Transportation Management System Performance Monitoring, Evaluation, and Reporting

A Technical Handbook

September 2005

U.S. Department of Transportation

Federal Highway Administration

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Form DOT F 1700.7 (8-72)

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HOP-07-124		

4. Title and Subtitle
Transportation Management System Performance Monitoring, Evaluation, and Reporting — A Technical Handbook

5. Report Date
September 2005

6. Performing Organization Code

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8. Performing Organization Report No.

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10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTFH61-01-C-00180

12. Sponsoring Agency Name and Address
Federal Highway Administration
U.S. Department of Transportation
1200 New Jersey Ave., N.E. (HOP)
Washington, DC 20590

13. Type of Report and Period Covered
Handbook

14. Sponsoring Agency Code
HOP

15. Supplementary Notes
Raj Ghaman (COTM)

16. Abstract

This handbook provides an introduction to TMS performance measurement, and explores the specifics of establishing a performance measurement program; developing individual and detailed performance measures for various functions and sub-functions of a TMS; data collection, screening, archiving and processing efforts; and performance monitoring, evaluation and reporting. This handbook focuses on the equipment, systems, and programs involved in a TMS that can be used to obtain the most efficient and desirable outputs and outcomes.

17. Key Words
Transportation management system, performance measures, data collection, data screening, archiving, data processing, performance monitoring, performance evaluation, reporting

18. Distribution Statement
No restrictions. This document is available to the public from: The National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	161	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

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Chapter 1. Introduction

Chapter Purpose: This chapter introduces the concepts of Performance Measurement applied to Transportation Management Systems (TMS). Specifically, the following questions are answered: What is performance measurement? Why should the reader consider it for their system? What is a TMS? How to measure performance? The handbook addresses all these questions in great detail. This chapter helps a reader to understand the broad context, and navigate through the handbook efficiently. For quick reference, a summary of the other chapters is also provided.

1.1 Introduction

Transportation engineering has evolved significantly in the recent past. Along with the traditional solution of capacity enhancements and construction of new roadway facilities, improving the operational efficiency of the existing facilities is increasingly being pursued throughout the nation and the world. The technology components used for such operational improvements are usually referred to as Intelligent Transportation Systems (ITS). Various ITS elements are often grouped together to provide viable solutions to local transportation problems and help build the visions of the communities. A Transportation Management System (TMS) provides a broader context, and may be loosely defined as the deployed form of ITS, along with the human resource contribution, towards transportation management. In particular, TMS includes computer hardware, software, communications, and surveillance technologies that service freeway and arterial systems. A traffic management center (TMC) is the physical facility that houses central equipment, software and personnel to monitor, control, and operate one or more TMSs.

TMSs are categorized based on the type of functions they perform. The TMSs controlled by the transportation agencies at all levels (states, metropolitan regions, counties, and cities) frequently focus on managing three particular systems – the freeways, the arterials and transit. Other specific types of TMSs include emergency management, toll ways, etc. Each TMS is further composed of several different functions. For example, a freeway TMS could include functions such as incident management, special event management, ramp metering, work zone management etc. Depending on the size of the region under the scope of a TMS, the number/type of activities and personnel involved in the traffic management functions could be quite complex. There are mainly three stakeholders extremely and directly interested in the degree of performance of a TMS: the TMS manager, the traveling public, and the elected officials.

The TMS manager is responsible for the efficient and effective operation of the TMS, and for bringing in sufficient funds for operations, maintenance, planning, and capital improvements to meet regional needs. Therefore gauging the system performance on a regular basis is one of his/her primary necessities. A system itself is defined as a collection of entities that work together towards accomplishing a common set of goals. In line with this definition, a TMS exists and functions to achieve specific goals, such as improved mobility and safety, for the transportation system users. The public is therefore interested in knowing the degree to which a TMS is working effectively and efficiently. Furthermore, these systems are funded with the taxes paid by the citizens. For this reason, the elected officials are interested in assuring that the promised goals are met (effectiveness) with minimal expenditure (efficiency). Besides these three, many other stakeholders such as independent transit organizations, law enforcement officials, emergency management agencies, regional officials etc. are also interested in the proper functioning of a TMS. Some specific questions of interest to all these stakeholders are:

- Were the correct investments made?
- Are demands of the public and state legislature being met?
- Are the agency goals and objectives being met, and improved upon?

