Using Performance Measures to Improve Signal System Performance

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Using Performance Measures
To Improve Signal System Performance

November 2010
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<td>16. Abstract: Recent emphasis on improving signal system performance has prompted research on the collection of enhanced quantitative data for making operational decisions, the development of a systematic method for monitoring and recording system performance and the definition of quantitative performance measures to identify opportunities to improve corridor traffic operations. This document summarizes the highlights from several publications which document the motivation, theory and application of traffic signal performance measures. Topics discussed include the advantages of monitoring signal system performance without labor intensive field observations. The benefits of real time monitoring and evaluation of signal system performance as well as system troubleshooting. The performance measures identified are capable of revealing the accuracy of equipment installation, green time allocation to adequately serve vehicle demand and quality of arterial progression. They allow agencies the opportunity to more efficiently manage their infrastructure which in turn provides benefits to the local agencies, the travelling public and the overall signal system performance. The document closes by discussing the equipment requirements, provides an overview of the performance measures and has a brief discussion of funding used for signal system infrastructure improvement.</td>
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INTRODUCTION

In 2007, the area of traffic monitoring and data collection received a grade of “F” from the National Transportation Operations Coalition (NTOC), which also reported an overall grade of “D” for traffic signals nationwide, as shown in Figure 1 (1). Two objectives have been identified as essential for improving this national grade:

- The collection of enhanced quantitative data for making operational decisions and
- The development of a systematic method for monitoring and recording system performance.

In addition to the technical challenges, urban traffic signal systems often span multiple local and state jurisdictions, making it all the more important to define quantitative performance measures to identify opportunities to improve corridor traffic operations. Indiana has been a national leader in the development of traffic signal performance measures that address these needs (2,3,4,5,6,7). A National Cooperative Research Program Study recently completed by Purdue University contains extensive documentation on the motivation, theory, and application of traffic signal performance measures (8). This document summarizes the highlights from those publications and draws some examples from those reports on the applications of these techniques to both state and local traffic signals.

FIGURE 1 National Traffic Signal Report Card

The current practice for designing urban traffic control systems is to use traffic design volumes obtained through traffic counts taken during typical conditions. Because of the required time and resources needed to collect the data, the designs are developed using limited information. The systems are not designed for weekend or off-peak conditions, and they are unable to handle variations in demand caused by unusual events such as extreme weather, traffic incidents, or special events. Gradual changes in demand patterns over time are also overlooked by the current design practice.
Once the counts have been entered into a modeling program, there are still many opportunities for error, specifically when transferring modeling software output to the controller timing databases. A significant percentage of the inputs require engineering judgment, and even one incorrectly entered value can lead to a signal timing plan that is not optimal (Haseman, 2010). Once a system has been designed, reevaluation of a timing plan may not occur for several years. The signal equipment provides little to no quantitative feedback to document the quality of operation. The primary monitoring device employed by agencies is public feedback (e.g. phone calls from the public expressing complaints). While this feedback can be helpful in identifying that there is a problem with a system, the public is typically unable to provide detailed information on the location and time of the problem.

When time and resources do permit new data to be collected for a system, the current state of the practice is to feed the data into software packages that evaluate and optimize the signal system using the same model that was used to design the existing system. It is not uncommon for the design software to return a timing plan that is the same as the current problematic situation. This can be overcome by manually adjusting the timing plan, but the design process then becomes less systematic and more reliant on the knowledge and intuition of individual engineers.

The intent of this report is to provide local agencies with an introduction on how traffic signal systems can help improve the operation of a signalized corridor. The performance measures and monitoring procedure presented in this report can help an agency identify problems along a corridor that is not working efficiently. Not only is data collection for these measures simple and cost-effective, but the data can also be collected for a variety of traffic conditions. The measures allow for remote troubleshooting using real time information and provide a procedure for assessing performance in a systematic way.

**IMPROVED MONITORING PROCEDURE**

Leveraging high resolution controller data (2) to derive performance measures that are relevant to personnel managing traffic signal systems (7,8) is much more efficient than labor-intensive field observation techniques currently used by agencies. Depending on the transportation modes served by a traffic signal and the operating agencies objectives, dozens of performance measures might be relevant. However, for the purposes of this report, a small portfolio of performance measures is proposed to quantify the performance of an intersection or corridor: cycle length, equivalent hourly flow rate, volume-to-capacity ratio, served green time, split failures, the Purdue Coordination Diagram, and percentage of phases with pedestrians (8). The performance measures are capable of revealing three factors essential to the optimization of a traffic control system (7):

- Accuracy of equipment installation (including detector functionality and phase activation),
- Green time allocation to adequately serve vehicle demand, and
- Quality of arterial progression.
Historically, vendors have offered software modules that provide limited performance measures regarding equipment functional status, but very little in regards to green time allocation efficiency or the quality of arterial progression. Since performance measurement is an area where the nation is deficient (Figure 1), this document is designed to inform agencies of the opportunities that traffic signal performance measures can have to more efficiently manage their infrastructure. Ideally, these performance measures will be incorporated into future procurement specifications. As of September 2010, one agency (Elkhart County, Indiana) has already incorporated signal performance measures in a central system procurement, and an additional agency (City of Lafayette, Indiana) is in the process of incorporating these concepts in their Fall 2010 procurement for a central system.

