Memorandum

TO: Wisconsin Department of Transportation

FROM: Cambridge Systematics, Inc.

DATE: January 21, 2014

RE: Traffic Operations Performance Management System (TOPMS) Task 3 – State-of-the-Art Investigation

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Purpose

For Task 3 of the Traffic Operations Performance Management System (TOPMS) project, Cambridge Systematics conducted a literature review to identify best practices among transportation agencies and private sector firms regarding the use of operations data to achieve performance improvements. Key findings are presented in the following order:

1. Best practices from state Departments of Transportation (DOT);
2. National studies on operations data collection and performance measurement;
3. Best practices from the private sector; and
4. International best practices.

Following the research results listed above, there is a discussion of the implications of these findings on the TOPMS project design and implementation.

State DOTs

Performance measurement is a popular topic of discussion across many state DOTs and other agencies around the country. While performance measurement is a broad topic, this section focuses on how other state DOTs collect and report operations data, as well as how these data are used to address problems related to safety and mobility. Below is a summary of the performance measures collected by several other state DOTs, and how they are either currently being used or planned for use in system management.

Michigan Department of Transportation

The Michigan Department of Transportation (MDOT) has placed substantial emphasis on data collection and the potential use of data from its Connected Vehicle program. The 2008 VII Data Use Analysis and Processing (DUAP) project looked at the uses and benefits of the data that comes from connected vehicle technologies, which allow vehicles to communicate with one another and with transportation infrastructure. The focus of the 2008 DUAP project (DUAP 1) was on user needs in a general way, considering many users such as universities, the state DOT, county road commissions, and others. The second and ongoing DUAP project (DUAP 2) focuses on user need within MDOT.

DUAP 1 incorporated many types of data, including probe data, wi-fi data, and cellular data. The specific data collected included vehicle location, road surface condition, traffic, weather data, and data related to specific infrastructure such as bridges. One question addressed by this project was how the data collected through these technologies can be used to address transportation problems including safety and congestion.

These data are sent to a server from the various sources noted above, at which point the data are cached by the DUAP system where software applications make this information available for analysis. The data are collected using a variety of methods. For example, some data were collected from snowplows, while others were collected from cars via an On-Board Device (OBD). Chrysler regularly collected data from vehicles that were driven to and from its headquarters daily. These data were collected via OBDs, and then shared with MDOT and incorporated into DUAP.

One objective of this study was, over time, to create a standardized set of data about assets, traffic, and other relevant system components. These data are used to help produce historical and real-time traffic information summaries related to incident management, weather and roadway conditions, and the states of various assets.

One important feature of the DUAP system is its ability to communicate with the transportation infrastructure, individual vehicles, or personal devices. For example, the DUAP system might broadcast a message about current travel times, an incident or other event, or recommendations for alternate routes. These messages and other data are also archived for future analysis. An additional benefit of the DUAP data is for planning and asset management purposes. The data collected via in-vehicle devices can be used to identify problems with the transportation infrastructure, including potholes and rough pavement. If enough vehicles in the traffic stream report this information, specific field data collection activities related to pavement condition could be curtailed, freeing up funds for other activities. In addition, a larger number of roadway miles could be covered allowing the system to be managed in a more comprehensive manner.

DUAP 2 began in the fall of 2011 and is scheduled to end in 2014. This phase includes additional partners and data sources, and is looking at this process from the user's perspective. Tasks include identifying data collection needs, enhancing current data collection and application efforts, trying to obtain more data from connected vehicles, and providing aftermarket devices for use in MDOT and other vehicle fleets.

DUAP 2 has applied the lessons learned from DUAP 1 and is trying to address some challenges encountered during the first phase. For example, one challenge is how to manage "big data." To manage, analyze, and process these data, algorithms will be created to process the data based on its characteristics, such as data source, the format in which the data were received and how MDOT wants the data to be stored, and which data elements will be included. One example provided ("Intelligent Traveler," Michigan DOT, October 2013) is multiple uses of pavement condition data collected from On-Board Units, including:

- **Trend information in the short term.** For planning personnel, a performance measure that would identify whether overall conditions across the state, a region, or a corridor are improving or deteriorating;

- **Trend information related to weather and traffic conditions,** For design personnel, a performance measure that stratifies conditions by weather (amounts of snow and ice) or traffic volumes, could be used to refine design criteria; and

- **Specific defects that exceed a preset threshold.** For maintenance personnel, an alert or automated work order could be generated for repairs when a defect that exceeds a specific threshold is clearly identified from the data.

While this specific example does not address operational issues, the opportunities are clear for providing data useful for operational purposes. For example, weather-related data coming off connected vehicles (wiper activation, anti-lock brake engagement) could be used to obtain faster information on road condition data that would feed both traffic management and traveler information systems.

Florida Department of Transportation

The Florida Department of Transportation (FDOT) has a robust performance measurement system that reports frequently on various performance measures for the entire system. Operations metrics are reported on a weekly, monthly, and quarterly basis; these reports are available on FDOT's web site by district. These documents report on a set of standard measures related to incident response. Performance measures were selected by FDOT, and a consultant is engaged to run the calculation routines and develop the reports.

Additionally, FDOT collects operations-related performance data regarding the agency's progress on implementing the Florida Transportation Plan. The most recent report, the *Florida Department of Transportation 2012 Performance Report*, includes such measures as travel time reliability by facility; incident response times by component (detection, verification, response, and clearance); and commercial motor vehicle crash rate on Florida public roads. Data are reported annually and are archived for 7 to 10 years. Crash data and asset management data are archived internally, while intelligent transportation systems (ITS) traffic records are archived through the University of Florida.