Establishing and carrying out a well-designed performance measurement program will help answer these questions. This handbook provides a number of definitions, explains how to establish a performance measurement program, and thoroughly details the various steps involved in carrying out such a program. Wherever available, best practices from around the nation have also been identified and included. An overview and background of these steps is presented in the next section.

1.2 Background

Every agency, system or process has one or more goals to achieve. Simply speaking, gauging the degree to which these goals are achieved and the efficiency with which they are achieved is termed as "performance measurement." This simple definition will be used throughout this handbook. Performance measurement is not a new concept. Ideas such as "what gets measured gets managed" have been around for a long time. But there has been a renewed interest and application of performance measurement among government agencies since the passage of the Government Performance and Results Act (GPRA). As president Clinton pointed out while signing the GPRA in 1993, performance measurement would help us to ". . . chart a course for every endeavor that we take the people's money for, see how well we are progressing, tell the public how we are doing, stop the things that don't work, and never stop improving the things that we think are worth investing in." (Gore, 1997)

As explained earlier, a TMS could be a very complex system with various types and quantities of equipment deployed over a vast region, to help monitor and manage the transportation system. Monitoring the transportation system requires sensors, communication, computer hardware, software, video, routers and other such equipment. Many TMCs also deploy incident patrol teams to identify and verify incidents rapidly. Transportation management also requires other types of equipment such as signals, ramp meters, gates, message signs, highway advisory radios, 511 phone systems etc. A TMS also requires personnel to work closely with various private and public agencies for the successful attainment of the agency [TMC] goals. TMC personnel perform a variety of functions such as:

- Continually monitoring the traffic to identify unusual situations,
- Verifying incidents and other situations when they obtain information from another source, and
- Acting on a regular as well as ad hoc basis to improve or restore traffic flow to optimal levels. Some of the regular actions performed include:
  - Updating messages on the variable message signs (VMS), highway advisory radio (HAR) and 511 phone systems,
  - Ensuring the safety of the workers and the traveling public at roadway construction and maintenance sites,
  - Operation and upgrade of software such as ramp metering, message signs etc.,

- Control/operation of signals, ramp gates, controllers, bus/train schedules etc.,
- Deployment/upgrade, operation and maintenance of all the equipment of a TMS,

- Monitor, request, and manage funds for the agency including outreach to elected officials, and
- Outreach regarding agency/system performance to the public

