

1. Report No. SWUTC/06/167147-1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle BACKGROUND DEVELOPMENT AND CONCEPT OF OPERATIONS FOR A REAL-TIME PERFORMANCE MEASUREMENT MONITORING SYSTEM.				5. Report Date April 2006	
				6. Performing Organization Code	
7. Author(s) Robert E. Brydia				8. Performing Organization Report No. Report 167147-1	
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. 10727	
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135				13. Type of Report and Period Covered Technical Report: September 2003 - April 2006	
				14. Sponsoring Agency Code	
15. Supplementary Notes Supported by general revenues from the State of Texas. Project Title: Real-Time Performance Measures Workshop URL: http://swutc.tamu.edu/reports/167147-1.pdf					
16. Abstract Recognition and response to incidents on a freeway is a vital function of freeway management. When an incident occurs, an established response mechanism seeks to return the freeway to normal conditions as rapidly as possible. The state-of-the-practice in current systems focuses on identification of the incident and rapid implementation of the established recovery plan. This is one example of an operational strategy used to monitor and improve conditions on the roadways. What is missing from these systems is systematic feedback on how the plan actually worked and a consistent basis for refining the plan to achieve better results, if possible. The use of a feedback system provides a quantitative basis for assessing the impacts of various operational strategies. That basis is known in other disciplines as system performance measures. While performance measures have been applied in transportation, the area of transportation operations has lagged behind in implementation. This research proposes an experimental design for a real-time performance measures system as well as a concept of operations for utilizing the information.					
17. Key Words Performance Measurement, Transportation Operations, Real-Time			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 75	22. Price

BACKGROUND DEVELOPMENT AND CONCEPT OF OPERATIONS FOR A REAL-TIME PERFORMANCE MEASUREMENT MONITORING SYSTEM

by

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Report 167147-1
SWUTC Project 167147
Project Title: Real-Time Performance Measures Workshop

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April 2006

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ACKNOWLEDGMENTS

The author would like to express gratitude for funding support provided via a grant from the U. S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center which is funded 50% with general revenue funds from the State of Texas.

The author would also like to acknowledge and express gratitude for the flexibility of the project oversight committee throughout the course of this project.

Dr. Martin T. Pietrucha, Director; Science, Technology, and Society Program, Pennsylvania State University, is gratefully acknowledged for his guidance and support during this project.

ABSTRACT

Performance measurement is recognized as a critical tool in analyzing and modifying actions to achieve consistently high quality results with an emphasis on customer satisfaction. Long utilized in the business world as a management tool for better productivity, performance measurement has been embraced by the sciences to achieve the same results. Transportation has also begun to embrace performance measurement, although the applications have been limited, both in scope and in time.

One area that could substantially benefit from the application of performance measurement techniques is transportation operations. In today's typical operating environment, pre-planned responses scenarios are common. For example, in incident management, the state-of-the-practice focuses on rapid identification of an incident and implementation of the established recovery plan.

While these systems have been a benefit to travelers, by restoring flow on roadways, the systems generally lack any significant feedback mechanism to evaluate the overall response and to improve it for the next time. Performance measurement can provide this evaluation capability.

This research presents the background and concepts for the use of performance measurement in transportation, as well as the experimental design and concept of operations for a real-time performance measurement system for operations.

EXECUTIVE SUMMARY

The father of performance measurement is generally considered to be William Edwards Deming. Deming is perhaps most famous for his work with Japanese industry, after World War II, when he taught the automotive industries to focus on what their customers wanted and then build that product with unsurpassed quality. The name of this approach was Total Quality Management (TQM). At the time, American industries followed a traditional management path with the use of quotas and a rigid chain of command.

The hallmark of the TQM approach is the continual evaluation of quality, using data gathered with scientific methods and tools. Over time, this benchmarking process and the TQM principles became known as performance measurement. Pictorially, the process can be expressed as shown in Figure ES-1. Performance measurement becomes the critical link in not



Figure ES-1 - Illustration of Management Approach Utilizing Performance Measurement.

only meeting the initial customer focus, but also as part of an iterative evaluation from the strategic planning process to keep the customer focus at the forefront of all activities.

Although American industries and agencies were somewhat slower to establish TQM, or performance measurement approaches, over time, the concepts have caught on and have been implemented as part of standard business practices. This includes the direction from the Federal Government to use performance measurement across all aspects of governmental services and federal agencies.

Defined as “the use of statistical evidence to determine progress towards specific defined organizational objectives”, performance measurement is an integral component of many aspects of transportation. In general, the concept has been used to evaluate and analyze the current situation to make it better. Long before the Federal mandate, this approach was used in publications such as the Highway Capacity Manual (HCM), where the term in use was Measure of Effectiveness (MOE).

While used in various applications such as design, capacity analysis, management, and maintenance, perhaps the area of largest impact and potential benefit is operations. Transportation operations is a vast area of programs and policies designed in large part, to address the congestion on the nation’s highways and improve the traveling conditions. Well-known tools of transportation operations are Transportation Management Centers (TMCs), particularly in the urban areas. TMCs may have operating responsibility for hundreds of miles of roadways and utilize programs such as Incident Management to improve the daily commute for millions of travelers.

These results of an Internet survey suggest that roughly 75 percent of TMCs are already using basic performance measures to examine or describe their freeway operations on a historical basis. Typically, this information is presented to the public or abstracted to a high level summary. As reported in NCHRP Synthesis 311 the results of a comprehensive performance measure survey indicated the following underlying reasons for using performance measures within operations:

- support for legislative mandates,
- planning process,
- quality initiatives,
- congestion management system,
- ITS operations,
- safety management system, and
- permitting process for commercial driveways.

The above facts clearly indicate that performance measurement can be and indeed is, being applied to operations to effect improvement. However, the basic supposition behind this research is that more can be done, and that in fact, the greatest benefit to using performance measurement can be realized from the application of the system in a real-time environment.

Using the systematic and on-going feedback from a real-time system, a TMC can refine operational responses to achieve better results and assess the true impacts of various operational strategies.

Figure ES-2 shows the conceptual model for a real-time performance measurement system. The system shows the various components under each major functional area (data, measures, dissemination), as well as the external linkages that are necessary to obtain information used in the calculation process.

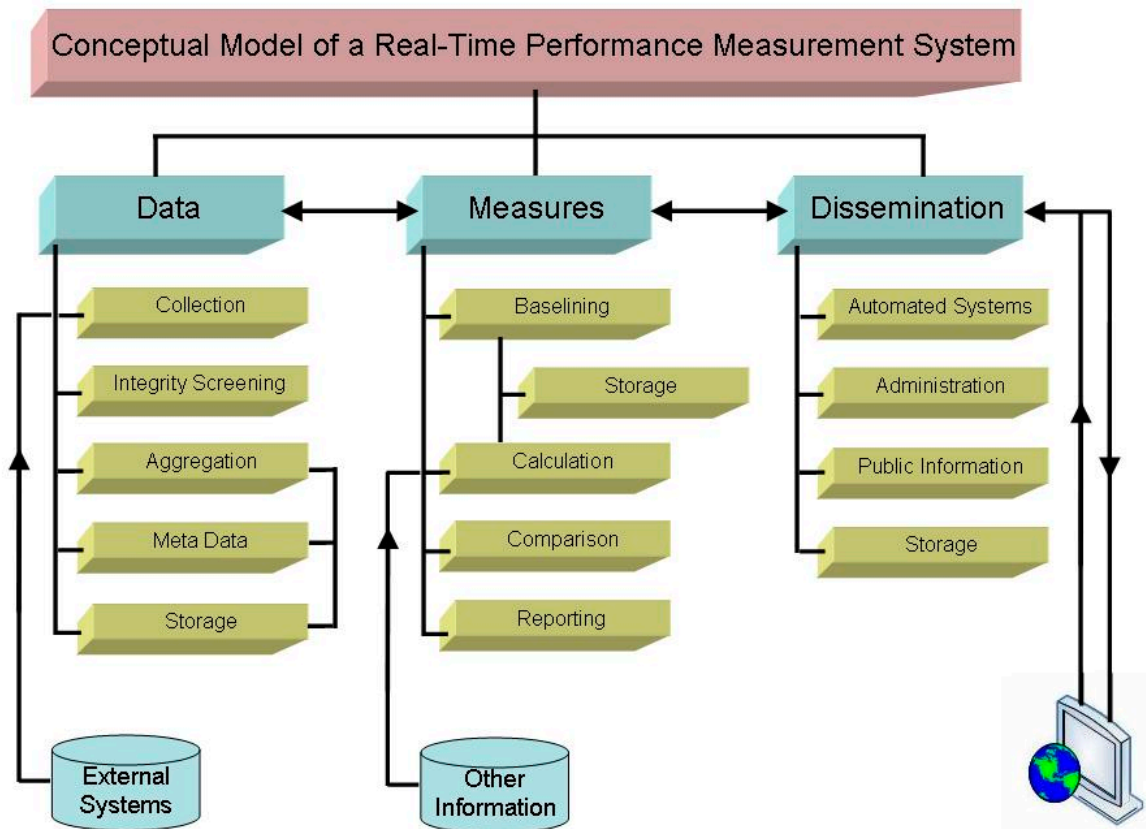


Figure ES-2 – Conceptual Model of a Real-Time Performance Measurement System.

Because a real-time performance measurement system for transportation operations has never been built or utilized, an additional critical step in exploring its use is understand how it would be used. Figure ES-3 shows a concept of operations where performance measurement is an integral part of the system architecture of a TMC. The performance measurement system would capture the actions taken in response to the incident, including (but not limited to):