**BENEFITS OF THE IMPROVED MONITORING PROCEDURE**

There are many benefits to using this improved traffic monitoring procedure for managing signalized intersections. Not only will the procedure help local agencies reduce costs and increase efficiency, but it will also provide the travelling public with improved traffic flow, reduced congestion, and improved energy conservation. In addition, **everyone** will benefit from the reduced traffic emissions, a result of more efficient traffic progression.

**Agency Benefits**

The performance measures developed using this method can help identify operating problems that currently may only have been discovered through public feedback. Physical issues that can be identified using the performance measures include detector failures, incorrect connections, damaged equipment, improper seating of detector cards, and controller programming errors. These types of problems may go unnoticed by local agencies for months under current evaluation techniques, particularly if their effects are subtle (7,8).

Once all of the equipment and previous settings have been checked, local agencies can use the performance measures to make adjustments to the signal timings. It is expected that more reliable adjustments to signal timing plans will be quantifiable, and able to cover a wider variety of traffic conditions. It will be possible to evaluate operation during weekends, holidays, and other time periods when manual counts are difficult or impossible to obtain. Furthermore, once signal timing plans are changed, the performance measurement system will be able to report the impact of the changes. The engineer can spend less time observing intersections to make sure that the signal timings work, enabling resources to be spent on other tasks.

Using the improved traffic monitoring procedure, it will no longer be necessary to wait years between signal timing assessments. Because the data collection, performance measurement calculation, and signal timing adjustments can all be completed in a short amount of time, with potentially low costs, reevaluation of traffic control systems can be completed on a more regular basis.
Public Benefits

Many regions of the country are rapidly embracing regional traffic signal management that encompasses many jurisdictions. This is potentially very beneficial to the public. After all, drivers are not concerned with how many jurisdictions a road passes through, but simply want to complete their journeys with short, predictable travel times. Objective, quantifiable performance measures are emerging as a critical element of regional traffic signal management systems because they allow decisions to be made using quantitative numbers, as opposed to opinion and judgment.

The travelling public will benefit from this improved traffic monitoring procedure. By improving signal timings, traffic control systems will have better progression and less delay. There will be improved traffic flow, less congestion, and more energy conservation. The travelling public will directly experience reduced travel times because they will spend less time stopped at intersections. Not only will the travelling public benefit from reduced fuel costs, but everyone will benefit from the reduced vehicle emissions. In fact, a recent application of these performance measures at 8 intersections on SR 37 in Noblesville resulted in an annual reduction of CO₂ emissions by approximately 220 tons, just by making adjustments to a Saturday plan (6).

EQUIPMENT REQUIREMENTS

Traffic signal vendors already have standard equipment necessary for collecting the essential data necessary for tabulating performance measures. However, as with all procurements, it is important to specify what items are needed. Specific elements an agency needs include:

- **Controller with high resolution data logging capability.** There are currently two vendors in Indiana that provide controllers with the logging capabilities (2).
- **Adequate vehicle detection.** To measure traffic volumes, vehicle detectors are required. Many existing detector configurations can be used, meaning that at many locations, few new detectors will need to be installed. Detector cards capable of producing vehicle counts are required. To analyze capacity utilization, conventional stop bar detection zones can be used, while an analysis of progression quality requires advance detectors. Typical detector locations for dilemma zone protection are adequate for this purpose.
- **Remote connectivity.** Data must be transferred from the controller to the agency central system. This can be achieved using a variety of means, including wireless modems, IP over radio, and fiber optic cable. These three methods have been used by various agencies in Indiana. One connection is needed at each isolated intersection or interconnected corridor.

None of these elements add significant costs to a new system. Of course, retro-fitting these items to an existing system that is more than 5 years old may incur significant costs associated with technology modernization of the traffic signal cabinet components.
PERFORMANCE MEASURES

There are many performance measures that could have been chosen to evaluate traffic signal systems, but in an attempt to keep the evaluation method manageable, only a few were selected as essential measures. Performance measures were identified that would require the least effort to create while having the most impact on a system. The following section provides a brief overview of seven performance measures that a local agency could use to adjust signal timings.

