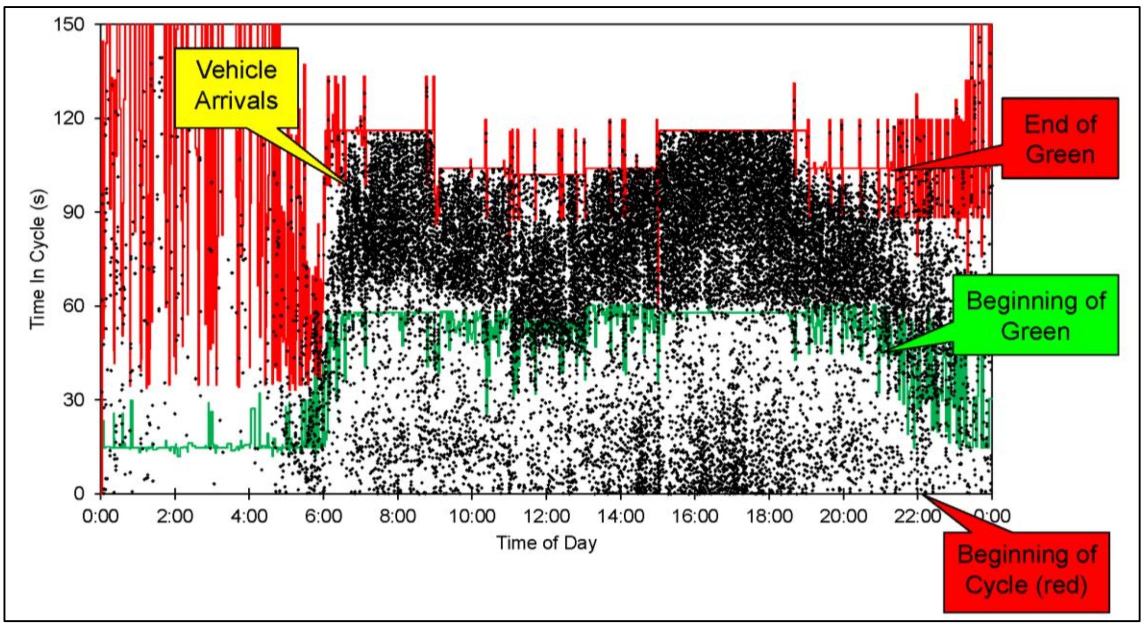


Figure 3: Example of Purdue Coordination Diagram (4)

Approach Volume Visualization

Additional Detection Requirements	Advanced Count Detection
Purpose	Graphically illustrates vehicle count figures over the course of a given period of time, on a directional or lane-by-lane basis, depending on the detector devices in place.
Benefits	In addition to evaluating potential capacity constraints at particular intersections, this measure has proved useful to local planning and economic development officials interested in vehicle movements that might be related to special events or changes in land use.

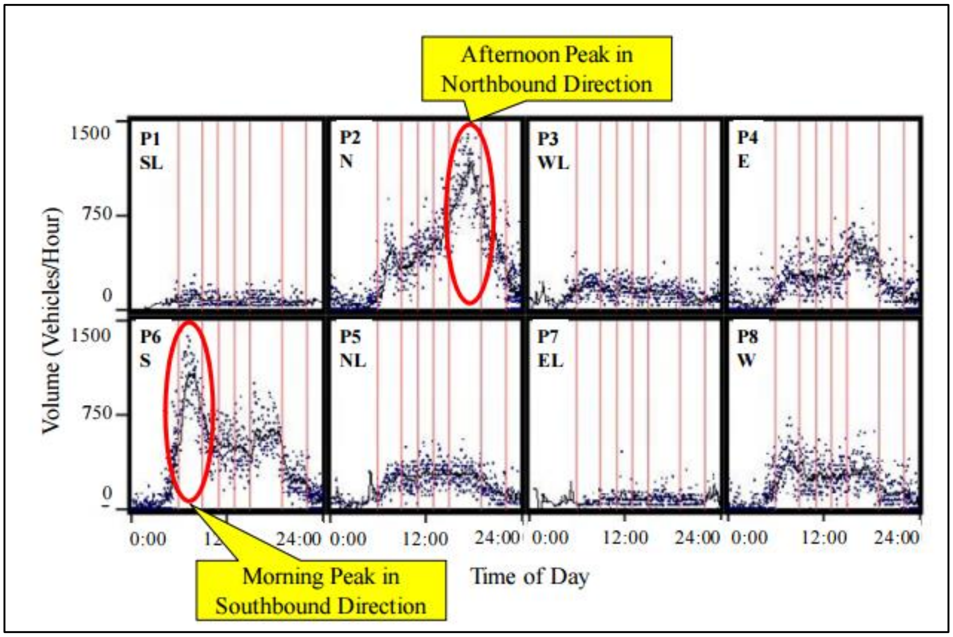


Figure 4: Volume Plots (5)

Volume-to-Capacity Ratio Charts

Additional Detection Requirements	Advanced Count Detection
Purpose	Displays the ratio of vehicle volumes to lane or directional capacity at a given intersection.
Benefits	Allows traffic managers to quickly understand where traffic volumes are approaching or exceeding the calculated roadway capacity.

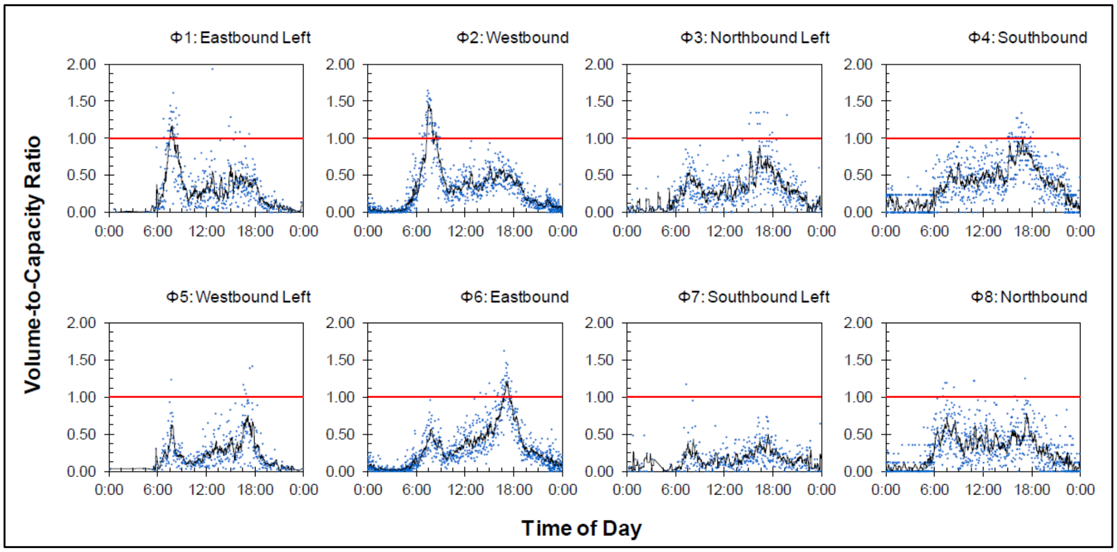


Figure 5: Example of Volume-to-Capacity Ratio chart. (6)

Approach Speed

Additional Detection Requirements	Advanced Detection with Speed
Purpose	Shows the speed at which the average vehicle, or vehicles at the 85th percentile are traveling as they pass through a given intersection.
Benefits	The chart produced by this metric can identify signalized intersections that pose a safety risk due to having a high proportion of drivers arriving at high speeds. The tool can help engineers identify locations at which a longer all-red time may be appropriate.