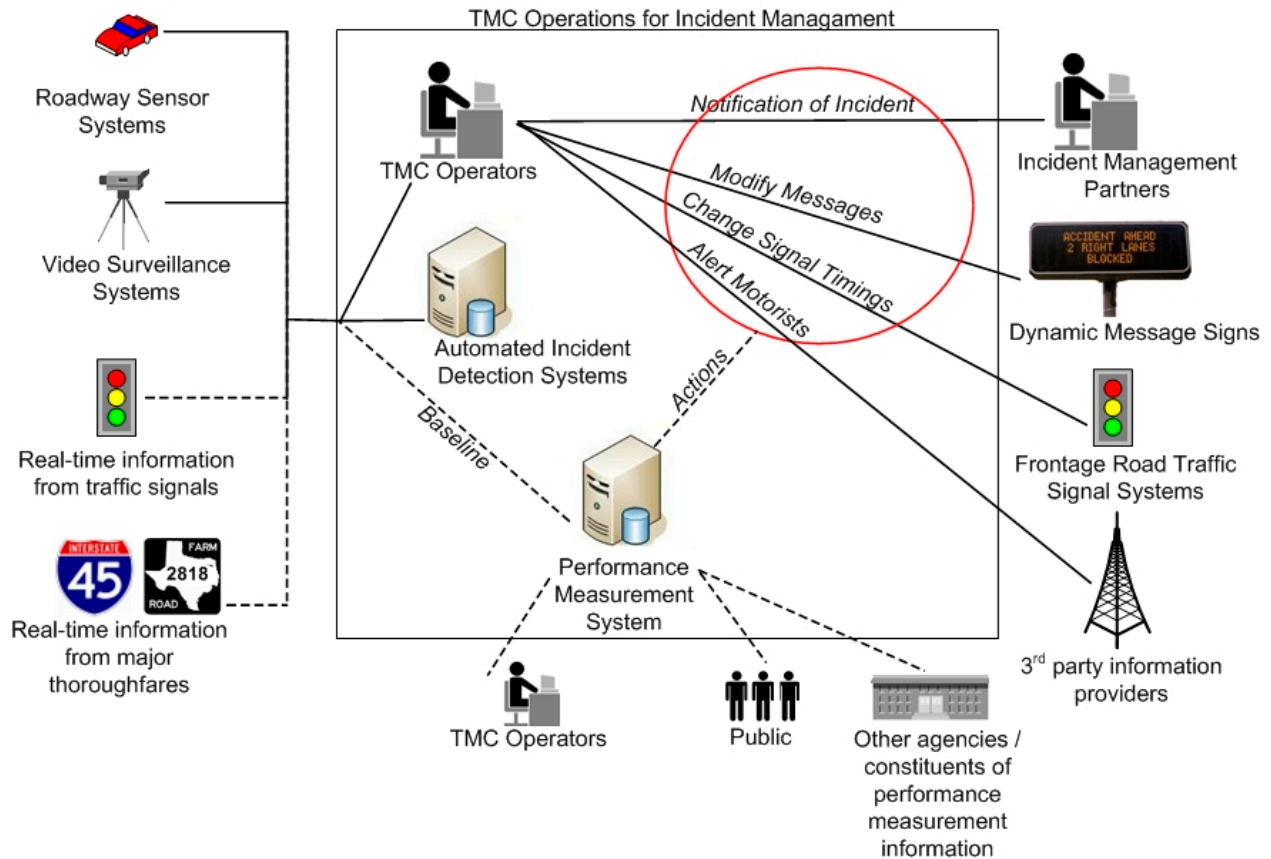


Figure ES-3 – Concept of Operations for Real-Time Performance Measurement System Use to Support Incident Management.

- Date and Time of Incident Detection
- Date and Time of Incident Verification
- Date and Time of Arrival of Incident Response
- Date and Time of Clearance of Incident
- Roadway Conditions at time of Incident
- Resources Sent to Incident
- Operators Actions in Response to Incident (Date/Time Stamped)
- Roadway Conditions in Geographic Vicinity Sampled at Regular Time Intervals (to be determined)

At the conclusion of the incident, the performance measures can be analyzed to determine the true effect of the operational response. Feedback loops would go back to the TMC operators to improve not only their performance, but their understanding of how their actions are reflected in roadway operations.

In summary, the concept of performance measurement as applied to transportation is not new. However, its use to support operations and analyzing the responses to various scenarios to effect improvement for the traveling public is not commonplace. In addition, the application of performance measurement concepts to real-time systems is non-existent. This research provides the fundamental concepts for understanding how performance measurement works and how it could be applied to a real-time system. The next step in this research path is to build a prototype system.

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CHAPTER 1 – HISTORY OF THIS PROJECT

INITIAL CONCEPT

Recognition and response to incidents on a freeway is a vital function of freeway management. When an incident occurs, an established response mechanism seeks to return the freeway to normal conditions as rapidly as possible. The state-of-the-practice in current systems focuses on identification of the incident and rapid implementation of the established recovery plan. This is one example of an operational strategy used to monitor and improve conditions on the roadways.

What is missing from these systems is systematic feedback on how the plan actually worked and a consistent basis for refining the plan to achieve better results, if possible. The use of a feedback system provides a quantitative basis for assessing the impacts of various operational strategies. That basis is known in other disciplines as system performance measures.

While performance measures have been applied in transportation, a real-time system for analyzing freeway incident response does not currently exist. The original scope of this research was to construct a prototype application to collect and analyze performance measures for real-time analysis and demonstrate the system and its benefits to TxDOT via a hands-on workshop.

IMPEDIMENTS TO SUCCESS

A critical component of the success of the original project was receiving, installing, and utilizing the Advanced Traffic Management Software (ATMS) from the Texas Department of Transportation (TxDOT). The timeframe that it took to accomplish step was significantly longer than planned, leading to substantial delays in the project.

Additionally, subsequent to the award of this project, a significant contributor to its success, Roelof J. Engelbrecht was stricken by a terminal illness. He passed away on November 16, 2004.

In light of these situations, the project was rescoped. The revised objectives are listed in the following section. The author of this report is grateful for the understanding and flexibility of the project committee

REVISED APPROACH

The revised objectives for this project focus on laying out a conceptual approach to the task of incorporating performance measurement into traffic operations. By starting with a background and literature review, the reader is introduced to the subject and given a brief overview of the state of the practice in performance measurement, as it applies to transportation.

The report then details a process for incorporating performance measurement into traffic operations. In particular, an overview of the process is presented along with an assessment of the levels of performance measurement that should be a part of any organization.

In turn, this process provides the basis for an experimental design for a real-time performance measurement system, capable of constructing measures from available data for a variety of purposes.

Finally, a concept of operations is presented, which describes how the system would be used and provides guidance on an implementation.

CHAPTER 2 – A BRIEF HISTORY OF PERFORMANCE MEASUREMENT

THE BEGINNINGS OF PERFORMANCE MEASUREMENT

The father of performance measurement, William Edwards Deming was born on October 14, 1900, in Sioux City, Iowa. Deming graduated from the University of Wyoming as an engineer and in 1928, completed his studies for a PhD from Yale University. Upon completion of his degree, Deming went to work for the United States government as a mathematical physicist.

Over the course of time, Deming developed both an interest and understanding in the use of statistical methods to experimental data. He applied these skills in his work at the US Department of Agriculture (USDA) and later at the National Bureau of Standards. . He also continued his studies into statistics at University College, the University of London. In 1939, Deming accepted a position as Head Mathematician and Advisor in Sampling at the Census Bureau in preparation for the 1940 census. The 1940 census would be the first census to employ sampling techniques in lieu of the previous approach of counting everyone. In 1943, Deming published a book ‘Statistical Adjustment of Data’ that detailed the application of least squares regression techniques to various data issues. Leaving the census bureau in 1946, Deming became a consultant for statistical studies, which he continued to his death in 1993. At the same time, he also joined the faculty of New York University, lecturing in survey sampling and quality control ⁽¹⁾.

In 1947, Deming was asked by the Japanese government to help prepare for the 1951 census. Starting in 1950, he gave a dozen lectures on statistical and quality control techniques. These techniques became known as Total Quality Management (TQM). TQM incorporates concepts of product quality, process control, quality assurance, and quality improvement. Deming taught TQM techniques to Japanese industries, most notably, the automobile industry. He is credited with significantly helping the country turn around from World War II and embrace the concepts of producing quality products in a new, more global economy ⁽²⁾.

It is important to understand that Deming’s work and teachings was not just about statistics or quality control. In reality, the core of his teaching was about management. By embracing what the customer wanted and designing a continuous process to create that product

with unsurpassed quality, the focus changed from quotas to customer satisfaction, from the results, to the methods. At the foundation of this continual evaluation of quality was the collection of data gathered by a scientific approach and tools. Deming predicted that adoption of his techniques would significantly improve Japanese market share within 5 years. History shows that change occurred in some market sectors in four years ⁽³⁾.

Deming's work did not become widely accepted in the United States until the 1980's. Whereas the Japanese industries were focusing on what their customers wanted and then building that with unsurpassed quality, American industries had focused on traditional management methods and the use of quotas and the chain of command. American industries had to embrace TQM as a philosophy that integrates all functions for the sole purpose of meeting customer needs and expectations. The overall process can be viewed as a multi-step path towards better business: ⁽⁴⁾

- 1) Improve product quality
- 2) Product costs decrease
- 3) Employee productivity increases
- 4) Company (and products) gain additional market share
- 5) Company prospers

As stated previously, the hallmark of this approach was the continual evaluation of quality, using data gathered with scientific methods and tools. Over time, this benchmarking process and the TQM principles became known as performance measurement. Pictorially, the process can be expressed as show in Figure 1. Performance measurement becomes the critical link in not only



Figure 1. Illustration of Management Approach Utilizing Performance Measurement.

meeting the initial customer focus, but also as part of an iterative evaluation from the strategic planning process to keep the customer focus at the forefront of all activities.

PERFORMANCE MEASUREMENT TODAY

Although American industries and agencies were somewhat slower to establish TQM, or performance measurement approaches, over time, the concepts have caught on and have been implemented as part of standard business practices.

Federal Government Usage

Perhaps the event that best highlighted the use of performance measurement as a scientific and systematic assessment tool was a benchmark study released by the federal government in 1997 ⁽⁵⁾. This study advocated the use of performance management across all federal agencies and provided an overview, best practices summary, and framework to assist in that process. Prior even to this study however, the Chief Financial Officer's (CFO) Act of 1990 required more than twenty major government agencies to appoint a CFO who's responsibilities included periodic systematic performance measurement information, as established by Public Law 101-576. The Government Performance and Results Act of 1993 also required strategic performance and planning initiatives throughout many of the federal government agencies. The Act provided for a seven-year staged implemented of annual performance reporting of performance against goals based on strategic five-year plans ⁽⁶⁾. As of result of these pieces of legislation and studies, performance measurement is an integral part of many federal level government agencies.

Today, a commonly accepted description of performance measurement is:

“the use of statistical evidence to determine progress towards specific defined organizational objectives.”⁽⁷⁾

It should be recognized however, that performance measurement is *not* simply the process of collecting data and seeing if a benchmark or value has been met. Rather, performance measurement *is* an overall management system which allows a business or agency to collect and evaluate information for the purpose of achieving goals, increasing efficiency, and meeting customer expectations.

Use of Performance Measurement In Transportation

As in other industries, the use of performance measures in transportation has been common for some time. In fact, many of the basic tenants of transportation, such as capacity analysis, are based upon performance measures, although they are not commonly referred to in those terms. The Highway Capacity Manual ⁽⁸⁾ has generally referred to these as measures of effectiveness (MOE). Density, speed, and volume have all been used as MOEs for different types of analyses. In addition to transportation operations, performance measures are frequently used in other areas of the transportation field, such as pavements, structures, Right-of-Way (ROW) and utility work, and communications.

In fact, the use of performance measures to analyze systems is of critical importance to transportation. Through consistent application and quantification of these measures, engineers gain the ability to measure and compare situations across different times, areas, and scales.

Wide-Scale Comparisons

Performance measurement can be used on a wide-scale to assess broad patterns and results. One of the best-known wide-scale comparisons utilizing performance measurement data is the Urban Mobility Study, published yearly by the Texas Transportation Institute ⁽⁹⁾. This study examines congestion across 85 urban areas in the United States utilizing data from 1982 through 2003. The study provides an on-going basis for cataloging and understanding the extent of mobility problems within the United States.

The main performance measure utilized in the study is the Travel Time Index (TTI), which measures the ratio of the time for a trip taken in peak conditions to the time for the same trip in off-peak conditions. As an example, a TTI of 1.4 means that a 30 minute trip in off-peak conditions will take 42 minutes in peak conditions. While the travel time index is the main performance measure utilized, the study includes many such measures and adds new measures over time to help explain the trends in urban mobility.