FDOT's recent operational reports include some metrics of interest to the TOPM project ("ITS Systems Performance Measures," Florida DOT, Fourth Quarter Report April 1 to June 30, 2013).

As shown in Figure 1, incident durations are broken down by district and by incident response component. The latter is a valuable management tool that can be used to help identify specifically what may be causing changes in incident response time. For example, an increase in response time could be quickly traced to the detection or verification stage, allowing management to hone in on that particular activity. Figure 2 shows the use of travel time and planning time indices to track system performance. These reliability indices allow tracking of trends over time, as well as assessment of the impact of activities such as construction. In anticipation of the Moving Ahead for Progress in the 21st Century (MAP-21), these and other measures are being incorporated into Florida's *MAP-21 2013 Performance Report*, published in February 2013. This brief report documents the State's performance in seven categories; many of which relate to operations. For each category, the report includes an overview, MAP-21 provisions, data, other issues, and preliminary results for the measures using a few years of data. An example showing roadway condition is included in Figure 3.

Figure 1. FDOT Incident Duration Measures

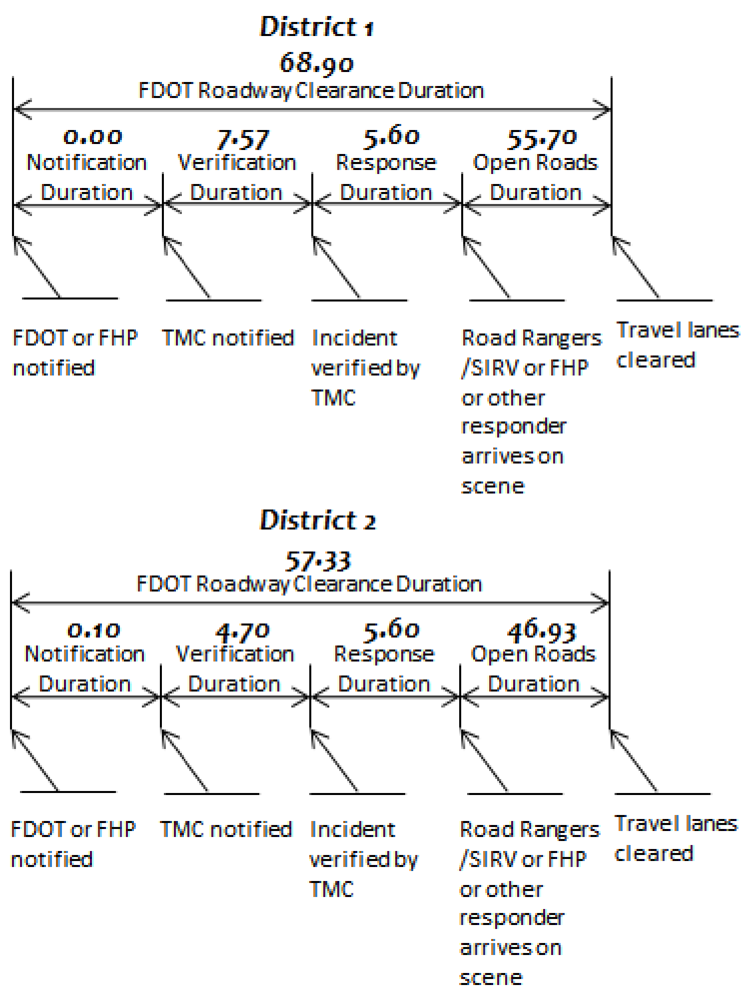


Figure 2. FDOT District 4 Reliability Indices

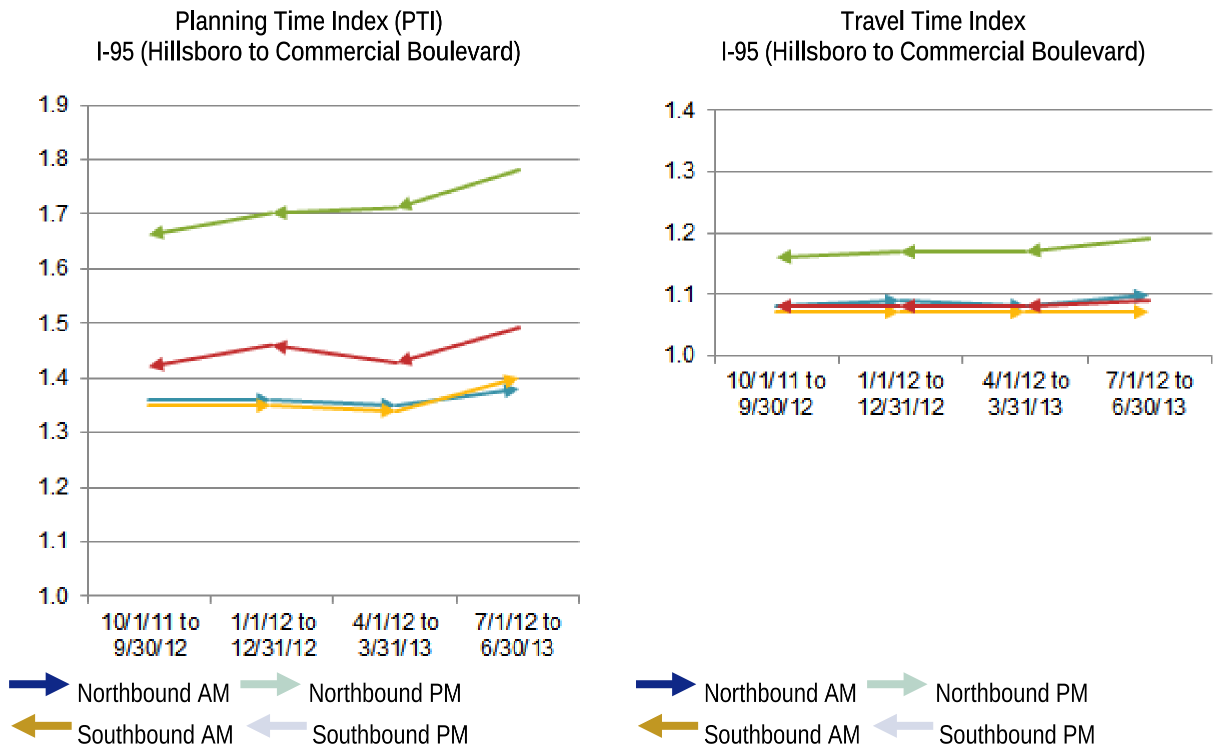
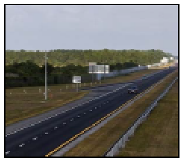