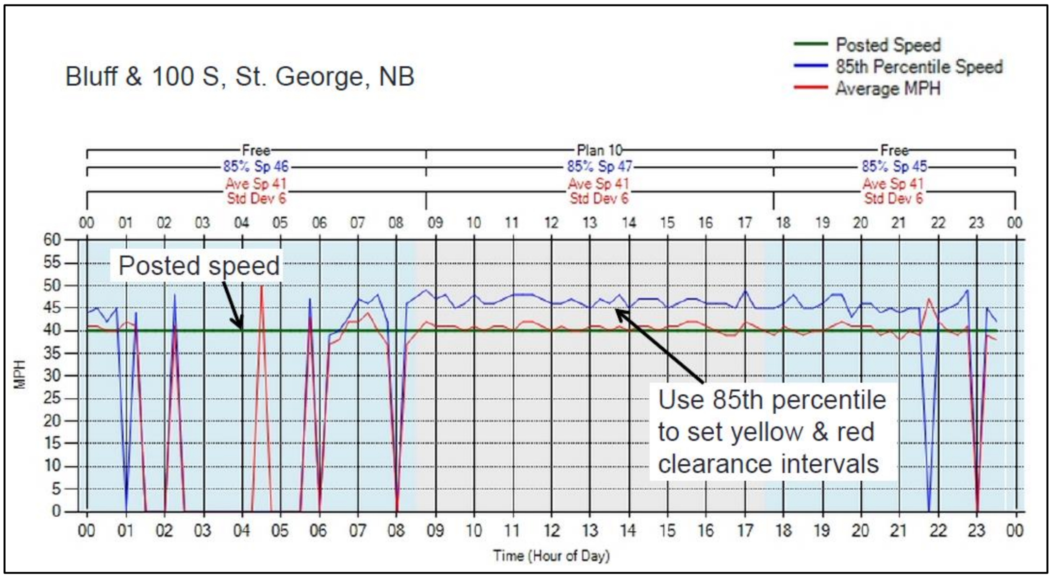


Figure 6: Approach Speeds. (2)

SPM Dashboard

Developed by the team at UDOT, the TSPM "Dashboard" provides an accessible way for members of the public and other users to access performance measures at specific signals and during specific days / times. Users can choose from the available measures so as to customize the data and information made available to them.

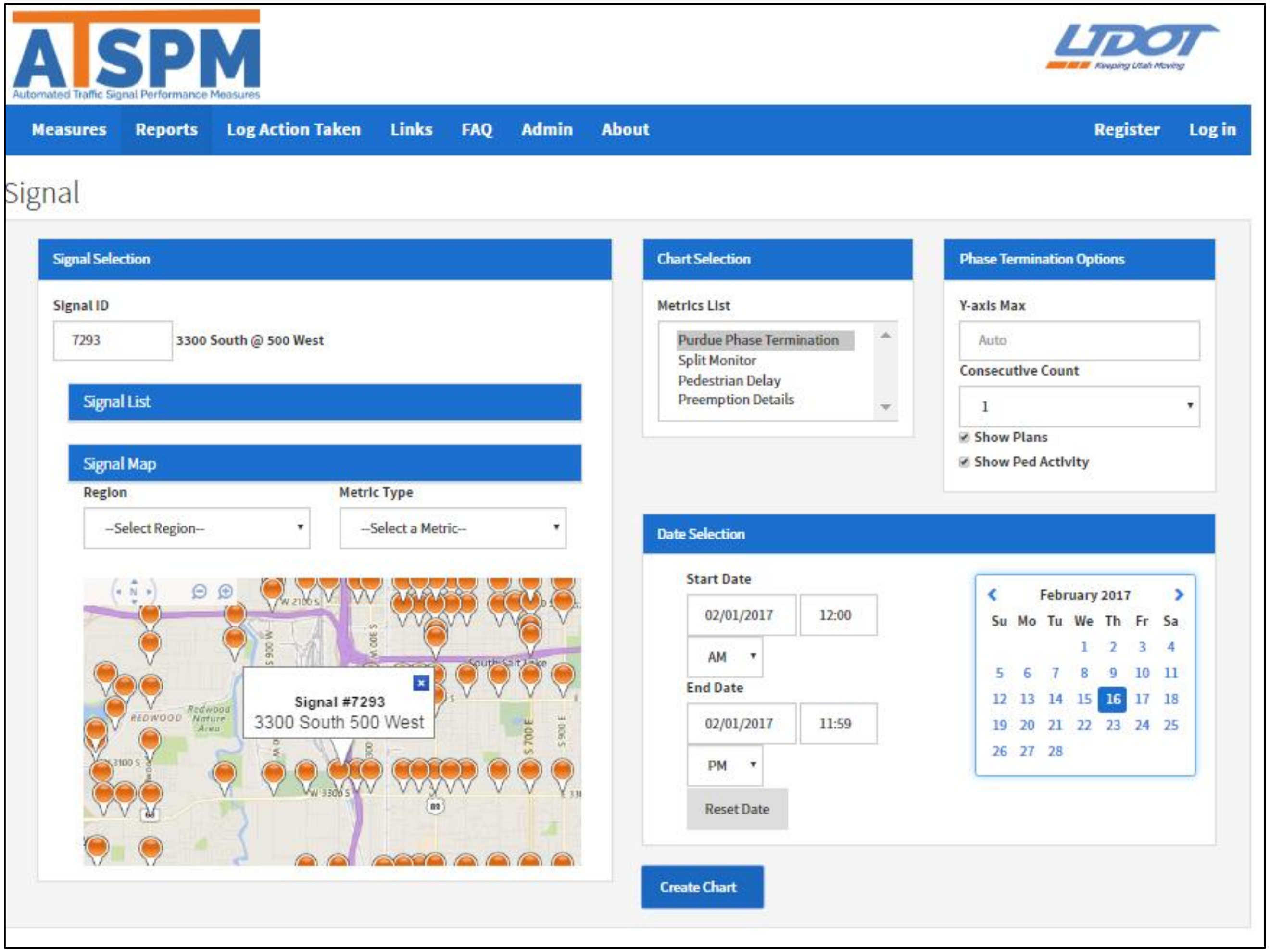


Figure 7: Utah DOT Signal Performance Metrics online "Dashboard." http://udottraffic.utah.gov/ATSPM/.

3.0 System Requirements

In contrast to other large-scale traffic systems implementations, TSPMs do not require advanced equipment and detection devices beyond what most traffic control agencies already have in place. Additionally, an advantage of TSPMs is that the technology was developed to be vendor-neutral, so no specific controller, detection device, or communications equipment is required. Instead, there are four key system requirements needed to transmit, process, and store controller/detector-generated data in a manner that can support TSPM analysis.