A similar methodology of looking at wide-scale impacts has been utilized for the assessment of damage to transportation systems, most notably, earthquake damage ⁽¹⁰⁾. Although more specific in application than the Urban Mobility Study, this study developed new performance measures using data that would still be readily accessible after a natural disaster. The measures also were utilized to evaluate the spatial and temporal characteristics of the

damage. This allowed for the measures to be tracked during the repair process and indicate recovery and restoration efforts to interested parties. It also allowed the measures to be applied to two other major earthquakes experienced by California (Loma Prieta in 1989 and Northridge in 1994) to determine comparative restoration periods and system performance. Lessons could then be drawn across the study areas to examine restoration techniques and time frames which differ by country.

Performance Measurement In Transportation Agencies

The use of performance measurement methodologies by state Department of Transportation (DOT) agencies has been commonplace for several years. DOTs such as Pennsylvania, Wisconsin, New York, Texas, and Oregon, to name a few, have long had performance measurement systems in place for various aspects of transportation. For many DOTs, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 formalized the need for performance measurement, by requiring states to implement management systems for several aspects of the transportation system, including:

- Pavement management systems
- Bridge management systems
- Safety management systems
- Congestion management systems
- Public transportation management systems, and,
- Intermodal management systems ⁽⁶⁾.

As part of the research conducted for NCHRP Synthesis 238, a survey was utilized to collect performance measurement information from state DOTs. The survey sought to identify where performance measurement was being used across all modes of transportation, as well as examining the reporting characteristics in terms of frequency and geographic basis. In particular, information was collected about the following program areas:

- Multimodal Transportation,
- Highway Construction,
- Highway Maintenance,
- Traffic Safety,
- Public Transportation,

- Ferry Service,
- Aviation,
- Railroads,
- Ports and Waterways, and
- Licensing and Registration. ⁽⁶⁾

Table 1, adapted from Table 1 of the NCHRP Study, shows that as of the 1997 publication date, performance measurement was gaining a strong foothold in many program areas across the responding states. As might be expected, measures were more often associated with traditional programs such as maintenance and construction, but were also being applied to other areas such as licensing and the overall performance of the agency’s administration. Table 1 also shows the frequency of reporting that occurs in each of the program areas. It should be noted that some rows may sum to more than 100% as a result of reporting at various frequencies.

Table 1. Response Rate and Frequency of Reporting for NCHRP 238 Survey [Adopted from Table 1 of Reference 6].

Program Area	In Use by States (%) ^(a)	Frequency of Reporting (%)			
		Monthly	Quarterly	Annually	Other
Multimodal Transportation	28	17	—	92	8
Highway Construction	61	28	8	28	38
Highway Maintenance	89	47	13	60	35
Traffic Safety	83	10	7	83	22
Public Transportation	64	17	22	61	7
Ferry Service	36	62	23	46	15
Aviation	58	42	19	32	19
Railroads	44	22	—	72	6
Ports and Waterways	33	42	17	42	17
Licensing and Registration	28	67	22	33	33
Administrative Performance	36	46	18	46	9

(a) Percentages are based on the total number of states (36) responding to the survey.

Examples of Prior Performance Measurement Implementations

An example of an early performance measurement system was the DataLink system constructed at the Texas Transportation Institute ^(11, 12, 13). First developed in 1996 and expanded with additional capabilities through 1998, DataLink utilized inductive loop data from the San Antonio TransGuide transportation management center in San Antonio, Texas. At the time of the DataLink system construction, TransGuide operated 26 miles of freeway on three major

freeways surrounding the central business district. Data of speed, volume, and occupancy were collected from the loops every 20 seconds. Loop spacing was approximately every half-mile in every main-lane. The amount of raw data collected exceeded 100 megabytes per day.

DataLink pioneered a number of considerations related to data management for performance measures. The primary consideration for the system architecture was the data storage requirements. Because of the enormous amounts of data being collected, especially for that timeframe in computing, appropriate strategies were necessary to keep storage costs within reason. DataLink employed a 5-minute aggregation routine to reduce the storage requirements by approximately 93 percent.

In a similar consideration to the size of the overall storage, the desired storage and retrieval capabilities necessitated the use of a relational database. Common desktop databases could not handle the requirements of the system and a larger enterprise level database was utilized. Specialized screening rules were developed to ensure data integrity within the database. Performance measures identified the number of data elements that were used in the calculation to ensure proper interpretation of the results.

The ability to easily access and work with the data contained within the database was a crucial factor in making the system feasible. DataLink utilized an open-standards web interface to provide access to and manipulation of the data within the system. This eliminated the need for specialized programming or database skills on the part of system user and expanded the ability to use the system to anyone in the target agency. This highlights a key finding related to performance measurement. The data should be available to those who need to use it and it should not be difficult to

In its most basic capabilities, DataLink output provided speed, volume, and occupancy information at user specified time intervals and locations. The aggregation techniques could be used to report on time periods from five minutes to one day. DataLink output also supported the calculation of performance measures based on both lane and corridor aggregation techniques.

The DataLink system was research-based and explored a number of never before examined questions pertaining to large-scale data archiving activities within transportation. A similar, but operational, system was constructed in Montgomery County, Maryland ⁽¹⁴⁾. Known as DASH, or Data Acquisition and Hardware, the system utilized many of the same components as DataLink. The system employed screening techniques for data integrity, automatically

updated itself as new detectors were brought on-line, was updated with new data once a day and allowed multiple end-user queries. DASH provided significant benefits to Montgomery County, including the ability to collect and store more accurate and precise data, improve information sharing throughout the agency, and reduce the need for supplementary traffic data collection.

Throughout the literature, a number of smaller-scale systems used performance measures constructed from archived data to analyze a more focused objectives. One such study ⁽¹⁵⁾, performed travel time analyses on the Katy Freeway in Houston, Texas. The objective was to quantify travel any time savings on the toll lanes as compared to the main lanes. This study was not a large scale exercise, but allowed for the development of an evaluation procedure and framework for using the travel time savings information as a performance measure.

Factors Affecting The Use of Performance Measurement in Transportation

While the data are a critical element of any performance measurement system, the literature also shows other factors which must be considered. One critical factor in the application of performance measurement is the geographic scale. Performance measures can be constructed to look a global, far-reaching objectives, to focus in on a detailed evaluation of any given component of the transportation system, or at any level in between. Table 2 lists the geographic scales used by transportation agencies reporting results to the survey in NCHRP 238.

Table 2. Geographic Basis for Reporting Performance Measures in NCHRP 238 Survey. [Adopted from Table 2 of Reference 6]

Program Area	Frequency of Reporting ^(a) (%)			
	Statewide	Regional/District	County	Urban/Local
Multimodal Transportation	58	25	25	25
Highway Construction	72	28	6	6
Highway Maintenance	69	52	28	3
Traffic Safety	81	20	22	17
Public Transportation	48	11	24	28
Ferry Service	15	31	8	15
Aviation	77	7	—	13
Railroads	78	—	—	6
Ports and Waterways	50	25	—	8
Licensing and Registration	89	22	22	22
Administrative Performance	73	36	—	—

(a) Percentages are based on the total number of states (36) responding to the survey.

As can be seen, many of the areas of measurement had widespread applicability across large geographic regions, such as statewide or across a region. The geographic scales and percentages listed above may also be skewed by the program areas in the survey. Other areas, such as incident management, may focus on smaller areas or aspects of the transportation system.

Other aspects to consider include items such as the availability of data and can the desired measure be supported. Choosing measures which require extensive collection or manipulation beyond the resources of the agency will only minimize the benefits that could be gained from a performance measurement system

Integrity of the data is a key concept as well, as the old adage of “garbage in, garbage out” applies to performance measures as well. Other factors to consider include the time frame of data collection, the geographic area, the scope, and aggregation techniques ⁽¹⁶⁾.

A comprehensive listing of factors affecting performance measurement may not be possible, as it would change by agency, but the listing below shows the main criteria that every agency should focus on when considering the implementation of a performance measurement system.

- Measurability – Can the data be generated with readily available tools and resources?
- Forecast Ability – Can the performance measure realistically measure future projects or needs?
- Data Collection – Can the necessary data be collected through field measurements?
- Clarity – Will the measure be understandable?
- Usefulness – Is the measure of direct relation to the issue or concern?
- Temporal Characteristics – Can the measure be used to differentiate results in different time periods?
- Geographic Scale – Will the measure be applicable to all areas of the system?
- Control – Can the characteristic being measured be controlled or influenced by changes in the system?
- Relevance – Is the measure applicable to the current evaluation process?
- Diagnostics – Can the measure be used to pinpoint corrective actions in the system?

PERFORMANCE MEASUREMENT FOR TRANSPORTATION OPERATIONS

Perhaps the aspect of transportation that has the largest impact on the daily lives of users of the transportation system is that of operations. Transportation operations is a vast area of programs and policies designed in large part, to address the congestion on the nation's highways and improve the traveling conditions. Areas such as:

- Arterial Management,
- Access Management,
- Operations Asset Management,
- Congestion Mitigation,
- Corridor Traffic Management,
- Emergency Transportation Operations,
- Facilitating Integrated ITS Deployment,
- Freeway Management,
- Freight Analysis and Management,
- Planning for Operations,
- Real Time Traveler Information,
- Road Weather Management,
- Tolling and Pricing Opportunities,
- Traffic Analysis and Simulation,
- Travel Demand Management,
- Traffic Incident Management,
- Planned Special Events Traffic Management, and,
- Work Zone Management.⁽¹⁷⁾

are all components of an effective transportation operations programs. Performance measurement can be used to support all of those areas, although obviously the measures themselves would be different.

What's critical however is the process of performance measurement. The following chapters outline the process of performance measurement and its application to transportation operations.

OPERATIONAL PERFORMANCE MEASURES USED IN TEXAS

Like most freeway management software applications, the Texas Department of Transportation uses performance measures in its TMC software. Although the software varies by TMC, a typical installation examines data from the roadway and reports speed, volume, and occupancy as basic indicators of performance. Figure 2 shows a screen capture from the TxDOT Advanced Transportation Management Software (ATMS) utilized by TxDOT in many of its TMCs.

As seen in the figure, operators can look at the volume at varying levels of aggregation. Inductive pavement loops typically report data every 20 to 30 seconds. Aggregation is used to combine data into larger time intervals for display to, and interpretation by, operators. Figure 2 also shows speed and occupancy values across different detector stations. The TxDOT ATMS also displays level of service (LOS) measure for each segment of the roadway, which is based on a calculation of density.