Figure 3. Roadways



ROADWAYS
Over 94% of Florida Interstate roadways meet MAP-21 good condition criteria

Overview: The Department has a long-standing commitment to ensuring that at least 80% of pavements on the State Highway System meet Department standards for non-deficiency. One of the MAP-21Program's performance goals is to maintain the pavements (including the traveled surface of bridges) on the National Highway System (NHS) in good condition.

MAP-21 Pavement Provisions:

- USDOT will establish performance measures on pavement condition and performance of the Interstate System and the remainder of the National Highway System within 18 months of enactment. [§1203; 23 USC 150(c)].
- States will set performance targets in support of those measures within one year of the USDOT final rule on performance measures. [§1203; 23 USC 150(d)].
- USDOT will establish minimum thresholds for Interstate pavement condition. [§1203; 23 USC 150(c) (3)].
- Each state will maintain minimum thresholds for Interstate pavement condition [§1106; 23 USC 119(f)].

Data Issue(s): The Florida portion of the NHS expanded from 4,500 miles to more than 8,000 miles under new MAP-21 definitions for that system. This creates a greater demand on state resources to collect, store, analyze, and report the additional NHS pavement data.

Other Issue(s): None.

2012 Florida MAP-21 NHS Pavement Condition *

NHS	Good - IRI<95		Fair - IRI 95 to 170		Poor - IRI > 170		Total
	Lane-Miles	% Lane-Miles	Lane-Miles	% Lane-Miles	Lane-Miles	% Lane-Miles	
Interstate	7,277.3	94.1	407.2	5.3	45.8	0.6	7,730.3
Non-Interstate	19251.7	73.1	6156.8	23.5	795.9	3.0	26,204.4
Total	26,529		6,664		842		33,935

* Includes roadways on and off the State Highway System as well as the bridges' traveled surface.

* IRI are in in/mile

MAP-21 Moving Ahead for Progress in the 21st Century

Utah Department of Transportation

The Utah Department of Transportation (UDOT) conducted a study to address weather and traffic data needs for weather-responsive traffic management strategies. The study involved a literature review that captured many international sources, as well as a survey of weather and traffic data from major metropolitan areas, including datasets from the National Weather Service, Clarus, and state DOTs; traffic data from the Federal Highway Administration's (FHWA) Mobility Mentoring program; and state DOTs. Analyses of these data were conducted based on proximity of weather and traffic stations, specific weather conditions, and other factors. Traffic Management Centers (TMC) and research institutions then conducted surveys to explore the relationship between weather and traffic flow. Data gaps were identified and recommendations for filling in those gaps were made.

The major findings are summarized below:

- **Ongoing studies.** There are many studies underway investigating the relationship between weather and traffic flow. Two variables that are of particular interest are precipitation rates and surface condition.

- **Agencies are collecting more data, but there are funding barriers.** In the past few years, agencies have begun to collect more traffic- and weather-related data, but limited funding can hinder this effort. Additionally, maintaining the necessary equipment can also be difficult.

- **Specific data needs.** It is helpful to have data in five-minute bins for situations such as snowstorms where conditions change rapidly.

UDOT has a number of innovative practices that make it a leader in the area of weather and traffic management, including having an in-house meteorologist who oversees the forecasting and Environmental Sensor Station (ESS) maintenance throughout the State. UDOT implemented a Weather-Related Traffic Management (WRTM) program that has involved identification and application of performance measurement and management systems.

UDOT's partnership with local National Weather Service (NWS) has been very beneficial in this area. UDOT participates actively in NWSChat and has worked with NWS on message wording. NWS grid forecasts are available on both the CommuterLink web site and 511. The most recent collaboration is on Winter Weather Road Impact Project which includes:

- A review of the travel time index (deviation from mean travel time) during specific days and peak periods. They were able to determine that the only events that had a major impact on system reliability were winter storms and holidays.

- Detailed analyses were conducted on two separate storms to identify the factors that influenced travel time reliability. They found that both snowfall amounts and road surface temperatures, as well as level and timing of mitigation activities, could have a major impact.

- They used sensor data to obtain a good estimate of the impact of winter storms on travel demand. There appeared to be a major reduction in discretionary travel, especially during p.m. peak.