Cycle Length

Checking intersection cycle lengths against each other is a simple way to evaluate if all of the time-of-day plans along a corridor are in working order. It is not possible to establish consistent progression along a corridor unless all of the intersections run consistent cycle lengths. To check that every intersection in a corridor runs the same plan on the same schedule, cycle length can be plotted. Figure 2 shows cycle length as the amount of time between yield points (termination point of coordinated phase, which is the controller event used to synchronize intersections). Any discrepancies between intersections can easily be identified using the plots (7).

FIGURE 2 Cycle Length (from (7))
Equivalent Hourly Flow Rate

The “equivalent hourly flow rate” is a measure of traffic volume where the raw counts (vehicles per cycle) have been converted into vehicles per hour. This measure can initially be used to determine if all of the detectors in a system were installed correctly and are currently operating. The equivalent hourly flow rate plots are also capable of displaying peak traffic periods and movements, as shown in Figure 3. Once intersection peaks have been identified, additional information can be collected and analyzed for those movements in order to improve the signal timings.

FIGURE 3 Equivalent Hourly Flow Rate (from (8))
Green Time

An easy way to identify if all of the signal phases are active and working properly at an intersection is to look at a plot of the green time per cycle, as shown in Figure 4. The green time for an intersection can also be used to help determine if the green time allocation is adequate. By comparing the green time to the equivalent hourly flow rate, it can be assessed whether the higher-volume movements are actually receiving longer green times.

FIGURE 4 Green Time (from (8))
Volume to Capacity Ratio

To assess individual phase capacity performance, we can calculate the volume-to-capacity ratios which combine vehicle flow rates (Figure 3) with green times (Figure 4). This metric can be used to identify capacity utilization and deficiencies. Plots of volume-to-capacity ratios help identify the movements that have plenty of green time available and the movements that could use more, as shown in Figure 5.

FIGURE 5  Volume to Capacity Ratio (from (7)).
Number of Split Failures

A split failure occurs when demand volumes exceed the amount of provided capacity. The volume-to-capacity ratio can be used to identify when this occurs by tabulating the occurrence of cycles when the volume-to-capacity ratio is greater than 1. A plot of the split failures that occur at an intersection can help identify the movements that require additional green time, as shown in Figure 6.

![Figure 6 Split Failures](image)

FIGURE 6 Split Failures (from (8))
Purdue Coordination Diagrams

A common method for determining the efficiency of traffic progression along a corridor is to calculate the percent on green (POG), which quantifies the proportion of vehicles that arrive during the green indication. While percent on green (POG) quantifies the quality of traffic progression, it does not explain why progression is good or poor, nor does it suggest any changes to the signal timing plan that can be made to improve progression. The Purdue Coordination Diagram (PCD) was developed in response to these issues (7,8). The PCD allows agencies to view large amounts of signal event data at one time to determine the reasons for good or poor progression, as shown respectively by Figure 7 and Figure 8.

The horizontal axis of the plot represents time of day, and the vertical axis represents the time in the cycle. Each dot represents a vehicle arriving at the intersection at a specific time of day and a specific time in the cycle. Therefore, the higher a dot on the vertical axis, the later in the cycle a vehicle arrived, and the further over a dot on the horizontal axis, the later in the day a vehicle arrived. The clusters of dots clearly show when platoons of vehicles arrive. The colored lines designate the signal cycle: the green line shows when the signal turns green and the red line shows the beginning of red, or when the cycle ends. The relative position of the vehicle platoons and the green bands allow the quality of progression to be assessed at a glance. In Figure 7, for example, most of the vehicles arrive in the green band, while in Figure 8, most of the vehicles arrive in red. When combined with a quantitative performance measure such as POG, the engineer can not only identify where problems exist, but also deduce reasons for them.
FIGURE 7 PCD for a Coordinated Approach with Good Progression (from (8)).
FIGURE 8  PCD for a Coordinated Approach with Poor Progression (from (8)).
Percentage of Phases with Pedestrians

The percentage of phases with pedestrians can be calculated based on the number of times the pedestrian button is pushed during various signal phases. The plots created using this data can provide useful information on the volume and primary movements of pedestrian traffic at an intersection, as shown in Figure 9.

FIGURE 9 Percentage of Phases with Pedestrians (from (3))
FUNDING ASSISTANCE

Although the costs of implementing the improved monitoring procedure can be minimal, some local agencies may be eligible for project funding. There are many federal-aid funding opportunities available to Local Public Agencies through the Indiana Department of Transportation (INDOT). The programs include (but are not limited to) Surface Transportation, Local Transportation Enhancement, Local Bridge, National Historic Covered Bridge, Safe Routes to School, Highway Safety Improvement/High Risk Rural Roads, and the Indiana Byway Program (9).