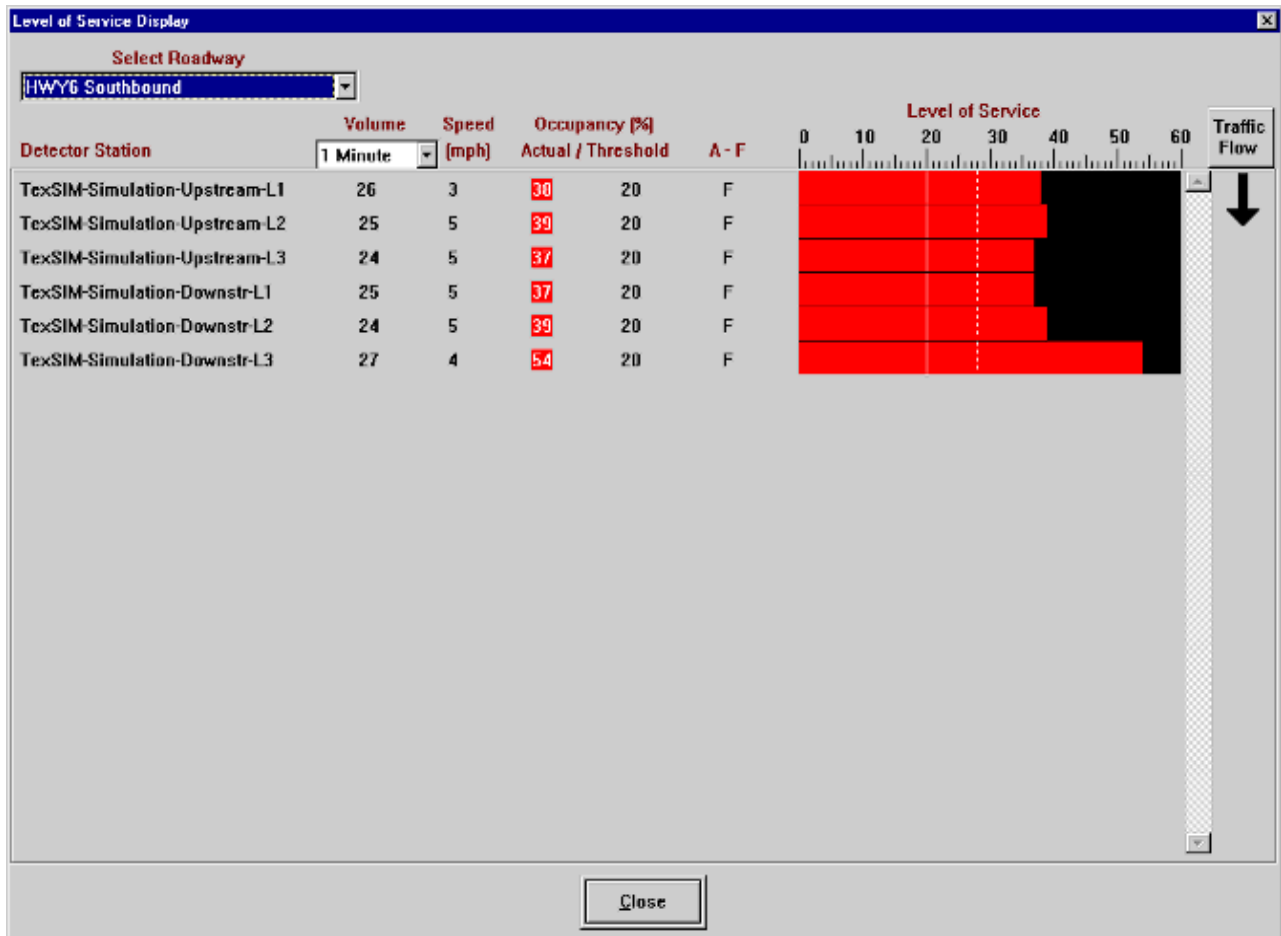


Figure 2. Performance Measures in TxDOT AMTS.

OPERATIONAL PERFORMANCE MEASURES IN OTHER STATES

It is known that other states also use performance measures to assess transportation operations. However, tabulation that information in a survey would have involved significant time and cost, and surveys traditionally have low response rates. Researchers therefore chose an innovative way to obtain additional information on the performance measures in use within DOTs and TMCs⁽¹⁸⁾.

As a result of the proliferation of the Internet, a wide variety of web sites exist that provide information related to traffic and roadway conditions. Because the data for these web sites typically come from the TMC that operates the roadway, investigation of these sites provided a surrogate survey for the operational performance measures in use.

In total, nearly 100 web sites were examined to determine the type of information that was being provided. In some cases, the web sites are published by the state or TMC, in others, the information and web site are provided by a third-party information provider, generally under an advertising or cost arrangement with the DOT. Table 3 lists the results of the web site survey.

There are two items that are important to understand when examining this table. First, there are multiple locations where more than one web site publishes traffic information. A typical example might be a city where the TMC publishes information as well as making it available to third-party information providers. The third-party sites may provide value-added services to customers. In this survey, there was no way to determine the “official” traffic site for an area, so all web sites that were found were included in the survey results. The data in Table 3 represent 97 traffic web sites representing 51 locations within the United States.

The second item to note regarding Table 3 is that different descriptors of the web site information may well mean the same thing. As an example, a web site detailing alerts generally provides the same information as a web site detailing incidents on the roadway. Likewise, the use of the word “conditions” typically means the same as alerts and conditions. The table listing therefore shows a number of categories where there is more than one descriptor of the information provided at web sites of this type.

Table 3. Performance Measures Used in Traffic Web Sites.

Primary Descriptor	Number of Sites
Alerts/Conditions/Incidents	30
Congestion/Delay	23
Speed	44

As a further note regarding Table 3, many web sites also provide additional information or data, such as travel time between selected points. These types of data and performance measures are rapidly increasing in significance to the traveling public and may increase in popularity in the future.

Table 3 shows that 45 percent of the sites are using speed as the primary method of presenting information to the traveling public. Roughly 25 percent of sites are using an indication of congestion or delay, which can be based on speed, level of service, occupancy, or other basic measures. These results suggest that roughly 75 percent of TMCs are using very basic performance measures to examine or describe their freeway operations. The 30 web sites corresponding to alerts, incidents, and conditions do not provide enough information to estimate the underlying performance measures in use.

An additional consideration for operations usage is that previous surveys of state DOTs have indicated multiple uses for performance measures. As reported in NCHRP Synthesis 311⁽⁷⁾, the results of a comprehensive performance measure survey indicated the following underlying reasons for performance measures within operations:

- support for legislative mandates,
- planning process,
- quality initiatives,
- congestion management system,
- ITS operations,
- safety management system, and
- permitting process for commercial driveways.

The report also noted that larger population areas may be more likely to have a performance measurement program in place to address mobility issues that are not present in smaller areas. Additionally, the report indicates the opportunity for improvement in the use of performance measures to support operations.

CHAPTER 3 – DEFINING PERFORMANCE MEASURES FOR TRANSPORTATION OPERATIONS

CHALLENGES OF PERFORMANCE MEASUREMENT^{1 (19, 18)}

It is perhaps an obvious statement to state that any system has its challenges, in both implementation and use. Performance measurement is no different. The biggest challenge of performance measurement, especially when applied to the operations side of transportation, is that the field is behind the curve of both other professions and other areas of the transportation profession. NCHRP 238 and other studies showed that some areas of transportation have embraced performance measurement for nearly two decades. Applying performance measurement to operations is much more of a recent focus.

There are several reasons for this lag. First, looking at the historical context of evaluating operations, the traditional indication of highway mobility and performance has been Level of Service (LOS). LOS is identified and calculated using procedures outlined in the Highway Capacity Manual (HCM) ⁽⁸⁾. LOS identifies broad ranges in traffic flow and is not responsive to many indicators of current performance, especially on a smaller scale. Also, LOS doesn't directly translate to concepts such as travel time, incident detection and clearance or other more targeted measures.

In addition, the concept of LOS is geared more towards the transportation professional. However, in recent years, much of the information that the industry needs to convey has been geared to groups other than transportation professionals. The traveling public has no basis or understanding of differences in LOS levels. As such, indicators of performance that are more explicit and more easily understood are necessary. In fact, the indicators used to discuss mobility and performance may change for different groups.

¹ Much of the information in this chapter is taken from previous works by this author, including:

Edward J. Seymour, James D. Carvell, Jr., Jodi L. Carson, Robert E. Brydia, James M. Paral., *Handbook For Developing A TMC Operations Manual*. Report FHWA-HOP-06-015. Federal Highway Administration, Washington, DC. November, 2005, and,

R.E. Brydia, K.N. Balke. *Performance Measures for Analyzing Real-Time Freeway Operations*, Research Report 0-1752-12. Texas Transportation Institute, College Station, TX. October 2003

Finally, the use of performance measurement requires a large amount of data, both real-time and historical, which many agencies are only recently beginning to collect and keep for this and other purposes.

BENEFITS OF PERFORMANCE MEASUREMENT

Despite the challenges listed above, performance measurement can offer a number of significant benefits to transportation operations. In particular, operations is an area that is highly visible to the traveling public, the overall customers of the transportation system. While a motorist might notice pavement conditions, a reduction in a bridge weight limit or some other roadway condition, items such as congestion, increased travel times, incidents, blocked routes and more are attention grabbing and something that public has shown they care about.

The real benefit to an effective performance measurement system is the capability to keep the agency focused on their core mission. Because operations is a core function of transportation management centers (TMCs), the statement of focus also applies to the work efforts of TMCs. The primary focus should be on meeting customer needs and expectations, which typically translates to items such as mitigating congestion, reducing travel time delay, clearing incidents more quickly and providing reliable travel time estimates.

In general, performance measurement can provide benefits in multiple areas, including:

- Accountability,
- Efficiency,
- Effectiveness,
- Communications,
- Improvements over time, and
- Future planning.

Accountability identifies if resources are being allocated to the priority needs. The desired effect is to achieve more informed decision making. This goes hand-in-hand with efficiency, which examines the output for any given level of input. A typical example might look at the staff necessary to provide a given level of management and whether improvements in the process can reduce staffing needs, save costs or free up infrastructure for other uses.

Effectiveness typically measures a shift in an agency's approach. By using performance measurement, agencies have been able to shift their thinking. Instead of recording how many

incidents took place in a given timeframe, the important concept shifts to questions such as: Has there been a reduction in incidents? Has there been a decrease in the average time of each incident?

Improving communication is perhaps an obvious and self-explanatory benefit of performance measurement. By focusing on primary goals that are important to the customer base, and identifying the appropriate information to convey results, communications can't help but to be improved.

Identifying improvements over time is another obvious benefit of a systematic evaluation process. By collecting and utilizing data in support of an on-going process, trends can be identified and long-term monitoring put into place. The feedback from these mechanisms can allow for the refinement of programs and services, both internal and external.

As a final benefit, performance measurement can't help but impact on future planning. As detailed above, the information gained from on-going focused evaluations allows for refinements. These refinements can be planned for and accomplished with greater accuracy and efficiency than would be possible without a performance management system. Additionally, the availability of a solid basis for future plans may lead to an increase in the dollars available for operational improvements.

EVOLVING TOWARD MORE SOPHISTICATED OPERATIONAL PERFORMANCE MEASURES

The results of the literature reviews, surveys, examination of ATMS software, and web sites, clearly indicate that the majority of agencies are still using the most basic performance measures to describe freeway operations, despite the valuable understanding that can come from using more sophisticated measures. There are several possibilities as to why this situation exists.

One potential reason is that assessing operational performance is still a relatively new area. Data needs for calculating measures beyond the basics may not be supported by existing infrastructure and ATMS programs. Because the use of supplementary measures may involve additional data collection or software development, significant cost may be involved in migrating toward more sophisticated measures.

A second potential reason why basic measures are used is that the variety of available performance measures is large. As an example, consider the measurement of congestion.

Performance measures related to congestion may be related to:

- Duration – focus on the temporal limits of the congestion,
- Extent – focus on the geographic limits of congestion,
- Intensity – focus on the severity of the congestion, or
- Reliability – focus on the variation in the congestion ⁽⁷⁾.