Detection Devices

As indicated in the previous section, detection devices vary widely by agency and by the given signalized intersection being monitored. An agency with advanced and specialized detection devices (such as setback count detectors, speed detectors, turning movement counters, etc.) is able to obtain a greater number of TSPMs, however some agencies report that the most valuable TSPMs can be achieved without special detection devices (Purdue Phase Termination and Split Monitor) (3).

High-Resolution Controller

High-resolution traffic signal controllers, capable of recording events at the 0.1 second interval are required for robust TSPMs. Because of the efforts of Purdue University researchers in convening groups of controller manufacturers to collaborate on data specifications, TSPMs can be achieved with nearly any high-resolution controller that an agency might have, including models from Econolite, Peek, Siemens, Intelight, Trafficware, and McCain.

Communications

Although some type of communications infrastructure is generally required to implement real-time TSPMs and achieve all of the benefits, the requirements are flexible and some agencies have, in fact, implemented TSPMs without a communication platform in place. The following are the three communications options that agencies have deployed to implement TSPMs:

- **Fiber connection**: The most reliable yet more expensive way to transmit controller data back to a central server is through a fiber connection. Fiber is common in many signal systems in urban areas.

- **Cellular modem**: If fiber connection is not available, traffic signals in the field can relay signal performance data to a central location via cellular modems. Agencies have reported that cellular modems represent a cost-effective way to deploy the communications infrastructure needed to realize TSPMs.

- **SneakerNet**: Even without communications capabilities at signals, some jurisdictions are nonetheless forging ahead with TSPMs. Through this configuration, data from the signal controller is stored on an SD memory card in the cabinet and retrieved periodically to upload to a central server, or otherwise reviewed only in the case of signal complaints.

Data Storage

Data storage capability on a central server is another system requirement that agencies must have to implement TSPMs. Large agencies typically have server capability at TMCs or other locations, but for some smaller agencies, data storage can be a challenge. Even agencies with existing servers that can be utilized for TSPMs have reported that providing enough storage to accommodate TSPM data from signals in the field can be difficult, especially as more and more signals become equipped with TSPM capability.

4.0 Benefits

The various measures that agencies have been able to extract from the deployment of TSPMs have achieved a number of significant benefits. Although some agencies have been able to quantify the benefits in the form of signal maintenance cost savings or travel time savings to the public, most agencies describe the benefits as more generally the ability to obtain data that is invaluable for traffic engineers to be able to accomplish their goal of providing efficient and effective traffic control systems to the traveling public. The following are the key benefits that emerged from a review of TSPM literature and through interviews with a range of jurisdictions that have deployed TSPMs.

- ***System intelligence and remote signal monitoring***: In various ways, interviewees who have experience with TSPM implementation describe its principal benefit as the ability to gather data and develop intelligence without the need to travel to the field (*20*). Importantly, signals can be evaluated and adjusted remotely so that valuable field technician time can be allocated to intersections where it is most needed for maintenance purposes.

- ***Travel time savings and reduction in delays***: Most agencies did not report that travel time savings was the primary or even a significant benefit of TSPMs, however they acknowledged that when signals are more reliable and functioning correctly, travel times likely exhibit a marginal improvement. Other agencies point to reductions in delays as a comparable benefit that results from well-functioning signals, although the impact on measurable travel times is hard to determine (*17*). Nonetheless, Indiana DOT has calculated the travel time savings related to an arterial re-timing project that was conducted as a result of data from TSPMs and found an annual savings of $2.7million for only a single, nine-mile corridor (*6*).

- ***Public Safety***: Not all agencies with TSPM experience reported verifiable public safety improvements, however anecdotal evidence from some agencies of TSPM data being deployed for various signal improvement projects suggests that the safety benefits can be significant. For example, the Regional Transportation Commission of Southern Nevada is deploying a new measure called Red Light Running which reports on how many vehicles are running red lights at specific signals. The report can be used to calibrate the all-red time at the intersection or to inform law enforcement on which intersections exhibit dangerous light-running patterns (*18*).

  Another TSPM that has valuable safety implications is the Speed During Green, which measures approach speeds. UDOT officials have used this measure to identify intersections at which the 85^{th} percentile speeds do not match the posted speed limits, and have thus adjusted the yellow interval time accordingly (*16*).

- ***Maintenance cost efficiencies***: Related to the benefit of remote signal monitoring, many agencies reported maintenance cost savings as a result of the deployment of TSPMs, due to the fact that signal re-timings are now performed only on travel corridors that need the most improvements, rather than by cycling through each and every intersection. Additionally, monitoring signal and detector performance through TSPMs streamlines an agency's ability to identify and repair faulty equipment. UDOT has estimated a cumulative cost-savings to the state of $1.5million as a result of this benefit (*4*).

- ***Additional verification of signal performance***: Agencies have reported that TSPMs have allowed them to validate the work of their consultant partners who are sometimes tasked with signal maintenance and re-timing tasks (*13*). Similarly, jurisdictions with more advanced, adaptive traffic signals are able to use TSPMs to evaluate their performance.

- ***Public information***: Agencies who have struggled in the past to communicate to the public around traffic signal performance have benefited from the ability of TSPMs to provide them with verifiable data on how the traffic system is performing. As an example, a jurisdiction in Indiana installed a "No Turn on Red" sign at an intersection in response to an increase in crashes at the location. This change led to a number of complaints from drivers to local officials, claiming unreasonable wait times at the red light. With TSPM data, the jurisdiction was able to demonstrate to city officials, and communicate to the public at large, that average wait times were less than 10 seconds.

- ***Low-cost implementation***: Unique among traffic signal technology deployments is the fact that TSPMs cost relatively little to deploy. Especially when compared to adaptive traffic signal systems, TSPMs can offer equivalent benefits for lower capital and operating costs.

5.0 Challenges to TSPM Implementation

Some of the challenges related to TSPM implementation have been alluded to in previous sections of this report. The following items emerged as the most pressing challenges related to TSPM implementation by signal control agencies and others.

- ***Technical support and documentation***: Small to medium-size agencies have reported difficulty obtaining the technical capacity to deploy TSPMs to new signals. Although most TSPM software has been made available to agencies for free, some still struggle to install and troubleshoot issues related to detector-controller-server communication. Documentation related to the installation and configuration of the latest version of UDOT TSPM software has only recently been released, raising expectations that TSPM implementation should be an easier exercise for local agencies. Nevertheless, few agencies have had experience installing the new software to-date.

  An additional challenge related to technical support can come from agencies' own internal IT policies and procedures. Agencies report wide variations in the level of cooperation and support that they receive from their IT colleagues, who are often asked to authorize signal software such as TSPMs to be able to operate on agency networks. Some agencies with TSPMs do not have publicly-available internet dashboards due to IT security concerns (*13*).

- ***Cultivating an understanding of TSPM benefits from on-the-ground engineers and technicians***: Aside from certain technical challenges to TSPM deployment, many agencies have reported difficulty in getting traffic engineers to embrace the data-driven value of TSPM, preferring instead to rely on field visits for traffic monitoring. Despite this, most agencies believe that this challenge will be overcome with time. An additional challenge related to TSPM "buy-in" from agencies and staff is related to the role that agencies perceive themselves as playing in traffic signal maintenance and operations. For example, some agencies that are not as responsible for, or invested in, efficient traffic signal operations may not welcome or understand the benefits of TSPMs.