- This effort included development of a common message on travel warnings from NWS, UDOT, Northwest Weather net, and the media.

- They continue to look for ways to increase the level of detail in weather information allows, which will allow more specific messages to be delivered. For example, thunderstorm warnings could be provided on a limited number of DMS when a very localized area is impacted.

One of the more advanced capabilities of the UDOT Traffic Operations Center is the implementation of weather-responsive signal timing plans by the TOC Traffic Engineer. The basis for modifications was a 2001 University of Utah study, which estimated a 30-percent speed reduction on arterials during snow events. There are three to four different weather responsive plans for each corridor that vary by time of day, which generally involve a change in splits or offsets. A slightly different strategy is used on one road, the Baumgartner Highway, where signal timing changes are made to facilitate plowing of intersections.

Missouri Department of Transportation

The Missouri Department of Transportation (MoDOT) publishes a quarterly report, called *Tracker*, which evaluates performance in operations and six other areas. Mobility and reliability performance measures are described, along with techniques for collecting them. For example, the performance measure that addresses winter storm events is "time to meet winter storm event performance objectives." There are two main objectives: 1) clear "continuous operations routes," which include regionally significant routes and major highways; and 2) address "noncontinuous operations routes," which are lower-traffic streets. For the lower-traffic routes, the protocol is to open the roadways to allow two-way traffic and treat with salt at key points, such as hills and intersections. The specific data collected include the time it took to meet the objectives described above; these data are submitted by maintenance staff after a winter event. Figure 4 includes a page from the operations chapter of the July 2013 *Tracker*, which describes a performance measure (i.e., closures on major interstate routes) and where the data are reported (i.e., closures with a delay of 30 minutes or more are noted on the Traveler Information Map on MoDOT's web site). An incident's start and end times are reported from first responders on the scene to operators at one of MoDOT's Transportation Management Centers (TMC), which are generally MoDOT staff or members of the state highway patrol. Those data are then input into a database and added to the MoDOT Traveler Information Map available on the web site and via smartphone apps.

Figure 4. Sample *Tracker* Performance Measure Page

RESULT DRIVER:
Paula Gough,
District Engineer

MEASUREMENT DRIVER:
Rick Bennett,
Traffic Liaison Engineer

PURPOSE OF THE MEASURE:
This measure tracks the closures on Interstate 70 and Interstate 44 due to various traffic impacts.

MEASUREMENT AND DATA COLLECTION:
The interstate route closures that have an actual or expected duration of 30 minutes or more are entered into MoDOT's Transportation Management System for display on the Traveler Information Map on MoDOT's website.

OPERATE A RELIABLE AND CONVENIENT TRANSPORTATION SYSTEM

Traffic impact closures on major interstate routes-5d

Interstates are the arteries that connect our nation and keep people and commerce flowing. When they shut down in Missouri, the country is literally cut in half. Keeping interstates free-flowing is a top priority for MoDOT, but sometimes nature and vehicle crashes impact our ability to keep the interstate moving.

During this review period, Missouri experienced several significant weather events including tornados and extreme winds. Interstate 70 was closed twice due live power lines crossing both directions of traffic. On May 31, St. Charles was impacted by tornado activity. Once again, on June 3, Berkeley was impacted by a very strong wind storm. On April 8, there were two Cooper County long-term planned closures erroneously reported as mainline interstate closures. However, these were actually rest area closures. On May 20, the westbound closure of I-70 in Cooper County was for the landing, loading and take-off of a Staff for Life helicopter. Responders estimate the westbound closure was only 20 minutes, not the 94 minutes erroneously recorded in MoDOT's TMS data. All other impacts on I-70 during the second quarter of 2013 were vehicle crashes including an overturned tanker carrying multiple flammable liquids in Jackson County that had both sides of the interstate closed in excess of 18 hours.

All six of the closures on I-44 during the second quarter of 2013 were for vehicle crashes.

During this review period there did not appear to be any particular corridor locations on I-70 or I-44 that appeared to be locations of reoccurring long term incidents. MoDOT continues to work with all Emergency Responders to minimize the delay caused by closures on our Interstate system.

Missouri Department of Transportation 5d

Washington Department of Transportation

The Washington State Department of Transportation (WSDOT) implemented lane control, dynamic messaging signs, regulatory speed limits, and other Active Traffic Management (ATM) strategies on I-5. As with the MoDOT experience, one factor that led to the success of this project was partnerships between the State and other agencies, including the Washington State House and Washington State Senate, who worked together to ensure Federal funding requirements were met.

Lessons learned through the WSDOT ATM experience include:

- **Be prepared for modifications to the original design.** Initially, the speed limits changed frequently under stop-and-go conditions, which was not what WSDOT intended. WSDOT identified and resolved the issue, and implemented a lower bound of 40 mph into the algorithm. Later, this was lowered to 35 mph, with the option of manually setting it to 30 mph, if needed.

- **Use specific data to add value**. Initially, dynamic message signs on the gantries were configured to display "Reduced Speed Zone" when congestion was ahead, but WSDOT eventually modified the message to provide travel times to different destinations instead. The latter was more useful to drivers, as it helped them to better understand the severity of congestion ahead.

- **Consider maintenance when designing the system.** For example, take into account how staff will access the equipment in the field, and how frequently maintenance will need to be performed.