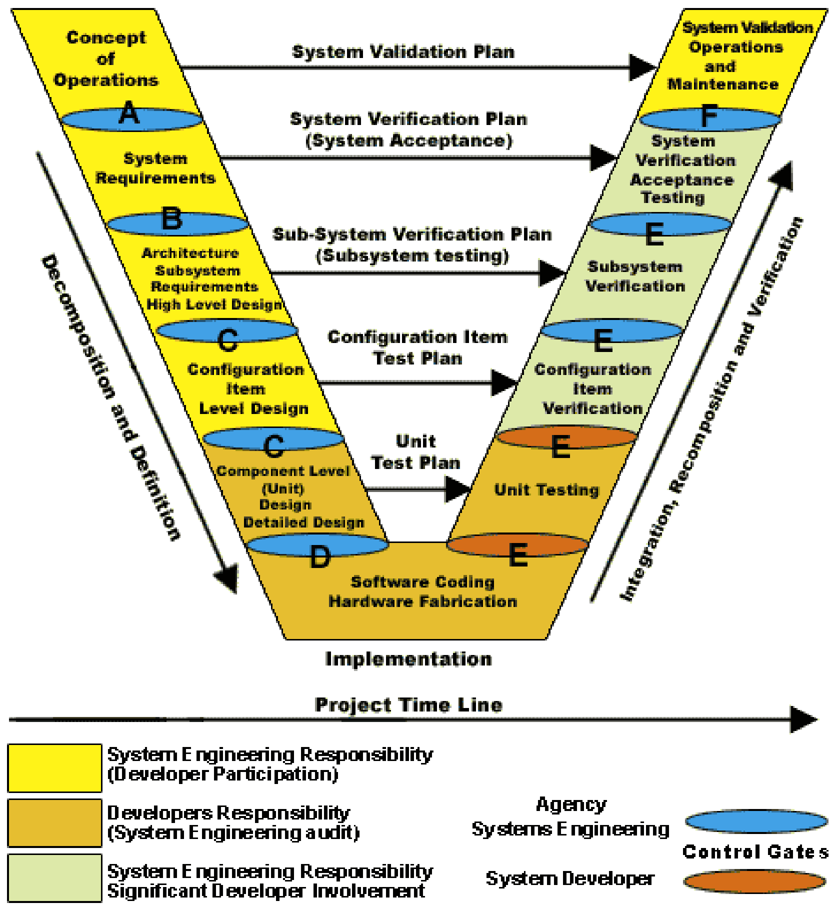

Figure 1-1. FHWA "VEE" Model for Systemic ITS Deployment (Graphic provided by ASE Consulting LLC)

In order to ensure the effective functioning of all this equipment and personnel, and the attainment of agency goals, their performance has to be monitored, evaluated and reported regularly. Performance monitoring is an ongoing internal process of examining the actual system condition through field data collection. Evaluation is the process by which the collected data is analyzed and the results are usually compared to locally set benchmark performance measures, based on historic data. In the event this data is not available, other means such as survey, experience from other regions, estimation etc. are employed to set performance benchmarks. Typically the components evaluated are the strategies, policies, systems, and operating procedures. Reporting provides information, such as trends and comparisons of the data and performance measures, for consumption by the stakeholders, usually in a very visual format. Performance measurement can illustrate how the system is effectively utilizing the agency's resources, how it compares to past work, and how it rates against the standards.

There are several TMS deployment aids available to the transportation practitioners and few for maintenance. But there is currently no standard documentation available for TMC personnel to develop and deploy a TMS performance measurement program, which details TMS performance monitoring, evaluation and reporting. For example, the National ITS architecture (version 5.1, hosted at Iteris.com), along with many other documents such as the ITS standards, provide a wealth of valuable information on several individual ITS components, and their groupings (often referred as market packages). Similarly, much information is also available for actual field deployment of a TMS, which often includes several market packages. The FHWA "VEE" model, in Figure 1-1, presents an excellent example for such a systemic deployment process.

Another exemplary document for ITS operations is Configuration Management for TMS (Smith, 2003). The deployment and operations of ITS, acceptance testing of individual equipment, and later their operational performance should ideally be monitored routinely. But as explained above, the enormity and complexity involved in a large TMS could be over-whelming for any manager or operator of the system, who is likely not aware of all the components at any given instant. This handbook attempts to close these existing gaps by providing a single reference for anyone interest in the performance of a TMS.

In these times of providing more with less (money), each TMS manager is faced with several challenges, especially in measuring performance, such as:

- A disconnect between the goals and the performance measures: There are often a large number of goals for a TMS. Tracking all these goals could soon become overwhelming.
- Inconsistency in data collection and analyses efforts, and
- Lack of information sharing among stakeholders.

This handbook addresses all these challenges.

1.3 Purpose

This handbook provides an introduction to TMS performance measurement, and explores the specifics of:

- Establishing a performance measurement program (developing the TMS goals and objectives, and identifying the stakeholders),
- Individual and detailed performance measures for various functions and sub-functions of a TMS,
- Data collection, screening, archiving and processing efforts,
- Performance monitoring, evaluation and reporting.

A number of performance measurement guides focus on the process or system outcomes instead of outputs. Outputs are the direct products and services delivered by a program, and outcomes are the results of those products and services (GAO report, 2005). In the case of a TMS, data for the transportation system performance measures (outcomes) are themselves collected by the TMS equipment. Good performance of the TMS equipment is therefore a primary requirement to insure reliable data. TMS outcomes are often the main interest of the traveling public, and hence the elected officials as well. This handbook therefore focuses on both the outputs and the outcomes of a TMS.

The focus of this handbook is mainly on the equipment, systems and programs involved in a TMS. It is believed that the efficiency and performance of the personnel involved in a TMS are better addressed through training and the involvement of the human resource managers.