The number of different measures that could be used to describe a single concept (such as density) may be very confusing to different audiences, perhaps most especially to the traveling public. The need for communicating exactly what the measures are describing is an impediment to their wide-scale acceptance and use.

A third potential reason why more sophisticated measures are not used may be the data necessary to support their use. Many of these more sophisticated measures require a baseline—a point of comparison for understanding normal conditions. This comparison requires data from the roadway to be collected, stored, and made available for comparison use.

Consider the use of speed as a performance measure. It is generally well understood and because it provides an indication of the system at a specific location and point in time, it requires no reference point. In comparison, consider the use of queue length after an incident. In order to be effective, this performance measure has to be examined over time. Is the queue length decreasing or increasing? How far back from the incident does the queue start? Analyzing these performance measures may provide a more detailed understanding of an incident and the operational response to clear it from the roadway, but it requires a baseline in time and space that translates to extensive data needs.

The archival of data to support this need is not an insignificant task. The roadway infrastructure generates a tremendous volume of data. As an example, consider that the 26-mile phase one deployment in San Antonio, Texas, generated nearly 1 gigabyte of raw data per day⁽¹³⁾. While that amount is not as difficult to deal with as it was even 5 years ago, expanding the coverage area to three or four times the phase one deployment and keeping the data for a year would result in the need for more than a terabyte of space. That amount of data storage can be costly and is certainly not a trivial matter to incorporate into an archive data library. Also, the

time required to process and perform calculations using that much data must be considered in any system design.

As operational performance measurement becomes more commonplace, programs will begin to employ a broad spectrum of measures capture all of the various facets of program use. NCHRP 446⁽²⁰⁾ discusses the differentiation of performance measures that reflect output or outcome. Measures that reflect output are indicators of resources utilized or perhaps the scope of activities performed. Output measures identify information about the management of resources and are most useful in a performance-based system. In contrast, measures that reflect outcome are often more indicative of how well an agency meets the goals and objectives. Outcome based measures are more likely to be significant and understandable to the general public. However, both types of measures are useful and a successful performance measurement system generally includes both.

Consider for example an area of concern related to safety in icy conditions. An output measure might be the number of tons of salt applied to the roadway. While this measure has a majority of the ten characteristics listed above and easily understood and measured, it is most applicable to the agency in charge of the roadways. The corresponding outcome measure might be the number of ice-related accidents. This measure is much more easily understood by the traveling public and can be shown over time and large areas to highlight improvements to the system. Both types of measures work in conjunction to provide a complete analysis and evaluation of the system⁽²¹⁾.

In addition to looking at the factors discussed above, determination of the appropriate performance measures must also consider other aspects of the system. One important consideration is who will be using the measures. There are a number of different types of activities that take place in a transportation environment, from planning and design to operations and maintenance. Careful consideration of each of these specific needs will create a stronger success potential for a performance measurement system. Performance measurement systems should also consider users beyond the general public. These can include elected officials, the media, and users in the judicial system, to name but a few^(22.)

Another consideration is the increasing assessment of the multi-modality of transportation systems. As such, measures that concentrate on the mobility of the entire system, rather than a specific node, may prove to be very useful and necessary. Mode-specific measures

may be used in conjunction with the multi-modal approach to identify any deficiencies and to determine individual mode effects.

What Makes A Good Measure?

First and foremost, a performance measure must measure or gauge the right item. It does so by focusing on the goals and objectives and determining if they are being met. A performance measure should focus on the end result—not the measurement itself.

The second trait of a good performance measure is that it is accepted. Generally, this means that the measure must be simple, understandable, unambiguous, and meaningful to the customer, regardless of whom the customer is. To best accomplish this, agencies may well use different measures for different customers.

The third trait is that performance measures must be responsive and/or sensitive to the data they are measuring. They do this by clearly showing any trends, changes, minimums or maximums. A performance measure that is insensitive to these events within the data will not be meaningful to the customer because it can not accurately depict progress towards the system goals.

The fourth trait of a good measure is that it is appropriate. Judging the appropriateness of a selection is typically done in two ways. First, the timeframe must be suitable to the desire. If the desire is to determine a percent reduction in incidents, the measure should look at a lengthy analysis period, such as a week, month, or even a year. Reporting on a timeframe of minutes, hours, or even a day, would make little sense and would be an inappropriate timeframe for this measure. Second, the measure must be geographically appropriate. Measures can be directed towards a point, a segment, and entire facility or travel corridor, and even a region. A reduction in travel time wouldn't make sense at a point location, but might be a good measure from a corridor or regional perspective.

A fifth and somewhat arguable trait is that a good performance measure should be supported by economical data collection. Measures that require large and expensive data collection are not likely to be determined very often, due to time and/or budgetary constraints. This makes the measure untimely and insensitive to smaller changes, and ultimately will not convey meaningful results. At the same time, TMCs should recognize that it is ok to stretch beyond the current practice and find and collect additional data sources, if the performance

measures can provide meaningful results. This trait is arguable as many agencies have fallen into the trap of only looking at measures that can be supported by data they already collect. This can hinder effective evaluations and often results in choosing measures that don't support the stated goals.

Goal Based Classification

Another typical classification used to organize performance measures is to group them according to their general goal. Mobility based measures, as one example, reflect the ease or difficulty of making a trip. Classifying performance measures based on their goal area can help provide continual focus on agency or TMC goals. The list of goal areas typically used in this type of classification include:

- Accessibility – ensuring convenience and or right-of-entry to customers.
- Mobility – the relative ease or difficulty of making a trip.
- Economic Development – the cost, economic health, and vitality of the transportation system.
- Quality of Life – the sense of community desires and customer satisfaction.
- Environmental and Resource Conservation – the assets saved or expended, either natural or man-made.
- Safety – levels and rates of incidents or other occurrences.
- Operational Efficiency – productivity, manpower, financial resources, etc.
- System Condition and Performance – physical conditions, service ranges, etc.

It is not uncommon for a goal based system to use a secondary classification scheme. Mobility may be broken down into passenger or freight mobility. Safety could be broken down into roadway, rail, transit, parking, freight, and more. Note that the secondary classification areas may not be consistent or common across all of the goal areas. To make things even more interesting, classification schemes can be intermingled, resulting in (as an example), a set of output based performance measures for freight mobility.

Keys to a Successful Program

Over time, a number of keys have been identified to have a successful performance management program. These keys, listed below, are not set in stone, but provide some guiding

principles to help organizations navigate through the chore of picking appropriate measures. These keys are not an exhaustive list from the literature, but rather a compilation of those items and advice which are commonly accepted and indisputable.

- Keep the number of measures manageable – Don't be afraid to include measures when significant, but exclude measures that are merely interesting and not directly relevant.
- Use a balance of measures – Provide both output and outcome measures. Determine the critical areas of focus in your TMC and select measures for each area. Remember that some measures are more suited to a particular audience and ensure that the selection of measures can adequately convey understanding to each group of stakeholders.
- Be flexible – TMCs, especially new ones, should be prepared to experiment with performance measures, in order to find the right mix and set that capture and support the specific operating environment.
- Go beyond the basics – While it is recognized that simplicity and ease of measurement are attractive characteristics, especially to a new TMC, an agency should not shy away from the “hard” issues, such as areas that are hard to quantify or where data may be difficult to obtain. This pushes a TMC to grow and increase its capabilities and ultimately provide a better service to the stakeholders.
- Establish regular reviews – The performance measurement process should recognize the need for regular review. While the framework provides iterative loops, a TMC must embrace this need. Regular reviews of performance measures can add, delete, or revise measures, identify additional data sources, refine the presentation of measures to stakeholders, and ensure a continued focus on operational goals.

Examples of Performance Measures

There are quite literally thousands of performance measures identified in the literature. A comprehensive compilation of those measures is well beyond the scope of this report. The list below is but a small sample of measures that can be used by a TMC. This sample listing is intended to merely provide the reader with an awareness of the diversity of available measures. These measures have been stratified according to the goal classification system presented in section 0. This list includes measures which are both outcome based (examine satisfaction levels) and output based (provide a quantitative assessment). It is also possible that measures may support more than one goal area and so may be listed twice.

- Accessibility
 - Average travel time
 - Average trip length
 - Model splits

- Mobility
 - Vehicle miles of travel by congestion level
 - Travel time under congested conditions
 - Delay per vehicle mile of travel
 - Delay due to incidents
 - Lost time due to congestion
 - Annual hours of delay
 - Increase in system reliability

- Economic Development
 - Jobs supported
 - Jobs created
 - Economic cost of accidents

- Quality of Life
 - Perceived satisfaction with commute times
 - Perceived improvements in safety
 - Lost time due to congestion
 - Change in vehicle emissions
 - Accidents per vehicle miles traveled
 - Ease of connections to inter-modal transfer points

- Environmental and Resource Conservation
 - Tons of pollutants emitted
 - Fuel consumption per vehicle miles traveled
 - Air quality rating
 - Modal splits

- Safety
 - Fatalities per vehicle mile traveled
 - Number of highway fatalities
 - Average duration of incidents
 - Average incident detection time
 - Average incident response time
 - Customer perception of system safety

- Operational Efficiency
 - Public expenditures on transportation system
 - Savings to taxpayers from incident management
 - Average travel cost per mile
 - Change in congested travel
 - Change in delay due to congestion

- System Condition and Performance
 - Lane miles of facilities under active management
 - Pavement serviceability rating

- Volume to capacity ratios

RECOMMENDED PERFORMANCE MEASURES

With so many performance measures to choose from, in addition to the incredible variety of applications where they can be used, it would be foolhardy for any reference or manual to identify a list of performance measures that *must* be implemented. Indeed, a comprehensive listing can not be established by anyone other than the particular agency or TMC operating the system.

However, experience and research have provided significant direction on establishing a *minimum* set of performance measures that are *recommended* for implementation by a TMC. Identified in Table 4, these measures represent a suggested best practice for all of the characteristics that have been discussed, such as output vs. outcome, corridor vs. facility vs. regional, different goals, different audiences, and more. Agencies should consider this list as a *starting point* and add or subtract measures, as appropriate to local needs and uses. For each measure listed in Table 4 the corresponding recommended geographic and time scale are identified. Additionally, the table is stratified by several common areas of performance measurement.