National Studies on Operations Performance Management

National Performance Management Research Data Set

Beginning in July 2013, the National Performance Management Research Data Set (NPMRDS) became available for use by state DOTs and metropolitan planning organizations (MPO). This dataset includes average travel time data in five-minute intervals from the National Highway System (NHS) and on arterials near border crossings. This dataset contains three subsets – freight, passenger, and "all traffic" – for use in different analyses by the FHWA. For example, the freight subset is used to support the FHWA's Freight Performance Measures (FPM) program and the "all traffic" travel times are used in the Urban Congestion Report (UCR). Instructions for access and guidelines for use are available on the following web site: http://www.ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/vpds/npmrdsfaqs.htm.

Archived data are being made available to agencies approximately two weeks following the end of each month. It is likely that MAP-21 requirements will include measures of delay and at least one type of travel time index for both freight and the overall traffic stream. It will be up to the states to set a threshold value against which to measure. This database can be an important input into the threshold setting process. The database also has great potential value as a performance management tool, particularly in areas that are not fully covered by ITS systems. It will provide a way to better establish the impact of incidents, adverse weather, and work zones on traffic flow; and can be used for analysis in places where detectors are not available or where stations are not close to the event that has occurred. Beyond just measurement, the database provides promise for evaluating and implementing traffic management strategies to mitigate the impact of these events.

Traffic Incident Response

A National Cooperative Highway Research Program (NCHRP) project report, *Recommendations for Improving the Use of Traffic Incident Management Performance Measures when Comparing Operations Performance*, seeks to compare traffic incident response performance among different states, with a focus on improving performance measurement in the area of Traffic Incident Management (TIM). However, the authors reveal that the original objective of comparing performance across states was hindered by the fact that data were not standardized across the different states. Consequently, the final report includes six recommendations for the adoption of standardized TIM performance measures by agencies. Many of these recommendations relate to standards for collecting data at TMCs and consistency in defining terms such as "traffic incident."

The concept of national standards for TIM is relatively new. Many surveyed agencies were not using TMC data to report incident performance measures, such as roadway clearance time (RCT), at the time of the study. This made it difficult to do a comparative analysis of the response time performance among different agencies. However, the authors were still able to compare data from 10 agencies, which included more than 600,000 incident records. The result was a series of recommendations for facilitating future comparative analyses.

The problem of the standardization of performance measures has also been identified by the FHWA in its *2011 Traffic Incident Management National Analysis Report*, which summarizes the results of the Traffic Incident Management Self Assessment (TIMSA) surveys. These are sent to state and local transportation agencies, public safety groups, and private sector partners, with the goal of identifying ways to improve incident management programs. Begun in 2003, the TIMSA results are used to motivate national TIM initiatives, including the National Traffic Incident Management Performance Measures Focus States Initiative. In 2011, the survey included questions about TIM performance measures with emphasis on roadway clearance time, incident clearance time, and prevalence of secondary incidents. From the survey results, these TIM performance areas were identified as key underperformance areas for agencies, with prevalence of secondary incidents receiving particularly low scores due to a lack of data for some respondents and the difficulty in measuring this quantity. In response, the TTI TIM Incident Performance Metric Adoption Campaign was initiated to improve reporting of secondary incidents (NCHRP, 2011).

Private Sector

The private sector – particularly corporations that rely heavily on logistics practices – regularly gathers and uses performance data to improve their operations and increase profitability. This section presents some examples of practices from the private sector that could help inform WisDOT's efforts in improving performance data collection and applications.

Wal-Mart

Wal-Mart is a prime example of a corporation that has become an expert in logistics. Its business model relies on selling items cheaply, but in high volume, such that its profit margins per item are slim. It invests a lot of time collecting and reviewing data about its performance and its customers, with the objective of reducing costs and therefore increasing margins. From its performance data, Wal-Mart determined that developing its own distribution system internally would be advantageous (Places, 2010).

Other best practices learned from Wal-Mart include:

- **Reducing environmental impacts.** Wal-Mart has used its logistics expertise to lessen its environmental footprint. Its goals include being supplied with 100 percent renewable energy, creating zero waste, and selling sustainable products. To this end, it has changed its methods of storing and transporting milk. Originally, milk was transported and stored in crates. However, after careful data collection and analysis, Wal-Mart began to use "case-less" milk containers that do not require racks or crates for shipping. This increased the milk transport capacity of its trucks by 9 percent, and translated into lower transport costs, lower fuel usage, and reduced product packaging that amounted to a savings of 20 cents per milk product (Places, 2010).

- **Sustainable product index.** Wal-Mart has recently undertaken an initiative to create a worldwide "Sustainable Product Index," which is a database with information about the life cycles of many products (effectively, a data collection and dissemination exercise). In the early stages of this product, Wal-Mart identified the need to collect data in a standardized manner, and distributed a consistent set of forms to its suppliers to fill out and return. Among the topics covered on the standardized survey were the energy, social cost, resources, and efficiency ratings for each product (as reported by suppliers). Wal-Mart used these responses to develop a database in cooperation with suppliers, retailers, non-governmental organizations (NGO), and universities (Places, 2010).

This initiative is relevant to WisDOT because it illustrates how a global measurement and reporting system was designed and deployed. While the scale of this project is global, the lessons learned from this effort could be scaled down to an agency level (Wal-Mart, 2013). One potential parallel application involves reporting of data from the regions to the Central Office. A number of areas have been identified where reporting practices and formats may differ between regions. While implementation of a single system across all functions of WisDOT or even the Bureau of Traffic Operations (BTO) would be difficult to undertake at once, there are clear opportunities to demonstrate the viability of a standardized reporting system.