- ***Staff resources for TSPM configuration, review, and improvement***: Although TSPM implementation does not require significant capital or maintenance outlays, agencies (particularly smaller ones) may struggle to allocate staff resources to TSPM implementation, monitoring, and improvement. Training on various signal metrics and their applicability to the local jurisdiction is likewise essential for TSPMs to be deployed successfully. The cost of such training, in the form of staff time, will vary from agency to agency.

- ***Data storage***: As mentioned in previous sections, for some agencies data storage capability or policies are becoming more of a challenge, particularly as TSPMs are deployed to a growing number of signals. Large agencies with ample server access struggle less with data storage constraints, but for smaller agencies that might be obligated by statute to store data for extended periods of time, this can represent a growing cost over time.

6.0 Recent Developments with TSPM Implementation & Application

A number of enhancements to TSPMs have recently been released by UDOT, which are expected to make the implementation and configuration of TSPMs easier for agencies who wish to experiment with their application for the first time. Additionally, TSPMs are creating opportunities for agencies to partner with companies or organizations around innovative traffic management ideas that have the potential to further improve traffic management in their jurisdiction. The following are several developments that any agency considering TSPMs will find noteworthy:

- UDOT has recently released a new, enhanced version of its TSPM software program which makes installation and configuration of the system much easier and faster. In addition, UDOT has added a "Reports" feature with the goal of providing TSPM users the ability to analyze metrics at the corridor level, rather than signal by signal. Agencies can download the TSPM source code for free at the following FHWA Open Source Application Development Portal website: https://www.itsforge.net/index.php/community/explore-applications#/30/129

- Detailed documentation on TSPM installation and configuration has been produced by the Georgia Department of Transportation (GDOT) and made available to agencies for free, with the goal of easing the process of deploying TSPMs. The documentation is available for download from the main UDOT TSPM website: http://udottraffic.utah.gov/atspm

- Additionally, UDOT hosted a multi-day "Train the Trainer" workshop in Salt Lake City in January 2017 to introduce the enhanced TSPM software and to train local agency personnel on how the system can be installed and configured. The training sessions were each video recorded and are available for viewing on UDOT's TSPM website: http://udottraffic.utah.gov/atspm

- As TSPMs continue to be deployed by more and more jurisdictions and to more signals, there are unique opportunities for innovative agencies to combine and analyze this data along with other traffic system information to create valuable tools for public officials and the general public to evaluate the performance of the transportation network as a whole.

- As an example of innovative partnerships around traffic performance, the City of Tampa has recently entered into a partnership with the mobile traffic app, Waze. The app provides the city with corridor-specific information that the city can verify and then make remote traffic signal adjustments. In return, the city provides information to Waze about upcoming road closures and special events so that the app can pass it along with users. FDOT has likewise entered into a partnership with Waze for incident management support.

- Currently, there are two jurisdictions in the State of Florida (Seminole County and the City of Tampa) that have begun to experiment with TSPM implementation. With the release of the new UDOT TSPM software, more agencies in the state are expected to implement TSPMs and experiment with the benefits that they have to offer.

7.0 Decision Framework for Agencies Considering TSPMs

To assist agencies in taking the steps to assess their current traffic signal system performance, and making a determination as far as whether TSPMs are an appropriate tool to deploy, the following diagram describes the processes and decision points that agencies should follow.

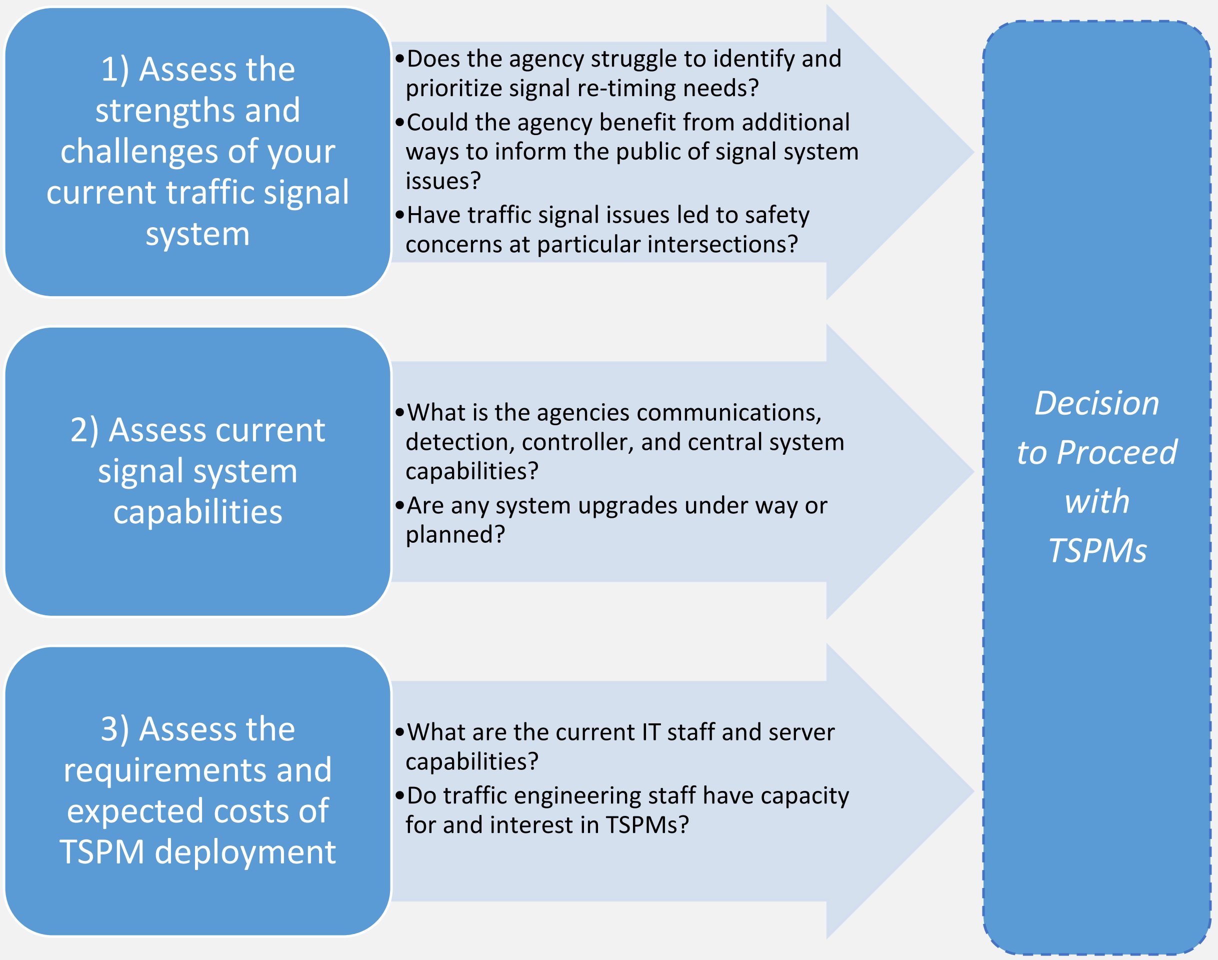


Figure 8: Decision Chart for TSPM Consideration by Local Agencies

The following implementation steps should be considered by agencies that wish to deploy TSPMs.