**Table 4. Recommended Minimum Freeway Performance Measures.
(adapted from Table 4-5, Reference 23)**

Performance Measure	Geographic Scale	Time Scale
Congestion		
Travel Time Index	Corridor , Areawide (minimum)	Peak hour, AM/PM peaks, Midday, Daily
Total Delay (vehicle-hours and person-hours)	Corridor , Areawide (minimum)	Peak hour, AM/PM peaks, Midday, Daily
Bottleneck (“Recurring”) Delay (vehicle-hours)	Corridor , Areawide (minimum)	Peak hour, AM/PM peaks, Midday, Daily
Incident Delay (vehicle-hours)	Corridor , Areawide (minimum)	Peak hour, AM/PM peaks, Midday, Daily
Work Zone Delay (vehicle-hours)	Corridor , Areawide (minimum)	Peak hour, AM/PM peaks, Midday, Daily
Weather Delay (vehicle-hours)	Corridor , Areawide (minimum)	Peak hour, AM/PM peaks, Midday, Daily
Delay per Person	Corridor , Areawide	Peak hour, AM/PM peaks
Delay per Vehicle	Corridor , Areawide	Peak hour, AM/PM peaks
Percent of VMT with Average Speeds < 45 mph	Corridor , Areawide	Peak hour, AM/PM peaks
Percent of VMT with Average Speeds < 30 mph	Corridor , Areawide	Peak hour, AM/PM peaks

Percent of Day with Average Speeds < 45 mph	Corridor , Areawide	Daily
Percent of Day with Average Speeds <30 mph	Corridor , Areawide	Daily
HOV volumes	Corridor , Areawide	AM/PM peaks
Reliability		
Buffer Time Index	Corridor , Areawide	Peak hour, AM/PM peaks, Midday, Daily
95 th percentile Travel Time Index	As needed	As needed
Incident Management		
Detection Time	Corridor , Areawide	AM/PM peaks (minimum)
Verification Time	Corridor , Areawide	AM/PM peaks (minimum)
Response Time	Corridor , Areawide	AM/PM peaks (minimum)
Clearance Time	Corridor , Areawide	AM/PM peaks (minimum)
On-scene Time	Corridor , Areawide	AM/PM peaks (minimum)
Total duration	Corridor , Areawide	AM/PM peaks (minimum)
No. of Incidents by Type	Corridor , Areawide	AM/PM peaks (minimum)
Reporting by (citizens, police, other agencies) per month	Corridor , Areawide	AM/PM peaks (minimum)
Service patrol assists (total and by incident type)	Corridor , Areawide	AM/PM peaks (minimum)
Work Zones		
No. of Work Zones by Type of Activity	Corridor , Areawide	Daily
No. of Lane-Miles Lost	Corridor , Areawide	AM/PM peaks; midday, night
Lane-Mile-Hours of Work Zones	Corridor , Areawide	AM/PM peaks; midday; night
Average Work Zone Duration by Work Zone Type by Lanes Lost	Corridor , Areawide	Daily
Average Time Between Rehabilitation Activities	Areawide	N/A
Average Number of Days Projects Completed Late	Areawide	N/A
Ratio of Inactive Days to Active Days	Areawide	N/A
Weather		
Hours affected by (rain, snow, ice, surface ice, high winds, fog, dust, smoke)	Corridor , Areawide	Daily
Lane-miles affected by (rain, snow, ice, surface ice, high winds, fog, dust, smoke)	Corridor , Areawide	Daily
General Operations		
Service patrol vehicles per mile	Corridor , Areawide	Annually
Service patrol vehicles in operation per shift	Corridor , Areawide	Annually

Percent freeway miles with (electronic data collection, surveillance cameras, DMS, service patrol coverage)	Areawide	Annually
Number of messages placed on DMSs	Corridor , Areawide	Annually
Individuals receiving traveler information by source (511, other direct means)	Corridor , Areawide	Annually
Percent of equipment (DMS, surveillance cameras, sensors, ramp meters, RWIS) in “good” or better condition	Corridor , Areawide	Annually
Percent of total device-days out-of-service (by type of device)	Corridor , Areawide	Annually
No. devices exceeding design life	Corridor , Areawide	Annually
MTBF for field equipment (by type of device)	Corridor , Areawide	Annually

One of the previous recommendations for implementing performance measures was to establish a balance of measures. This really means establishing a program that assesses all areas of transportation operations. Figure 3 illustrate this concept by showing a pyramidal approach to

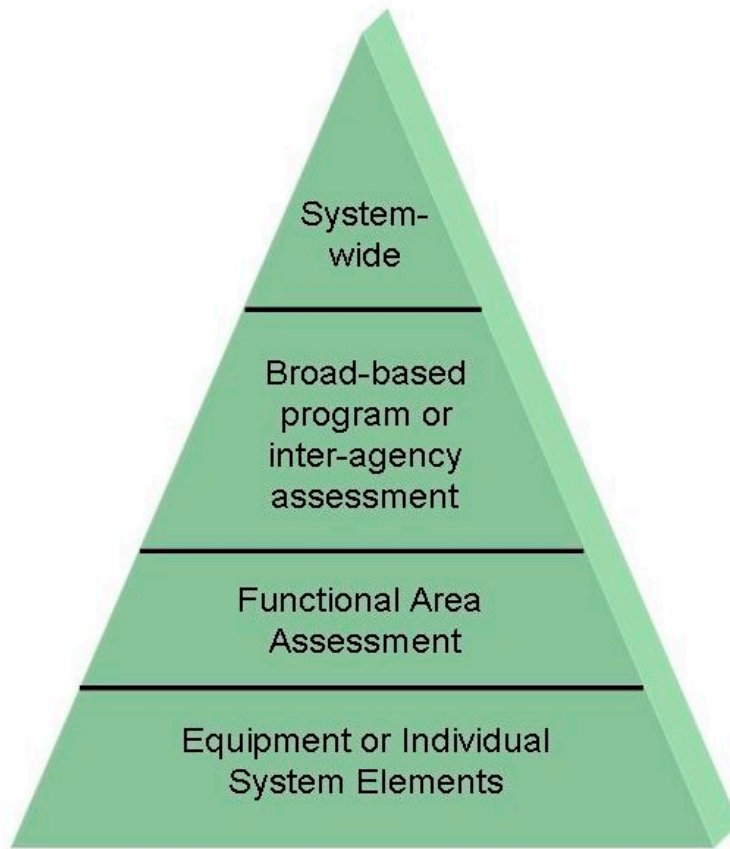


Figure 3. Multi-Level Approach to Defining Performance Measures (adopted from Figure 1.1, Reference 24.

to defining performance measures. At the base of the pyramid are those measures that focus specifically on equipment or very discrete elements of the transportation system. They may examine up-time, reliability, integrity of data or more. Looking at these measures should provide an overview sense of how the data collection, processing, storage and calculation components of performance measurement are operating, across the entire extent of the operation.

The next level focuses on functional areas. In reality, this is a department level review process. Measures may focus on the work aspects of TMC operators, service patrols, maintenance crews or other contained functions within the TMC or agency.

The next step up in the pyramid is that of programmatic or inter-agency assessment. Operations such as incident management, congestion mitigation, air quality and more are typically a joint effort between multiple agencies. The performance measures at this level focus on defining how these programs are working and if the various resources are being used effectively to bring significant improvement to the program.

The final step in the pyramid is that of a system-wide assessment. This is the most global view of operations and serves a multitude of purposes. For one, this may be the information that the public and elected officials receive on a consistence basis, identifying the stat of the overall transportation system and the progress the agency is making in operating it in an efficient manner. These type of system-wide assessments may be instrumental in focusing funds and personnel on critical priorities.

A Special Note for Rural Environments

It should be noted that the use of performance measurement, the choice of performance measures, the data collected, and communications to stakeholders may be significantly different in rural, or smaller areas. The following list identifies some of the major differences and contains recommendations for where smaller communities should focus their efforts.

- In smaller communities, planning agencies often lead the charge of conducting operational performance measurement.
- Operations in smaller communities are typically focused on major arterials and signal operations.
- Mobility measures are likely to be of greatest interest to smaller communities.

- Because the typical activities of involved agencies in smaller communities involve planning, performance measure focusing on the facility-level are likely to provide the best starting point.
- There are currently only a few small communities using travel time reliability measures.
- Performance measures looking at operational efficiency measures should be of interest to small communities.
- Most small communities are interested in measures that are readily understandable by the general public.
- Few small communities have developed a dedicated performance measurement system.
- In smaller communities, accessibility measures are not critical.

Overall, in terms of transportation operations, defining the goals and objectives of the various functions and determining which supporting measures will be used can help answer and address the following questions:

- How well are we doing in operating our roadways and transportation system?
- Are we meeting our goals?
- Are our customers satisfied?
- How can we improve our communication to our customers?
- Where are improvements necessary?
- Are there opportunities for a tighter link between operations and other aspects of transportation, such as planning?

UNDERSTANDING THE PROCESS

Illustrated in Figure 5, a performance measurement process can be formalized in nine steps, as identified below:

1. Identify the critical activity
2. Identify the goals and objectives of the activity
3. Develop a set of candidate performance measures
4. Identify performance targets
5. Identify uses of performance measures and potential audiences
6. Identify data needs and requirements for analytical tools
7. Establish data collection and evaluation procedures
8. Compare actual performance to targeted goals
9. Determine corrective actions or progress needed to achieve goals

Figure 5 represents an overview of the process. While there are additional details that could be illustrated at each of the steps, the overview of the entire process is the important aspect to consider at this stage of describing performance measurement.

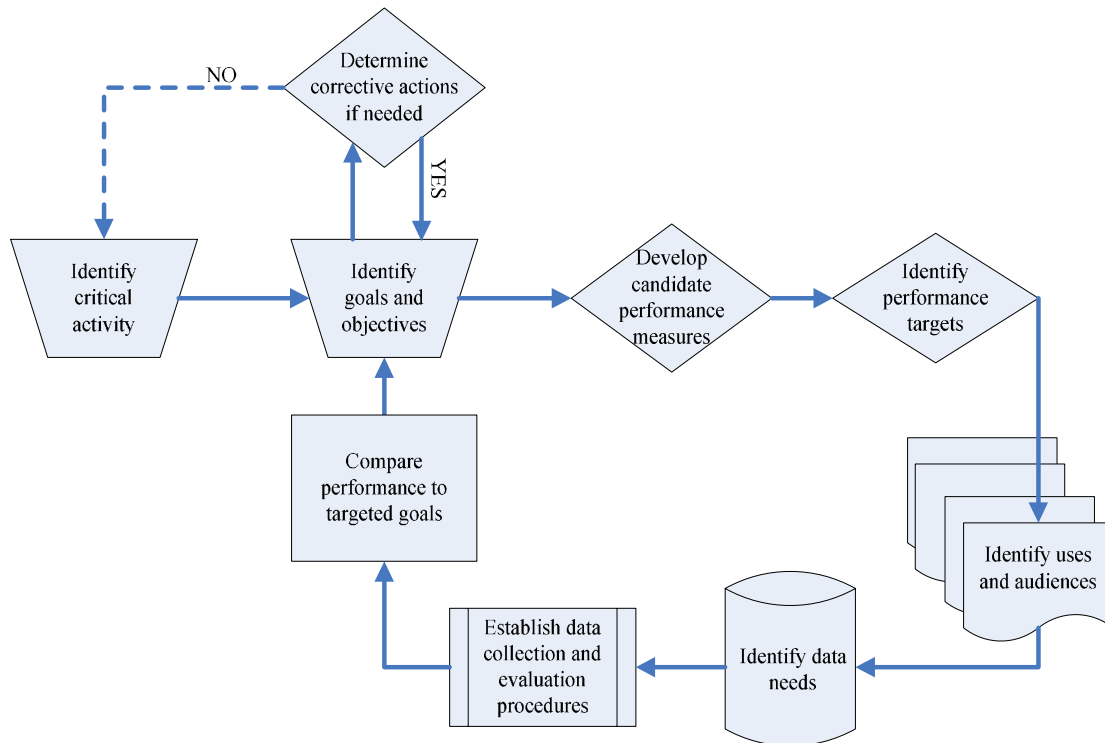


Figure 5. The Performance Measurement Process.