United Airlines

In August 2011, United Airlines initiated a program to provide all of its pilots with iPad for use on flight decks for real-time weather and other navigational information. The 1.5-pound devices will replace 38 pound flight bags filled with reference handbooks, charts, and other information that pilots have traditionally carried around. As a result, United projects that the switch to Electronic Flight Bags (e.g., iPads) will save 326,000 gallons of fuel and reduce greenhouse gas emissions by 3,208 metric tons.

The iPads will enable pilots to see real-time weather layers (e.g., radar overlays, lighting strike maps, volcanic ash indicators) superimposed on maps of their routes, thereby, enabling them to make informed rerouting decisions in flight to avoid turbulence and other undesirable operating environments. Information can include 15-minute forecasts in addition to current weather information, so that pilots can be proactive rather than reactive to the conditions around them. Benefits will be wide-ranging and include reduced maintenance costs due to less environmentally-induced aircraft damage, improved safety associated with fewer turbulence-related passenger injuries, improved customer service due to faster flight times, and reduced fuel costs due to more efficient flight paths.

In an illustrative example, United Airlines estimates a time savings of 11 percent (25 minutes) and a fuel savings of 2,100 pounds of fuel as a result of pilots using real-time weather information to dynamically obtain a better flight path through a storm as it evolved over time, relative to the original flight plan that included a much larger diversion and time/cost penalty.

Samsung

An electronics manufacturer and supplier based in South Korea, Samsung competes in the random access memory market, where prices drop from year to year by substantial amounts. As such, effective use of data for operations optimization is critical to the long-term success of a company such as Samsung. In this industry, "cycle time" refers to the amount of time it takes to produce a finished product from the fundamental inputs (in this case, silicon wafers). In Samsung's case, the process can be divided into four stages: wafer fabrication, intermediate sorting, assembly, and testing. In this case, the primary performance metric was cycle time, with the goal being to minimize it as much as possible.

Using an innovative equipment scheduling algorithm called Short Cycle Time and Low Inventory in Manufacturing (SLIM), Samsung was able to reduce its cycle times and improve the performance of its business substantially. The approach considers all the steps in the manufacturing pipeline that use a particular piece of machinery, and schedules different lots of intermediate goods (i.e., collections of incomplete products that are at some intermediate production step) for that machine based on statistics for the machine's completion time of the pending step for each lot. Other factors considered by the algorithm are the inventory of goods that are between each bottleneck step; the amount by which a particular batch is ahead of or behind schedule; and the changeover times for each machine (i.e., the time it takes for the machine to be reconfigured to perform a different step). This represented a major shift in scheduling paradigm from a lot-based (i.e., product-based) approach to a machine-based/step-based approach.

For example, consider a memory module that takes 10 steps to process, and the same machine is used to handle Steps 2, 3, and 8. The algorithm determines an optimal schedule for that machine based on the current inventory of wafers that are ready for each step; the expected time it will take the machine to perform Steps 2, 3, or 8; the current inventory levels of wafers at other steps (particularly the steps that are ahead of common bottlenecks in the pipeline); the shipment schedule for finished products; and the amount of time it takes the machine to be reconfigured to perform Step 2, Step 3, or Step 8.

Using real-time inventory data, equipment timing statistics, knowledge of pipeline bottlenecks, and real-time shipment needs, Samsung implemented SLIM in 1996. The result was a drop in late production deliveries from 26 percent before implementation to 3 percent afterward; and an increase in memory sales revenue of $954 million ($1.1 billion including nonmemory products) between 1996 and 2000, where the increase is measured by comparing the actual sales numbers and the estimated sales revenue assuming operational changes had not occurred (i.e., SLIM had not been implemented). During the same period, Samsung's market share also increased from 18 percent to 22 percent.

Clorox

In the 1980s, rapidly rising interest rates prompted a focus on inventory reduction and more efficient use of warehouse capacity. This was complicated by the fact that the company used several factories around the U.S., with each having its own sets of equipment. Furthermore, each manufacturing machine was used for several lines of products, could only be used for one production type at a time, and was subject to a "changeover" downtime period when switching from one production line to another. In this case, the primary performance metric was inventory levels, with the goal being to minimize it (and associated storage costs) as much as possible.

To accomplish this, Clorox implemented a new production planning algorithm that optimized inventory levels to ensure on-time delivery of customer orders while minimizing production costs, overtime costs, interplant shipment costs, inventory holding costs, and outside inventory costs. As real-time inputs, the algorithm used current inventory levels and storage capacities, status of overtime at each plant, current product orders, and forecasted demands.

In addition to this, a scheduling algorithm was used to determine daily production schedules with a rolling horizon for each machine at each plant. The algorithm began by estimating current "run-out" times (i.e., the expected dates that inventory of a particular item will fall below the minimum allowable level) based on a moving average of demand rates by product; and determines the optimal cycle length by finding the minimum cycle that avoids any stock-out situations (i.e., drop of product inventory below the minimum allowable level). The algorithm also evaluates whether a down period of one day could feasibly be taken without violating any of the minimum inventory requirements; and if so, suggests that production be omitted for that day to help bring unnecessarily high inventory levels down. More recently, Clorox has gone to a commercial algorithm for managing the supply planning portion of the business, SAP APO Supply Network Planning software (http://global.sap.com/campaigns/benchmark/appbm_snp.epx).