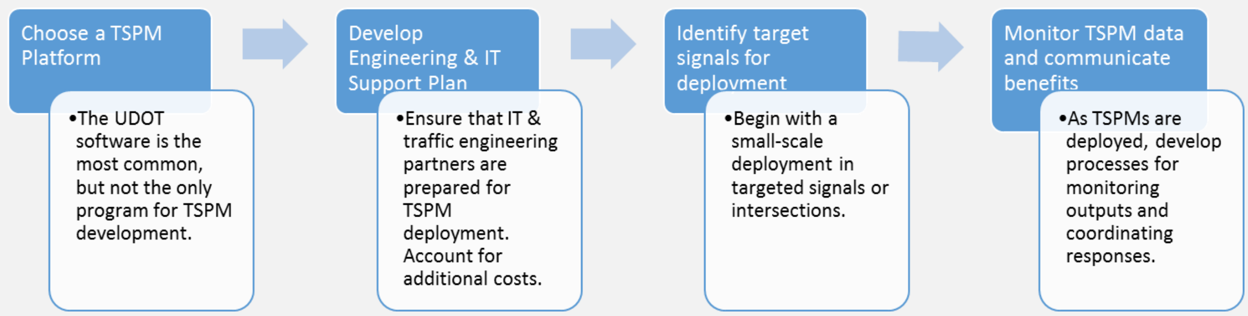


Figure 9: TSPM Implementation Process Chart

Appendix

List of Performance Measures

Performance Measure	Description
Background Cycle Length	Programmed cycle length as measured from time between successive yield points.
Effective Cycle Length	Actual time that it takes to serve all phases in a cycle.
Green Time	Actual green time displayed on a phase or overlap.
Capacity	Green time scaled by saturation flow rate to derive the provided capacity
g/C Ratio	Ratio of green time to effective cycle length.
Vehicle Count	Number of vehicles detected on a phase or overlap during a cycle.
Equivalent Hourly Volume	Vehicle count scaled to vehicles per hour.
Volume-to-Capacity Ratio	Equivalent hourly volume as a proportion of the provided capacity.
Phase Termination	Reason for phase termination in each cycle.
Phase Termination Diagram	Graphical plot of repeated phase force-offs.
Green Occupancy Ratio	Proportion of green time that the detector is occupied.
Red Occupancy Ratio of the	Proportion of the first 5 seconds of red that the detector is occupied.
GOR/ROR Diagram	Composite plot of GOR and ROR_5 with phase termination.
Degree of Intersection Saturation	Overall utilization of capacity provided by each phase in the critical path of the intersection.
Percent on Green	Proportion of vehicle arrivals taking place while the intersection is green.
Arrival Type	A version of the percent on green that is divided by the green-to-cycle ratio and fitted to a qualitative 1–6 scale.
Input-Output Delay	An estimate of delay on an approach based on relationship between arrival profile and assumed departure profile.
Purdue Coordination Diagram	A visualization of individual detector events relative to the status of the downstream phase or overlap.
Flow Profile	Cyclic distributions of the probability of green and proportion of vehicle arrivals taking place during a cycle.
Estimated Queue Length	Estimated length of queue based on analysis of shockwaves and detector occupancy.
Pedestrian Cycle	Indication of whether a cycle included a pedestrian phase.
Pedestrian Actuation to Service Time	Time between onset of a call for pedestrian service and beginning of pedestrian service.
Pedestrian Conflicting Volume	Volume on a movement that conflicts with a pedestrian phase.
Preemption Event Diagram	Visualization of event durations relevant to preemption entry.
Preempt Duration	Duration of preemption events.
Priority Time to Green	Time between onset of a call for transit priority and beginning of desired phase or overlap green.
Detector Failure	Histogram describing frequency of reported detector failures.

**This list is from the 2014 Purdue monograph,* Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach*. Additional measures may be available with the latest release of the UDOT software.*

Literature Review

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Peer Review: Interview Notes

Departments of Transportation Interviewees

13. ALAN DAVIS, GEORGIA DOT – 11/22/16

Current Involvement

- We have been running the old version of the Utah DOT's ATSPM code. It is cumbersome and broke our servers several times.
    - Update: we have upgraded to the newest open source release (4.0) and it is very stable and user friendly.
- Upon learning that a new version of the code is being developed, we volunteered to develop documentation that can be shared with agencies across the country. The documentation we are creating will be released on December 15th and will have three sections:
    - Section 1: Explanation of how each application works and runs (e.g., "the Purdue Coordination Diagram accesses these data points and plots them in this manner.")
    - Section 2: "How-To" work the website and how to run the watchdog service, etc.
    - Section 3: Installation guide to the new software.
- Currently, GDOT and the City of Johns Creek have implemented ATSPM. Johns Creek has approximately 100 signals and GDOT has approximately 2,300 signals statewide—500 in metro Atlanta, and the remainder in outlying districts.
- Our communications infrastructure is mostly cellular 4G, with some fiber signals in Atlanta (approximately 1,500 signals on fiber).
- We have not made the Utah dashboard public yet. It is still behind our firewall, but we intend to make it public once the new software is installed and vetted.
- We plan to expand ATSPMs so that every signal that GDOT maintains (about 3,000) will be able to collect high resolution data. There could be 10K signals running ATSPM in Georgia in the next few years.

Benefits

- As we have integrating ATSPMs into our processes, it has been useful as a validation of consultant work. We have typically been at the mercy of re-timing contracts with consultants for which travel time runs were the predominant metric. As you know, this is not best metric. Now, we can examine the data and make tweaks remotely.
- We are also able to target where we put our resources so that we don't do a full re-timing study on a corridor that does not display signs of a problem.
- ATSPMs allow us to see which detection devices are not working well. We have found that video detection is the least effective.

Challenges

- Initially, integrating with the Centracs system was a problem. The systems did not want to communicate with one another, but we resolved this.

- Data storage may become a problem going forward. We have so far stored 800 GB of data but will continue to receive more and more.
- Getting our technical community to sign on to ATSPMs can be an issue. We have some "old-school" engineers who don't see the value in data and prefer to conduct field observations.

Costs

- I don't think we've spent more than $100K on backend upgrades related to TSPMs (aside from the separate cost of upgrading controllers, which was a $20M project).

Future Developments

- We are excited to have all of this data, but we still don't have a good sense of what do we do with it? The real benefit that will come from having the data is to be able to develop analytics. We want to be able to aggregate all of this data (e.g. Bluetooth travel time data) so that we can make advancements in how we improve operations going forward. We have been collecting freeway data for 20 years, but really we don't do much with it. I believe there will be a market for consultants to develop tools that integrate this data and package it for use by elected officials and policy-makers.