Step 1-Identify Critical Activity

The first step of the process is basically a selection tool. The concept is to select a single activity that a TMC performs, focus on establishing the on-going performance measurement process for that activity, then return to step 1 and repeat it for another activity.

Step 2-Identify Goals and Objectives

Every activity has goals and objectives that can be defined. As an example, if the activity is incident management, a typical goal may be to ensure the timely emergency response to incidents. Notice that the goal sets forth the large-scale vision. A corresponding objective may be to reduce the incident detection time. Another objective in support of the same goal may be to reduce the incident verification time. Take note that objectives tend to be more specific and focus on a particular aspect of achieving the overall goal.

Step 3-Develop Candidate Performance Measures

The identification of performance measures follows directly from the goals and objectives. Continuing with the example from Step 2, a performance measure utilized in the evaluation of incident detection would be the current average incident detection time. Note that

this measure could be stratified by type of incident, location, time of day or other variables that would provide a more detailed understanding of the system's response.

Step 4-Identify Performance Targets

The identification of performance targets goes hand-in-hand with Step 3 above. Continuing with the example of incident detection, a specific performance target could be to reduce, by 25% from current levels, the incident detection time, within a timeframe of one year.

Figure 6 provides a detailed illustration of Steps 1-4 and shows the logical progression from vision (Step 1) to detailed and measurable targets (Step 4)

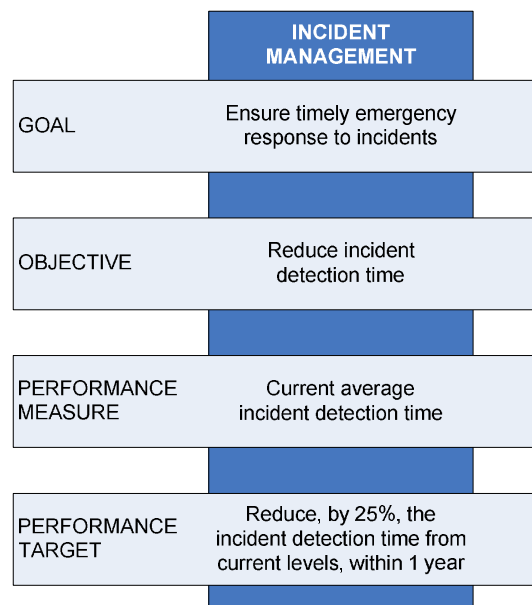


Figure 6. Steps 1-4 of the Performance Measurement Process. Adapted from Figure 2.3, Reference 23

Establishing Performance Measurement Thresholds

A threshold can be thought of as a bar or even a line in the sand. The objective is to reach the bar or cross the line. The line in the sand may be 15% fewer crashes or reducing average trip delay by 5%. Regardless of which measure is being utilized, a threshold serves as the evaluation point for determining the progress.

Without thresholds, there is no real basis for choosing what to measure, how to assess it or what action to take. Establishing reasonable thresholds is a critical step in the performance measurement process.

The key consideration is reasonable. Targets should be stretching and challenging to an agency or TMC, but not unrealistic. It wouldn't be prudent to set a threshold of a 100% reduction in accidents on the freeway. It may however be reasonable to establish a target of 5% or perhaps even 15%. When that target has been reached, the iterative nature of performance measurement will lead the TMC to establish a new target, therefore pushing for continuous improvement.

The previous sections identified numerous sample performance measures as well as a recommended minimum set of freeway performance measures. It is however, beyond the scope of this manual to offer suggestion on specific thresholds that an agency should establish as part of their overall system. The information necessary to establish specific thresholds is entirely local in nature and can not be identified at the level of this document. However, what can be offered are some simple guidelines that an agency can use to establish appropriate thresholds.

Thresholds should be:

- Realistic
- Specific
- Challenging, but should not punish the agency
- Achievable (lest staff feel they are out of reach and doomed for failure)

In additional, thresholds should include a timeframe for completion. An open ended timeframe does not promote focused and consistent efforts for meeting targets

Step 5-Identify Uses and Audiences

Any performance measure could be used in a variety of settings, but there are certainly measures that are most appropriate to particular audiences. A measure that is time based is easily understood by a non-technical audience and can be presented in a variety of methods. On the other hand, measures that are based on rates, such as percent travel delay reduction per 100 million vehicles miles traveled (VMT), may be much more difficult to visualize and effectively display to a non-technical audience. The concept behind step 5 is to examine the list of measures and ensure that you will have information that can easily and quickly be understood by the target audience. It is also important to realize that there may be multiple audiences, including such diverse groups as politicians and city leaders, the general public, agency management, planners and engineers. Each group has a different need for information and a different capacity for

evaluating the information presented to them. Understanding those facets and how your performance measures support those presentations is the outcome of this step.

Step 6-Identify Data Needs

The concept, at this step in the process, is to identify exactly what the data requirements are for any given measure. How much data? From what locations? How often? Can it be used “raw”, or does it have to be processed? How must it be processed? Does the data need to be stored? For what period of time? What is the reliability of the data? These questions and more, can be used to establish detailed technical requirements for the data needs to support performance measurement.

Step 7-Establish Data Collection and Evaluation Needs

Following directly from Step 6, a solid plan for data collection is the result of this step. Whereas Step 6 identified the data need (e.g., 5-minute vehicle counts), this step identifies the source and mechanism for obtaining that data (e.g. automatic traffic counters at multiple locations along the freeway. Data stored in 5-minute bins in flat files and transmitted automatically, on a 24-hour cycle, to the TMC.) This step would also identify the specific tools and techniques that may be necessary to produce the final measure.

Step 8-Compare Performance to Targeted Goals

Perhaps the simplest of steps in the process, this phase of the system compares the actual results of the performance measure to the desired results, or goals, detailed in Step 4. An explicit categorization of the comparison results should be made, including date, time, overall result, measure, measure value, target, and difference between the value and target. This level of detail is an important input to Step 9 in the process.

Step 9-Take Corrective Action, If Necessary

Perhaps the most nebulous of all the steps in the process, Step 9 seeks to identify what, (if any), remedial actions are needed to continue to push the performance measures towards their targets. In essence, Step 9 becomes a planning or brainstorming exercise. How can incident detection time be reduced further? Could additional sensors provide for a more rapid analysis of the system response? Where should they be placed? How much will they cost? These and other

questions can be utilized to analyze the overall system response, evaluate shortcomings, and identify solutions to address those shortcomings.

A critical concept to understand is that even though Step 9 is the final step in the sequence, the process is an on-going and iterative evaluation methodology. This is perhaps best illustrated by the feedback arrows in Figure 5, which direct the reader back to other steps in the process, depending on the needs. If additional or corrective actions are necessary, the process returns to Step 2, to identify the goals and objectives. If no changes are required and the process is working as planned, the outcome of Step 9 is to return to Step 1, where a new activity is examined and the process starts again.

Table 5. Typical Information Sources for Performance Measurement Data..

Travel Times	Speeds	Densities	Capacities
<ul style="list-style-type: none"> • Corridor • Facility • Average, • Regional, • Peak vs. off-peak 	<ul style="list-style-type: none"> • Average • Estimated • Corridor • By vehicle type 	<ul style="list-style-type: none"> • By lane • By facility • By time of day • Incident vs. non-incident 	<ul style="list-style-type: none"> • By section • By facility • Incident vs. non-incident
Queues	Throughput	Incident Characteristics	Other Sources
<ul style="list-style-type: none"> • Length • Speed • Duration • Rate of growth 	<ul style="list-style-type: none"> • By facility • By vehicle type • By time of day 	<ul style="list-style-type: none"> • Detection time • Duration • Response measures • Extent 	<ul style="list-style-type: none"> • Weather • Work Zones • Staffing • Expenditures • Customer satisfaction

Notice that the table lists numerous data sources that originate from real-time or historical roadway information, such as speeds, densities, or incident response information. However, the table also lists several other information sources, such as staffing and performance levels, expenditures, and customer satisfaction surveys. These types of information are perfectly valid as data sources for performance measures. Indeed, as detailed in previous sections, a balanced approach to performance measures is best.

Aside from the question of *what* data should be collected, a number of other important parameters must be considered that affect the ultimate usefulness and/or application of the performance measure. These include items such as the:

- Frequency of data collection.
- Schedule of data collection.
- Location(s) of data collection activities.
- Data collection responsibilities.
- Data analysis needs (cleaning, quality screening, aggregation, etc.).
- Data manipulation or calculation needs.
- Data analysis responsibilities.
- Database or historical record keeping requirements.
- Data presentation needs.

Many of these needs are explicitly recognized in Figure 8. A successful performance measurement system will identify the answers to each of these questions, for every performance measure in use. In fact, it is recommended that a standard format be developed for the system requirements that explicitly identifies the type of data in use, the location, and all of the considerations that must be addressed prior to its use and incorporation into the system. This documentation in effect becomes a library of capabilities, so that when new measures are desired, a determination can quickly be made if the necessary data is available.

Methods of Collecting Data

Data collection can be one of the most labor intensive, and therefore costly, aspects of performance measurement. While some information can be obtained from the typical roadway devices, they can not provide the full extent of the data necessary for the wide range of measures likely to be employed. In fact, roadway devices can not provide all of the data necessary for the minimum recommended list of performance measures identified in Table 4. Additional methods of collecting data must be employed.

Typical methods of collecting data include:

- Automatic collection
- Regular (manual) collection
- Periodic collection
- Random sample collection
 - small-scale samples such as travel time runs using the floating car method;
 - simulation modeling data rather than direct measurement.

Each of these methods has their advantages and disadvantages. Wherever possible, agencies should use automatic data collection, as that will be the most cost efficient mechanism, as well as providing the most comprehensive coverage, both in terms of geography and time. In fact, data costs, more than any other factor, will likely govern the amount of data collection that can be performed. An agency just beginning a performance measurement process would be wise to take a minimum or bare-bones approach at first, in order to establish a smooth process, work out all of the bugs and create a positive experience.

Other Data Issues

As if the difficulties of determining which data to use, and where to find that data weren't enough, there are a number of other considerations that may need to be addressed before performance measures are calculated.

Data integrity is an often overlooked issue. Many systems assume that if information is being reported from field devices or other systems, that it is correct. That is certainly not always the case. A strong consideration should be given to building a data integrity component to ensure good quality, accurate data. While not every data source can be checked for integrity, some automated flagging capabilities can be easily built, such as inductive pavement loops that report both high speeds and high occupancy values.

Data storage is always an issue. Although the physical cost of storing data in electronic form has continued to fall, there are other factors to consider such as the format of the data, e.g. flat files or internal to a database. Regardless of the choice, it takes time and effort to take raw data from any source and make it be ready for long-term storage.

Data manipulation is another hidden issue. As an example, speeds on freeways are often collected in bins of 20 to 30 seconds. However, a presentation to external audiences would typically show average speeds over a much longer time period, such as a day, week, or month. This aggregation, or averaging, while a simple calculation to perform, must be accounted for in the process of creating performance measures. Likewise speed information may need to be averaged along the length of a facility instead of at point locations, where it is typically collected. It may even be necessary to store data at multiple levels of aggregation, or construct a system to aggregate information on the fly, to support the data requirements of the various measures.