After implementing the new planning and scheduling algorithms on a daily basis using real-time data, Clorox was able to reduce its business-wide inventory by 29 percent, from $85 million to $60 million, without any negative impacts on customer service or production costs. In its application, the scheduling algorithm also typically revealed that a down week (i.e., shutting down production for one week) could be scheduled at the plant it was analyzing, implying that they were generally holding or producing an inefficiently large amount of inventory or safety stock.

International Best Practices in Operations Performance Measurement

Active Traffic Management

Active Traffic Management (ATM) systems in the United States and internationally have been shown to provide a range of safety and mobility benefits. The Virginia Center for Transportation Innovation and Research (VCTIR) published a report, *Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies* (October 2012), which discusses a number of international ATM projects, including hard shoulder running, variable speed limits, queue warning systems, and dynamic ramp metering. As part of these discussions, the authors address the problem of calculating appropriate performance measures for these ATM strategies. Although there are also ATM projects in the United States, the VCTIR report emphasizes European experience due to the greater prevalence of ATM systems there. Because it discusses how to incorporate operational initiatives into the planning process, it is relevant to this current contract with WisDOT.

For example, hard shoulder running (also known as dynamic shoulder lanes) allows for the shoulder to be used as a travel lane during periods of high demand. In an ATM context, the shoulder is opened to traffic dynamically in response to prevailing traffic conditions. In Europe, this application is generally coupled with variable speed limits (VSL) and queue warning systems (QWS). Performance measures were used to describe the benefits of hard shoulder running in terms of reduced travel time, reduced crash rates (both primary and secondary), and increased capacity (measured in vehicles per hour). Table 1 summarizes the performance results of several hard shoulder running deployments (Fontaine, M. D., and J. S. Miller, October 2012).

The authors of the VCTIR document also recommend an emphasis on performance measures rather than technologies during the planning process, and explain that focusing on performance measures could help provide transportation planners and operators with a common language for discussing the benefits of both capital and operations projects. Lyman and Bertini (2008) suggest that reliability metrics be incorporated as performance measures as well, to help promote the inclusion of operational strategies in the transportation planning process.

Table 1 provides only a handful of the types of performance measures that may be used to evaluate ATM projects. As another example, consider dynamic ramp metering in Minneapolis, Minnesota. After the system was activated, throughput increased and crash rates decreased.

Table 1. Hard Shoulder Running Applications and Results

Location	Results
United Kingdom (M42 roadway)	• Travel times decreased by 26% in one direction and 9% in opposite direction. This was based on a 17-km long test area on the M42 roadway. Data are based on the first 6 months of operation. • Average crash rate decreased (from 5 crashes/month to 1/5 crashes/month).[a]
Netherlands[b]	• Crashes decreased by 50% (2004 study). • Crashes decreased by between 5 and 55% (Mirshahi, 2007). • Capacity increased by 7-22%.
Cologne, Germany	• Congestion decreased by 68-82%. • Average speed increased by 9%.
Paris, France	• Capacity increased by 1,000 vehicles/hour (veh/hr) in one direction and 660 veh/hr in the opposite direction.

Source: Fontaine, M. D., and J. S. Miller, VCTIR, October 2012.

[a] Based on limited data.

[b] This incorporates data from two different studies in the Netherlands, which is why two different crash rate decreases are included.

ERTICO/ITS Europe

STADIUM stands for Smart Transport Applications Designed for large events with Impacts on Urban Mobility, and is an ITS project that seeks to aggregate lessons learned and best practices from around the world with regard to large event transportation planning. This project was funded by the Seventh Framework Programme for Research and Development of the European Commission's DG Research. Three major events are considered in this study: the South Africa World Cup in 2010, the India Commonwealth Games in 2010, and the London Olympics in 2012.

Intended as a guide for other large events in the future, STADIUM includes an interactive tool that ranks the applicability of various transport strategies to the event conditions based on the input characteristics provided. There are 30 ITS strategies incorporated into the STADIUM toolbox, organized into six broader categories: demand management, alternative transport/ transit, payment systems, platforms, traffic management, and traveler information. For each strategy, there is a discussion of the data and technology needed for a successful implementation, followed by a description of the potential benefits and a summary of past deployments for large event situations.

For example, in the case of the India Commonwealth Games in 2010, the data and technical needs outlined in the summary report are as follows:

- Common data model for ITS applications;
- Communications standards including data dictionaries, message sets, and protocols; and
- Existing wired or wireless communications, given that there is sufficient bandwidth.

Also recommended in the summary is a review of international ITS standards for other ITS-related components.

For example, one strategy in the Demand Management category is Parking Management. The STADIUM toolbox describes the objective of parking management: using pricing to efficiently manage limited supply by sending appropriate price signals to drivers. Performance data needs of an effective parking management system include parking lot occupancy rates, traffic flows, and historical traffic data in the form of origin/destination (O/D) matrices. The outcomes include improved traffic efficiency (as drivers can make informed choices at the start of their trips regarding where they will park, instead of cruising from one full lot to another looking for parking); modal shift to public transport (which engages the returns to scale associated with increased transit usage); reduced air pollution (as drivers cruising for parking are removed from the roads); and enhanced safety (fewer accidents as a result of fewer vehicle miles traveled while cruising for parking).

eCoMove

Reducing emissions and fuel consumption by providing guidance and information to drivers is the overall goal of eCoMove, a project that received funding from the European Commission between April 2010 and March 2013. The proposed system uses real-time traffic data and vehicle-specific characteristics to identify the most fuel-efficient routes for a particular trip, and takes advantage of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technology for data acquisition. Historical and real-time emissions data are used to evaluate certain routes; and past driver behavior is used to provide real-time guidance to drivers regarding fuel-efficient driving habits (i.e., speed and gear suggestions).