14. STEVE MISGEN, MINNESOTA DOT – 11/8/16

Background

- Misgen currently serves as the district traffic engineer. Involvement with SPMs began around 2006 as a research project with the University of Minnesota—Professor Henry Liu. The initial project was to determine if queue lengths could be measured/estimated by using the in-place detectors at a signalized intersection. Over the years, and through numerous research projects, different measures were developed which were integrated into the "Smart Signal Product." We ultimately incorporated a lot of Purdue measures into our system.
    - Impression is that the Utah SPM system is a bit more polished.
- We have 120 intersections that have Smart Signal now.
- Before TSPMs, signal performance was measured by complaints, field observations or by collecting data and analyzing in Synchro.
- Now, MnDOT has performed three retiming projects using only the data and information collected in Smart Signal, not Synchro. Before and after measures were collected.
- We are now working with Audi to see how we might integrate it into vehicles.

Benefits

- Agency cost savings – Historically, MnDOT's Metro District has retimed its major arterials every 3-4 years whether they needed it or not, usually they did. It's our intent to monitor the signals on a regular basis to determine when and if the signals need to be retimed.
- For the public, the benefits will take the form of better travel times and less delay.
- There is a need to create universal measures so that politicians and city management can evaluate the health of signal operations. Historically, delay or travel time was used but only after data was collected and analyzed. SPMs can provide as close to a real-time measure of how the system is doing.

System Components

- We have a system that pulls the data logger between 2 and 12-hour increments depending on the intersection. Everything is on fiber or ethernet modem comm.
- Initially we used a separate recording device but transitioned to using the Econolite ASC3 data logger. We had a few problems with the data logger in the ASC3 locking the communications up but these issues have been resolved.

Challenges

- Our own staff has been the biggest challenge. Getting staff to embrace the technology is tough. Biggest challenge was our own internal IT people—"the NO people". Their issues included the servers, storage volume, firewall, field devices, etc.
- With the latest release coming from UDOT, the IT department's fear is related to open source software. They don't want anyone else to have credentials.
- "Old-timer" traffic engineers are also slow to embrace SPMs. At first glance, the Purdue coordination diagram is difficult to interpret.
- It would be useful to organize a user's group of those involved with the pooled study to share challenges and experiences. Most of the presentations available online are basically success stories.

Costs

- For MnDOT, the capital cost would only be the cost of the servers. The majority (420 of 700) of the signals are on a central system with constant communications, Ethernet over fiber. The software has been at no cost to the agency—both Smart Signal & Utah's SPM system. We are also upgrading to Intelight's MaxView which will have SPM integrated into the software.

15. JIM STURDEVANT, INDIANA DOT – 11/15/16

Background

- Our involvement in TSPM grew out of a collaboration with Purdue University in 2002 when we were gathering data on how well various types of detection systems operate. Now, we are involved with the Everyday Counts program (NCHRP 3 – 122)
- Involvement in TSPM started in 2002 when evaluating how well various vehicle detection systems performed. In 2007, we worked with Purdue at the time when the Purdue coordination diagram was still spreadsheet-based.
- Indiana has 2,500 signals under the control of INDOT. Of those, 1,500 are on coordinated systems. The others are is rural areas and not linked up to any central system or capable of collecting TSPM. We are limited as far as how many signals we can bring online because we need to use the repair budget—UDOT has connected all signals with fiber optics comms through a trading program with the telecommunication industry.
- Only 300 signals are running TSPMs. Goal is to triple this number in three years, but some districts don't have the budget to connect to the signals.
- Have not employed focus groups to collect public feedback.

TSPM System Components

- Having widespread comms capability is the biggest issue for us. Cellular modems make this rather cost-effective (this is what GDOT is doing).
- Of the signals we have that currently are comms-equiped, the ones in urban areas are connected via fiber, and in less-populated areas they are running cellular modems.
- Some adaptive signals in Indiana, but not at INDOT (e.g. running Synchro Green or Rhythm) also have built-in performance metrics, however it is still useful to have additional TSPMs because they can tell you how truly adaptive the signals are. ("*You want to have cruise control and a speedometer in your car*")
- NEMA – some states have NEMA controllers in which the hardware and software is bundled together. The 2070 model is separate.

Benefits of SPMs

- We have used TSPMs to investigate signal performance related to fatalities at railroad crossings, and to confirm that signals were working. Prior to that, we would not have data to indicate how the individual that ended up on the tracks.
- We have also been able to provide valuable info to city officials when they receive feedback about traffic systems. For example, we installed a "no turn on red" sign at an intersection with lots of crashes, which led to an influx of complaints from motorists who claimed they were waiting at the light for minutes on end. In fact, we were able to show that the average wait time was 7 seconds.

Implementation Challenges

- IT can be a major issue. Jurisdictions must have an IT tech and a server to run the system on. Also must have buy-in from IT staff.

Costs

- We use repair parts funds to implement SPMs. There are no additional costs as we already have a database, and already have a database staffer from IT. Cities can justify the comms costs alone in the reduction of trips to the field to investigate signals.

Future Plans / Developments

- We intend to adopt the UDOT system and run it, along with our existing system which we developed several years ago, side-by-side. We can compare both systems and see if we get the same answer.
- Going forward, there will be many more ways to capture SPMs in the cabinet. There could be states that aren't NEMA states, but there is still devices in controller that can get the PMs. There could be a situation where they have a system that can't do PMs, but there is tech coming that will allow them to get it.
- Consultant involvement will allow smaller jurisdictions to engage with SPMs.

16. MARK TAYLOR AND JAMIE MACKEY, UTAH DOT – 11/7/16

- Over the past six months, we have partnered with FHWA's "Everyday Counts." The fourth iteration will kick-off next year. As part of this program, we have decided to re-write source code so that it's easier for jurisdictions across the country to use. We are going to release the source code on the FHWA web site within the next week or so. Our hope is that other agencies will take the source code, incorporate and improve it, and then share it again with us.
- We are trying to get away from being tech support for the entire country. Our hope is that the private sector will become engaged too and help agencies implement the code and TSPM.
- The new code is much simpler and will allow other agencies to install it in half a day or less (down from 1.5 days currently), as well as to configure it easier and add more metrics.
- As far as I know there are 17 different agencies that are using UDOT's TSPM source code.
- Some agencies are have tweaked the code, such as Las Vegas, who have added a few additional measures. Indiana has their own software currently but are going to begin using ours. Minnesota also has another package.
- The National Operations Center of Excellence hosts an online forum for discussing TSPM topics and issues. Available here: http://forum.transportationops.org/forum/5-traffic-signals/
- An online resource specifically for issues related to the installation and configuration of the UDOT source code is available through a portal on the FHWA's Open Source Application Development Portal: https://www.itsforge.net/forum/ATSPM

How did your involvement with TSPM begin? How was signal performance being measured before vs. after?

In 2011, our senior leaders looked at traffic signals as assets to the state. They asked how do you know if things are getting better or worse, etc.? We put together a quality improvement team and wanted to have real time measurements of metrics. We teamed up with Purdue and because we already had the right type of data recorder, we were able to get 100 signals up and running in about a month.

UDOT owns about 1,200 signals. 85% are connected via communication and TSPMs. We own 60% of the signals in Utah and the cities and counties have 40% of signals. 85% of all traffic signals statewide have TSPMs. Goal within a couple of years is to be 100%.

What are the most significant benefits from TSPM to your agency?

There are many but the most valuable is the troubleshooting. Ability to identify immediately what the problem is. We can dispatch the right technician and make sure they are looking at the right problem. We have an alert system that tells us what the problem is as soon as it happens.

What have cost savings been?