Specifically pertaining to the improved traffic monitoring procedure presented in this report, there is a program for Congestion Mitigation and Air Quality (CMAQ) (Office of Urban and Corridor Planning, 2007) that funds projects that strive to improve air quality and reduce congestion (10). There are also opportunities for funding assistance available through other state departments, including the Energy Efficiency and Conservation Block Grant (EECBG) Program offered through the Indiana Office of Energy Development (11). “The EECBG program is designed to help eligible entities create and implement strategies to create jobs, reduce total energy use, and improve energy efficiency in the building and transportation sectors” (11).

ADDITIONAL RESOURCES

For local agencies interested in pursuing this traffic signal monitoring procedure, more information is available from the references listed in this document as well as upon request from the Indiana Local Technical Assistance Program.
REFERENCES


### What Are the Current Challenges?

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<td><strong>1. Infrequent Reevaluation</strong></td>
<td>Reevaluation of traffic control systems may not occur for several years because of the required time and resources.</td>
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<td><strong>2. Focuses on Weekday Patterns</strong></td>
<td>Traffic control systems are not typically designed to account for weekend conditions, off-peak conditions, gradual changes in demand, or variations in demand caused by weather, traffic incidents, or special events.</td>
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<td><strong>3. Difficult to Validate Public Feedback</strong></td>
<td>Public feedback plays a significant role in assessing current system performance. However, the public does not always provide sufficient detail (or the accurate location information) necessary to efficiently address problems.</td>
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<td><strong>4. Manual Adjustments</strong></td>
<td>Often, manual adjustments to timing plans are required, a procedure that is currently done by an engineer according to intuition or limited field observations, without any measures of the system performance.</td>
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<td><strong>5. Relies on Traffic Models</strong></td>
<td>Signal timing plans are optimized in software models that optimize traffic flow. The performance of these plans is limited by the accuracy of the model.</td>
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<td><strong>6. Lack of Real Time Performance Measures</strong></td>
<td>Current systems lack the capability to generate real time performance measures to report the quality of operations and suggest potential changes to timing plans.</td>
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**Active Management Procedures Can Be Developed Using Performance Measures**
How Can Real Time Performance Measures Be Implemented?

1. **Detection**
   - Detectors throughout an intersection or corridor collect information on traffic conditions.

2. **Datalogging**
   - Vehicle counts and signal operations data are recorded in real time by the traffic signal controller.

3. **Connectivity**
   - Data is collected remotely, minimizing the need for site visits or labor intensive manual traffic counts.

4. **Monitoring/Analysis**
   - Newly developed performance management procedures process the real time traffic information and display the results in charts of the most relevant performance measures, allowing signal system performance to be rapidly evaluated.

5. **Adjustment**
   - Based on the performance measures, local agencies can adjust signal timing plans and quickly evaluate any resulting changes in performance.

What Are the Benefits of Using Real Time Performance Measures?

1. **More Frequent Reevaluation**
   - Data can be collected and traffic control systems can be adjusted more efficiently and cost-effectively, allowing reevaluation on a more regular basis.

2. **Implementation Costs Can Be Low**
   - The monitoring procedure may not require much additional cost, depending on the existing equipment.

3. **Simple Data Collection**
   - Connectivity through wireless modems, a dedicated radio frequency, or direct cable connections allows for data collection, thus minimizing the need for site visits or intensive traffic studies.

4. **Detail of Information Collected**
   - The information provided by real time signal event data logging is more accurate and complete than traditional traffic logging, providing more quality information about signal performance.

5. **System Validation and Maintenance**
   - The information can help identify issues with the existing signal infrastructure, including incorrect programming, damaged equipment, malfunctioning equipment, or incorrect connections.

6. **Reduced Travel Times and Associated Costs**
   - The travelling public will experience reduced travel times and associated costs through improved traffic flow.

7. **Reduced Emissions**
   - With improved traffic progression, a reduction in overall vehicle emissions should be realized.

Is There Funding Available?

Several funding sources are available for local agencies through the State of Indiana:
- Congestion Mitigation & Air Quality Program
- OED Energy Efficiency and Conservation Block Grant Program

Who Has Additional Information?

Indiana Local Technical Assistance Program (LTAP)

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LTAP is an established nationwide system of technology transfer (T2) centers. Funding for the centers comes from federal LTAP funds, state departments of transportation, universities, local agencies, and finances designated by State legislation.

Indiana LTAP provides technical assistance and training to the highway, road and street departments of all counties, cities and towns in Indiana that are responsible for over 80,000 miles of roads and over 12,000 bridges.

Indiana LTAP works hard to serve city and town street departments, county highway departments, city and county engineering departments, city mayors and town managers, county commissioners, county surveyors, MPOs and RPOs, police departments, consultants, and contractors.