These strategies will be applied to both commercial vehicle and private automobile operators, with an estimated potential savings of 20 percent in fuel consumption and carbon dioxide (CO_2) emissions. Using current traffic information and vehicle characteristics, the project seeks to improve overall performance of the transportation system by choosing routes that will result in the lowest amount of emissions and minimize additional contributions to congestion as a result of the trip.

This project also explored the integration of traffic signal states and operations into the framework. This enables operators to develop energy-efficient timing plans that improve green waves, minimize the total number of stops, and even have the potential to give priority to fuel-inefficient vehicles that have relatively high costs (from an emissions perspective) associated with stop-and-go driving.

HeavyRoute

With freight shipments projected to increase across Europe in the coming decade, HeavyRoute was sponsored by the European Commission to mitigate the infrastructural, operational, and environmental impacts of this additional traffic. The HeavyRoute project explores ways to supply truck operators with appropriate route guidance given the vehicle characteristics, infrastructure constraints, route restrictions, and current conditions.

Data sources used by the HeavyRoute applications include descriptions of physical roadway characteristics (e.g., clearances, pavement characteristics, grade) and real-time conditions (i.e., weather and traffic information). This data is then fed into three separate applications as needed: a route planner, a real-time route navigator, and a bridge advisor. The router planner identifies feasible routes for the truck and selects the best one based on fuel consumption; safety risks; environmental externalities; and road impacts (e.g., pavement deterioration). The real-time navigator alerts the driver of unexpected or dangerous conditions ahead (e.g., sharp corners), while the bridge advisor alerts the driver specifically in situations where the truck weight may place excessively load the bridge.

While the trip planner is not designed for real-time applications, the bridge advisor uses the vehicle's weight and real-time bridge volume to determine a recommended speed and spacing for the truck. Furthermore, the real-time navigator continually monitors the vehicle's speed and alerts the driver when the speed exceeds the recommended maximum for a particular roadway feature ahead. The benefits of the project include longer infrastructure lifetime due to loading limits; improved safety as a result of the driver support on horizontal curves; and reduced environmental impacts due to route choices that minimize fuel consumption, environmental externalities, and infrastructure stress.

COSMO

The Co-Operative Systems for Sustainable Mobility and Energy Efficiency (COSMO) was a three-year project between 2010 and 2013 that explored the effects of innovative traffic management services on energy efficiency.

As part of the research effort, three pilot sites were tested and analyzed in Europe: Salerno (Italy), Vienna (Austria), and Gothenburg (Sweden). At Salerno, vehicle-to-infrastructure, vehicle-to-vehicle, and infrastructure-to-vehicle systems were tested, including a smartphone application that provided drivers with real-time parking information. At both Gothenburg and Salerno, a program called Eco-Driving was tested, which involved giving drivers feedback that encouraged them to adjust their behaviors to be more energy efficient. In Vienna, a large demonstration of several services working together in concert was held. The demonstration included participants driving through an actual field site and receiving in-vehicle information regarding roadway conditions, such as road work and congestion ahead.

Potential benefits of the COSMO approach include reduced energy use, improved safety, and lower operational costs. The eco-driving program, in particular, had benefits with respect to travel times, emissions, and traffic flow. Another program involving intelligent roadway lighting allows for energy savings by dimming and brightening the lights depending on traffic volume, ambient brightness, and weather conditions.

Implications for TOPMS Project Design

This literature review has touched upon several examples from public and private experiences that can inform the design of WisDOT's TOPMS project. The state DOT examples reveal how agencies have approached performance measures related to operations, and how some MAP-21 requirements might be addressed. The examples also cover handling unforeseen problems (i.e., the ATM project experience) and collecting weather/traffic data for performance metrics (i.e., the UDOT example).

The Federal examples illustrate some challenges that many DOTs face related to data collection and performance measurement. These include the difficulty associated with reliably measuring the occurrence of secondary incidents, and the lack of national standards in the realm of incident management data. Adherence to national standards, and particularly upcoming 1201 and MAP-21 reporting requirements, is an important consideration for WisDOT in its design of the TOPMS projects.

The private sector and international examples illustrate how data and performance measures can be used to identify areas where improvements can be made in an organization or process. While WisDOT is not specifically concerned with shipping more products or impressing stockholders, the examples still help by providing WisDOT with ideas for improving the efficiency of its own services.

The examples in total, particularly those from the private sector, highlight the importance of organizational culture in implementing performance management. While accurate, reliable, and accessible measures are critical to understanding where improvement is needed, the workforce must understand the need for continuous improvement and employees at all levels must be willing to contribute ideas. Some of the other lessons learned include:

- Measures must be closely tied to the clearly defined objectives and must remain tied together throughout the process. If objectives change, measures need to be revisited.
- Measures need to be meaningful, understood by all parties involved and should not be too numerous in order to maintain focus.
- Improvement efforts should be focused on specific functions so that participants understand their roles.

- The manufacturing and logistical examples provided show clearly that there will always be bottlenecks in the system, and that once one is identified another will identify itself. This is why a performance management system needs to be part of a continuous improvement process.

- Knowledge databases built up over time are a critical component of performance management. Transfer of this knowledge is essential, given employee turnover and increasing use of contractors for service.

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