We don't have any quantitative data on that. Qualitatively we can speak to the reduced number of calls that we get. A few years back, we estimated the benefits at $3million of user benefit in the form of reduced delay time.

However, we are moving away from travel time as sometime that will improve… We want to keep travel time from degrading. The travel time savings are not huge, but arrivals on green have been a significant improvement.

What is the most common metric to trigger an alert?

Percent max-out between 1 and 5am… It's hard to tell in the PM peak if you have a detection problem, but in the early AM hours if the signals are not working you will know.

Public Benefits?

2 years after implementation we did a focus group on TSPM. They were asked if signals were getting better / worse, etc. After focus group in 2014, we were shocked with result. It showed that people thought it was getting better. Big shock! Never good when you ask about traffic signals.

Safety benefits?

- Yellow / Red Actuation metric: This metric looks at vehicles traveling more than 15mph (?) during yellow and red intervals. The idea is that you can start to see when you're having a red light running problem. We have not followed through with this one yet. Idea is that if we see that red light running is only an issue for 30 mins per day, we can fix it by allowing for more green time, or maybe we work with local law enforcement, e.g.
    - We have not had the opportunity to follow through with issues that have been revealed via this metric, but we would like to at some point.

- Speed during green metric: Looks at approach speeds on green. We have used this to see when 85 percentile speeds don't match with posted speed limits and adjusted the yellow time accordingly.

What have the challenges been with regard to implementation of TSPM?

You have to size the server based on your needs and requirements. Do you want to store data for 1 year – 5 years? We are running 10 – 15MB per day per signal. Seminole county is running much more data for some reason.

In Utah, we had the hardware, but not software. We had to upgrade the firmware. For other agencies it depends. Seminole County had hardware.

In Colorado, they are getting ready to switch out all of the controllers and they are supposed to be vendor neutral. As soon as they get those controllers they will be ready to go. We have met a lot of people and heard a lot about barriers, but in the next few years, I expect that there will not be as many.

It's important to change the standards and requirements that anything new you buy will have data logger built in.

What does it mean that TSPMs are independent of a central system?

A central system is not needed or used for TSPMs. The way it works is that the traffic signal has a data logger that runs in the background. We are making a direct connection to the data logger and bringing it to our server.

We have a central system here but that's independent of TSPMs. We LOVE our central system. We use it for event management, etc. and thus we do not advocate getting rid of a central system. But it can be cost a lot to implement if an agency does not already have one.

With a central system, often agencies don't want the public to get into the system. We have thus decided to move TSPMs to separate website. Everyone can use. I know public is using it because I get calls from people when the site goes down.

In areas where we don't have communications, we have a device that stores data in the cabinet on an SD card. This way if we get a complaint we can send a technician there and upload the data to the server to see what's been happening.

In Indiana they use a modem to transmit the data through the cell network. Most data loggers can only store data for 24 hours.

What metrics are useful to the general public?

Planners in particular are interested in approach volume counts and turning movement counts.

City / County Jurisdiction Interviewees

17. VIK BHIDE, CITY OF TAMPA – 11/7/16

Background

- Our involvement with SPMs began two years ago when FDOT approached us about their Arterial Management Program, in which the city would partner with FDOT to monitor signals.
- At that time, we were implementing ATMS from the TMC and were documenting the changes to the signals and reporting on the AM and PM peaks and emailing the reports to internal staff and FDOT. We then started expanding and implemented BlueToad to integrate with our traffic management processes. This was one data source.
- Earlier this year we partnered with Waze to get corridor specific information. We get incident data from Waze, we verify it with CCTC, Blue Toad data or google maps and then we implement timing changes. (Waze data comes directly from them. In exchange, we inform them about road closures and special events, etc.)
- The situation in Tampa is unique because we have some of the oldest signals. We are migrating to ATMS and we wanted to expand our capabilities so we had Utah install SPMs, and we worked with Seminole County because they had more experience with it.
- Currently, only 3 signals are using SPMs. We have the potential to equip up to 120 signals (those that are on the central system). There are 560 total signals in Tampa. Most of the signals on the ATMS platform are equipped with fiber.
- We have the capability to use the Dashboard but we don't do so now.

System Requirements

- Three conditions are needed for SPMs:
    - Controller capable of high-resolution data transmission
    - NTCIP-capable communications
    - Reliable network (our locations are all fiber) to support high-res data

- We have a center to center connection with FDOT that transmits the BlueToad data and CCTC feeds.
- Econolite is developing a tool that can interface with Centracs. We would like to learn more about this, as we have started to transition to Econolite and we will be completely converted by 2021-2022.

Benefits

- Travel time is just one measure but delays should also be included. Example of Purdue coordination diagram to tell how many arrivals are on green.
- Another reason that we are motivated to get TSPMs is because Tampa is part of the USDOT connected vehicle / smart city challenge. As part of this, we have two use cases that involve signal progression. We are implementing a system that will take elements of adaptive signal control and apply it to our network. Once that comes in we will need to have more robust metrics to evaluate it. It will be 16 – 18 months before anything is up and running.

Challenges

- No challenges related to hardware / software. The bigger challenge is getting training on how to use the tool, and which tools are the right ones.
- We don't have the technicians that can add a few more signals to the network. The signals that are equipped with SPMs were installed by folks from UDOT and Seminole County. The Econolite Centracs MOEs module will help us implement SPMs at all 120 locations on ATMS.

Costs

- Because we want to get SPMs as a module for our existing software, our costs will be higher. There will be a one-time cost of about $25,000. The other cost will depend on the number of signals that we have. FDOT will cover part of the cost under the Maintenance and Compensation Agreement.

Recommendations

- I recommend that you work with the ITS committees to increase awareness and education around TSPM. Partly because within operating agencies you may have some reluctance to expand their footprint, but some regional agencies might see the benefit and could help in bringing them along.
- The industry has a lot of tools and toys but the question is: are they really translating into better operations? Sometimes the SPMs are more about gathering data, and not about improving operation. How do we bridge the gap? Where do we go after we do our study? The state should think about not just the training and tools, but what are the actions that are going to be generated from the SPMs? Who does this and how do we follow through?

18. SHITAL PATEL & GANG XIE, RTCSNV – 11/8/16

Background

- Several years ago we were using an old signal system from Siemens and were in the process of upgrading to a new ATMS system.
- We have 1,500 signals in the Valley. 900 are now on the ATMS system. Converting the others will take another 2 years.
- 300 intersections have TSPMs. Our comms is fiber.
- We are responsible for all freeways, arterials, and transit. For signals, we are only responsible for timing and coordination – not maintenance.
- We don't have as much ITS as they do in Utah—it's harder to make adjustments. We mostly use video for vehicle detection. One agency has thermal video, and some have loops as a secondary.
- We recently developed an app that we are testing to check travel times on various routes.

Benefits

- Maintenance time savings is important. If a ped button is broken we can troubleshoot it quickly.
- We have not done corridor studies to evaluate travel time savings. But, in examining the Purdue coordination diagram, if you have good coordination, you will get good travel times.
- A new measure is called red light running and allows us to see how many vehicles are running lights at the signals. This will allow us to calibrate the all-red time, which should provide a safety benefit to all.