Some performance measures require more than one type of data. This points to a need to match up or "fuse" data from more than one source. This can be a difficult and time consuming task, especially if the data originates from different devices or systems which do not share common time clocks, formats, or even definitions.

As a final note, small or rural TMCs may face special challenges in data collection. Typically, small TMCs either do not have, or simply can not afford, to allocate all of the resources necessary to support large scale data collection efforts for performance measurement. In these situations, it is recommended the agencies look for data sources from external agencies, such as the city, county, or state. Also, agencies should explore sharing the costs of data

collection efforts, particularly in the case of automatic devices, as the same data can often be used for multiple purposes by multiple agencies.

Performance Measures Components – Turning Data Into Information

The types, number, and recommended minimum set of measures has already been discussed in previous chapters of this report. However, the cautions bear repeating.

- Keep the number of measures manageable – Don't be afraid to include measures when significant, but exclude measures that are merely interesting and not directly relevant.
- Use a balance of measures – Provide both output and outcome measures. Determine the critical areas of focus in your TMC and select measures for each area. Remember that some measures are more suited to a particular audience and ensure that the selection of measures can adequately convey understanding to each group of stakeholders.
- Be flexible – TMCs, especially new ones, should be prepared to experiment with performance measures, in order to find the right mix and set that capture and support the specific operating environment.
- Go beyond the basics – While it is recognized that simplicity and ease of measurement are attractive characteristics, especially to a new TMC, an agency should not shy away from the “hard” issues, such as areas that are hard to quantify or where data may be difficult to obtain. This pushes a TMC to grow and increase its capabilities and ultimately provide a better service to the stakeholders.
- Establish regular reviews – The performance measurement process should recognize the need for regular review. While the framework provides iterative loops, a TMC must embrace this need. Regular reviews of performance measures can add, delete, or revise measures, identify additional data sources, refine the presentation of measures to stakeholders, and ensure a continued focus on operational goals.

One of the critical components identified in Figure 8 was baselining. This refers to the process of establishing how the system is performing, on Day 1. Without a baseline, there is no effective mechanism by which to compare current operations against targets. A sub-component of baselining was also identified in the figure as storage. It is critical to store not only the baseline information, but also results of the periodic calculations of the measures, so that progress can be identified, tracked, and ultimately, communicated, as discussed in the next section.

Information Dissemination—Communicating The Results

All of the performance measures the system will use have been identified. The TMC has developed a comprehensive process for finding, collecting, compiling, and analyzing all of the necessary data. Reasonable performance targets have been established and compared to the targets. While this is exactly the process, a critical aspect remains. The information must be communicated to others, either internally or externally.

The key to communicating performance measurement information well is to understand the audience to whom you are presenting. When speaking to external agencies, political or legislative office holders, or even the general public, the golden rule of “less is more” is generally applicable. While you want to be sure to present a fair and accurate assessment, the display of significant levels of detail, with countless charts, tables, and figures, will likely be confusing. These types of audience need an overview and the bottom line—the numbers that make up the bottom line are generally not as important.

When communicating to the public or an agency not involved in the day-to-day operations of the TMC, a recommended approach is:

- Start with the message – identify the reason for communication.
- What is the area of concern? (identify it as a roadway, a corridor, the region, a particular location, etc)
- What is being measured? (keep it simple – speeds, travel times, accident rates, etc.)
- How is performance being measured? (provide a brief description of the performance measure and its purpose)
- Where did the data come from? (identify the data sources used and an overview of any necessary manipulations)
- What are the results? (strive for clear, effective, concise information)
- What do the results mean for your audience? (make it personal – relate this information back to them)
- What are the next steps? (Identify the options or future actions)

This approach is certainly not intended to imply that audiences are incapable of understanding the details associated with the performance measurements. It is likely however that the details of data collection, manipulation, storage and more are not necessary for your audience to understand the results and most importantly, the actions or next steps.

In essence, this same outline can also work for presenting material to a more technically oriented audience. While the steps remain the same, the level of detail presented at each step may increase.

Perhaps the most difficult step in the above process is item 6, the clear and concise communication of results. As engineers, a typical approach is to use charts, tables, and figures to graph or otherwise illustrate large amounts of information. This typically works well, but be careful to avoid common pitfalls.

Common Presentation Pitfalls

One common pitfall is to use a chart that shows every piece of data. While technically accurate, this typically leads to needless complexity and can actually hide the bigger picture or trends. If data was collected at 5 minute intervals, but your performance measure illustrates information on a daily basis, you can probably use one data point instead of showing the 288 individual 5-minute intervals.

Another common pitfall is to make information on charts or displays too small. Before presenting any information, view it from the back of the room. If you can't read it or see it clearly, neither can your audience!

Avoid excessive uses of colors and fonts. Colors and fonts can be used effectively to separate and group information, but too much is overkill and distracts from the message.

Be very aware of how your information will be presented. Charts designed for a color presentation do not translate well to black and white. If your information will be printed in a local newspaper or other publications, make sure that you provide displays that are tailored to that particular media.

Finally, don't assume that the charts will communicate the message for you. Charts are a backup and a visual aid—they are not the primary method of getting information across to your audience. Follow the presentation outline provided in the previous section for a consistent and tried and true approach to communicating information.

Methods of Presenting Data

Previous sections have discussed identifying the requirements for every performance measure in use. A final item to include in that list is data presentation needs. What method(s)

will be most effective for presenting that particular performance measure to the intended audience(s)?

Indeed, if the measure will be used in multiple settings, there may be more than once method of presenting the information. It is critical that the presentation of the data focus on the audience for the information.

The presentation of many performance measures will be supplemented or aided using typical and well-known types of charts. Charts are easily understood, can be adapted to a variety of audiences and situations and can be used at multiple levels of detail, as the audience warrants. However, some guidance on when to use what type of chart to use is warranted. The information below applies to typical situations. Like most aspects of engineering, individual judgment should be used to determine the most appropriate method of displaying information.

- Line – Highlights trends or changes over time. Can be used to show multiple series of data, but be careful of overcrowding the chart.
- Pie – Shows the relationship of the parts to a whole. Good for expressing percentages.
- Bar – Shows variations over a period of time. Horizontal bar charts typically give people the impression of time flow. Vertical bar charts typically give people the impression of movement in space, e.g., different roadways.
- Area – Shows the variation of data over time, but emphasizes the overall magnitude of the change, not the individual changes or rate of change.
- Combination – These charts excel at showing the background data but also highlighting the significant trend. A typical combination chart would utilize a bar graph in conjunction with a line graph.
- 3-D charts – Creating a chart in 3-D may help to highlight the information or improve the visualization. There are 3-D versions of all of the charts above.

EXTERNAL LINKAGES TO A REAL-TIME SYSTEM

While Figure 8 showed the detail behind each elemental building block in the system, the final experimental design must also take into account the capability to both interact with, and be revised from, feedback with external links. Figure 9 shows the full system, with external links in place.

Finally, Figure 9 shows an external link to the world outside of the operating agency. While this need should be readily understood, it is important to again stress that the focus of the performance measurement process should be on the customers. That likely entails multiple sets of customers, including the traveling public, agency administration, transportation planners, operators of the system, other agencies, legislative officials and more. Each audience will have a specific set of needs for receiving and understanding information. In many case, these links and information are made automatic, such as the publication of information on the Internet.

CHAPTER 6 – CONCEPT OF OPERATIONS FOR USING REAL-TIME PERFORMANCE MEASUREMENTS IN TRANSPORTATION OPERATIONS

Previous chapters have detailed the history of performance measurement and examined its application to transportation, especially, operations. Discussions examined the types of performance measures, a process for implementing performance measurement and a conceptual design for a performance measurement system. The final step in examining the entire application is looking at a concept of operations for how such a system would truly function.

This text will do so within the application of incident management. Other operational applications will have similar implementation scenarios.

CRITICAL BENEFIT OF PERFORMANCE MEASUREMENT

Recent interviews with TxDOT personnel regarding performance measurement have highlighted the critical benefit to using the process in support of traffic operations⁽²⁶⁾ While the recognition of, and response to, incidents on a freeway is a vital function of any freeway management system, there is generally no system in place to provide feedback on how the plan actually worked.

When an incident occurs, there is generally an established response mechanism, which seeks to return the freeway to normal conditions as rapidly as possible. What is missing from these response scenarios is a system to provide information, data, and feedback, other than circumstantial, for refining the plan to achieve better results the next time.

The key to providing this feedback is utilizing performance measurement to monitor not only current conditions, but also to capture the response actions, monitor the changing conditions, and store all of this data for analysis. This requirement was reflected in the component design presented in Chapter 5. The change in operations from normal condition to current conditions can be used to create performance measures. The goal of the performance measures is to assess the change in the system from the stimulus, in this case, the operator's action. This allows operators to assess such questions as:

- Are the operator's actions having any effect on the system?
- Is the traffic moving through the congested area faster?
- Is the length of the queue upstream of the incident shorter?

earlier, if the current status of the system is unknown, a change in its operations from an incident can never be accurately determined.

The performance measurement system also should capture the actions taken in response to the incident. These would include, but not be limited to, items such as:

- Date and Time of Incident Detection
- Date and Time of Incident Verification
- Date and Time of Arrival of Incident Response
- Date and Time of Clearance of Incident
- Roadway Conditions at time of Incident
- Resources Sent to Incident
- Operators Actions in Response to Incident (Date/Time Stamped)
- Roadway Conditions in Geographic Vicinity Sampled at Regular Time Intervals (to be determined)

At the conclusion of the incident, the performance measures can be analyzed to determine the true effect of the operational response. Feedback loops should go back to the TMC operators to improve not only their performance, but their understanding of how their actions are reflected in roadway operations.

In addition, the performance measurement information may eventually be slated for public information dissemination, as well as being used with partnering agencies to examine and enhance the incident response operations.

CHAPTER 7 – CONCLUSIONS AND RECOMENDATIONS

CONCLUSIONS

Nearly 50 years of use across numerous agencies have proven that performance measurement is a valid part of the organizational landscape. Utilizing it can enhance the quality of an organization's performance and improve the focus on customer quality. Recent literature has applied these same concepts to transportation.

While the initial focus of performance measurement in transportation was on process analysis, the possibilities for real-time applications are tremendous. Transportation operations in particular, could achieve a significantly better understanding of how traffic reacts to external influences. Achieving this understanding would allow operators to refine their actions in response to items such as incidents and may serve as a method to extend the physical capacity of the already developed infrastructure.

The key to utilizing performance measurement in a real-time application is building a comprehensive capability into the existing operational systems. This report has put forth not only a step-wise methodology for utilizing performance measurement, but also a proposed architecture for what a real-time performance measurement system should entail. In addition, this report details a concept of operations for how this system would be integrated into an operational context.

RECOMMENDATIONS

While the concept of real-time performance measure analysis has taken significant strides forward, it is not commonplace. In fact, before it can be so, a number of research questions remain:

- What is the proper method for establishing baseline conditions along monitored roadways?
- What is the influence and extent of additional information that can be combined for performance measure assessment in transportation operations?
- What are the appropriate algorithms for determining performance measures across both temporal and spatial aggregation needs?

Further research and prototype systems and applications are necessary to examine these issues and determine appropriate answers.

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