Challenges

- Data storage poses two challenges: one for SPMs and the other for ATMS.
    - SPMs: Data storage on the server is becoming a problem because of the amount of data we are collecting. We have regulations that require us to hold the data for a certain period (3 – 5 years) for studies. We have considered using the cloud, but that involves an additional cost. We receive data every 15 mins.
    - ATMS: Since we are also responsible for transit, our vision is to eventually bring data in from other sources (e.g. transit) and create performance measures for the entire system. The challenge is to figure out how central system vendors (we were working with Trafficware) can store SPM data but not slow down the system.

Costs

- Server was the only real cost.

Recommendations

- Reports on corridors/ routes with information on travel times would be very useful. This is expected to rollout shortly.

19. CHARLIE WETZEL, SEMINOLE COUNTY, FL – 11/9/16

Current issues with UDOT SPMs:

- In reality, we are not using our SPM system very much. Utah DOT helped us to install it 1.5 years ago, but it has not been updated since.

- We have about 8 metrics, but the current UDOT SPM version has 10, including Pedestrian Delay and Corridor Reports.
- Our current *ATMS.NOW* system already does much of what our version of the UDOT SPM system does. For example, we have 24/7 volume counts, arrivals on red, split histories, etc.
- The UDOT SPMs that we have are time consuming to use. For example, if you want to do a corridor study, you need to pull the data from every signal on the entire corridor separately. The newer version of UDOT's SPMs have a function to quickly get reports for the entire corridor.
- When UDOT makes their newest version of SPMs available in November, 2016, this will be a "game-changer" because it will be easy to install. Especially smaller agencies that don't have a central system or good comms equipment would benefit. These agencies would be able to get email alerts when there are signal issues.

Status of signals in Seminole County:

- County has 383 signals that use the centralized ATMS. All but one of these signals are connected by fiber.
- By the end of this year we will have all new signal equipment that will allow us to expand the deployment of SPMs.

Recommendations

- FDOT should look at the UDOT documentation and see if it's possible for a local jurisdiction to install TSPM by themselves, or whether they might need the help of a consultant to get it up and running.

University / Academic

20. CHRIS DAY, PURDUE UNIVERSITY – 11/9/16

Benefits

- Biggest benefit of SPMs is being able to develop intelligence without going to the field.
- Additionally, agencies can start to track performance over time, as conditions in the field change.

Challenges

- Getting good documentation in the field as far as what the detector configurations are. This varies from one agency to another.
- Second challenge is figuring the right way to implement the system to collect the data. UDOT has developed one option, but all agencies will be pioneers at this to some degree.
- Understanding who is going to benefit from the data can be another challenge to implementing SPMs. Some agencies might be more concerned about maintenance and therefore consider consultants the ones responsible for signal timing. In these cases it's harder to get enthusiastic about SPMs.

Applications to Florida

- Evacuations due to hurricanes
- FL experiences a lot of fluctuations in demand due to tourism. Could be an interesting case study of SPMs to see what happens during events.

Next steps?

- We haven't taken the next step of trying to come up with composite index. The difficulty there is to determine who the audience is.
- We are at a point at which we have wrapped up the pool-funded study and are brainstorming now as far as what to do next. Thoughts that come to mind include trying to mine the data to see what more can be extracted. We started to look at red light violations. Can you quantify the impacts to changes in signal timing based on that? There is a 2016 TRB paper with more information (Available here: Lavrenz, S.M., C. Day, J. Grossman, R. Freije, and D.M. Bullock. Use of high-resolution signal controller data to identify red light running. Transportation Research Record No. 2558, 41-53, 2016. Available here: http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1010&context=civeng).
- We are also trying to think about where connected vehicle technology comes in. Trying to identify what we can do before we have 100% vehicle coverage.

21. ALEK STEVANOVIC, FLORIDA ATLANTIC UNIVERSITY – 11/22/16

Benefits

- There is mostly a "planning" benefit from knowing how the signal has worked in the past and then being able to make adjustments for how it can work better in the future.
- Another benefit that's coming has to do with maintenance and management of the asset. There are measures that aren't so much about the performance of the traffic system, but about the maintenance of the system.
    - For example, some of these detectors can be used to detect when something is happening to the signal cabinet. It can tell you whenever the cabinet is being opened, or when a light is on. This can be a good indication, on an annual basis, of how many resources you are using to maintain a given signal vs. other signals.
- Other tools can be used for re-timing of signals for adaptive traffic control systems. Signals can also be re-timed based on real-time data.

Challenges

- One major challenge is the database update process. Once you install a database right now, there is no way that you can update it if there is a newer version. New PMs are being developed, so there is a need for newer versions of the software. Every time there is an update of the software, database owners need to completely uninstall the old version and install the new one.

Florida-specific issues?

- Video detection usually works better here than in other parts of the country.
- Florida has a lot of different traffic control vendors.

Where do TSPMs go from here?

- TSPMs will need to be summarized so that a regular traffic engineer can take info from the system and create reports on a weekly, monthly, (etc.) basis.
- How can TSPMs be made to be useful for policy-makers?

Interview Guides

Non-Florida Agencies

- How did your involvement with TSPM begin? How was signal performance being measured before vs. after?
- What are the most significant benefits from TSPM to your agency? Are there other benefits, such as:
  - Safety
  - Cost savings
  - Travel time savings
  - Other benefits observed by the public
- What have the challenges been with regard to implementation of TSPM?
  - Have technology / equipment and data storage issues affected the implementation of TSPM?
  - Are there issues with regards to integrating existing traffic signal systems with the systems involved in Purdue's TSPM?
- What are the capital and operating costs related to TSPM?
- Aside from the Purdue-developed TSPM, are there other technologies or systems that your agency has considered as a way to enhance traffic signal performance?

Florida-based Agencies

- How did your involvement with TSPM begin? How was signal performance being measured before vs. after?
- What are the most significant benefits from TSPM to your agency? Are there other benefits, such as:
  - Safety
  - Cost savings
  - Travel time savings
  - Other benefits observed by the public
- What have the challenges been with regard to implementation of TSPM?
  - Have technology / equipment and data storage issues affected the implementation of TSPM?
  - Are there issues with regards to integrating existing traffic signal systems with the systems involved in Purdue's TSPM?
  - Have there been any issues integrating TSPM into any centralized signal control software systems that are prevalent in Florida? For example, how do TSPM integrate with ATMS.now, Centracs, or QuicNet?
- What are the capital and operating costs related to TSPM?

- Aside from the Purdue-developed TSPM, are there other technologies or systems that your agency has considered as a way to enhance traffic signal performance?
- Does the FDOT Traffic Signal Maintenance and Compensation Agreement have any impact on the ability of your agency to install and operate the TSPM system or dashboard?
- What would your advice be to other FL agencies that are considering TSPM or on the cusp of implementation?

Universities

- What do you see as the most significant benefits that an agency receives from implementing TSPM?
- What have been the challenges with regards to implementation of TSPM and integrating them into existing signal software /systems?
- What are the most significant challenges that agencies have faced in implementing TSPM and how can these challenges be mitigated?
- Are there any particular benefits / challenges that might be unique to agencies in FL, or that agencies in FL should be specifically aware of?
- Where do TSPM go from here? What is the next frontier and what should agencies with no experience in TSPM be thinking about?