1.4 Intended Audience

This handbook can be useful for a diverse audience. This section identifies these groups, and describes how different people might want to navigate through the handbook. The primary audiences are the TMC managers, supervisors and operators. Those who are responsible for operating, maintaining and reporting on the performance of the TMS. This handbook also serves agencies interested in monitoring the performance of a TMS. They include the federal, state and local agencies such as the DOTs (Departments of Transportation), MPOs (Metropolitan Planning Organizations), Counties, Cities etc.; specific TMS-related agencies such as law enforcement, emergency response, bridge management, toll management etc.; and also transportation researchers. The general public as well as the elected officials could also learn what to expect from and ask for, in a TMS context.

Chapters 2, 3 and 4 explain performance measures and their processes at a high-level and are targeted for stakeholders and upper-level managers. Chapters 4 through 6 provide very detailed technical information for setting up and using a TMS performance measurement program. These are most likely to be of interest to the TMS managers, supervisors and operators. Chapter 7 is similarly tailored for existing TMSs to gauge their current state-of-practice in performance measurement and identify areas for further improvement.

1.5 Handbook Organization – Chapters At-A-Glance

This section provides an overview and description of the organization of the document.

- **Chapter 1 – Introduction**. This chapter details the background, purpose, scope and intended audience of the handbook. A summary of the handbook chapters is provided to help readers quickly find sections of their interest.

- **Chapter 2 – Overview of TMS Performance Monitoring, Evaluation and Reporting**. This chapter provides a high level overview of performance monitoring, evaluation, and reporting, in the context of a TMS. The chapter also highlights examples of some successful practices and programs.

- **Chapter 3 – Performance Measurement Program.** This chapter discusses the purpose of and need for a TMS performance measurement program. It also details a recommended system and the functional components of such a program.

- **Chapter 4 – Agency Goals and Performance Measures.** This chapter presents typical goals of TMS-related agencies, such as state departments of transportation, metropolitan planning organizations, law enforcement, emergency response agencies etc. Various types of TMSs, their functions, corresponding performance measures and some example formulas are identified and presented.

- **Chapter 5 – Data Requirements, Collection and Archiving.** This chapter maps data requirements with the performance measures, and provides various details about data collection, screening, and archiving. Data quality details, for pre-processing the data before their use in evaluation analyses, are also explained.

- **Chapter 6 – Overview of TMS Performance Monitoring, Evaluation and Reporting**. This chapter explains performance monitoring, and details various evaluation methodologies and processes related to TMS performance. It also discusses recommended techniques, formats, and frequencies for reporting TMS performance.

- **Chapter 7 – Self-Assessment.** This self-assessment tool is in the form of a checklist of questions related to TMS performance measurement. This checklist can be used by agencies to assess their current status in measuring TMS performance.

- **Appendix A – Survey Questionnaire**

- **Appendix B – Contact List of Traffic Management Centers**

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Chapter 2. Overview of TMS Performance Monitoring, Evaluation and Reporting

Chapter Purpose: This chapter provides a high-level overview of all the information covered in this handbook. The chapter also highlights TMSs (Transportation Management Systems) with successful practices and programs, which are expanded upon throughout the rest of the handbook.

2.1 High-Level Overview of TMS Performance Monitoring, Evaluation and Reporting

The transportation system, in an operations context, is fittingly described as a Complex, Large-scale, Integrated, Open-System (CLIOS) (Sussman, 2001). The reasons for such a description is that:

- The subsystems within transportation operations are integrated.
- The degree and nature of the relationship among the subsystems is often imperfectly known.
- The impacts of the system are large in magnitude, and often long-lived and of large-scale geographical extent.
- The systems explicitly include social, political and economic aspects.

The performance measures of such CLIOS are quite "difficult to define," and even "difficult to be agreed about by all the collaborating agencies." This handbook provides the performance measurement context, a number of applicable measures, examples and references. Considering the complex nature of the subject and the tall order, the handbook strives to improve clarity about performance measurement of TMSs, in a language familiar to the operations personnel.

TMS includes software systems, computer hardware and communications and surveillance technologies that service freeway and arterial systems. The integrated system also includes the TMC, which is the building or room monitoring command and control of the automated system. To understand the information in the subsequent chapters, the reader needs to have a solid comprehension of the basic tasks. Figure 2-1 illustrates these tasks in the context of this handbook.

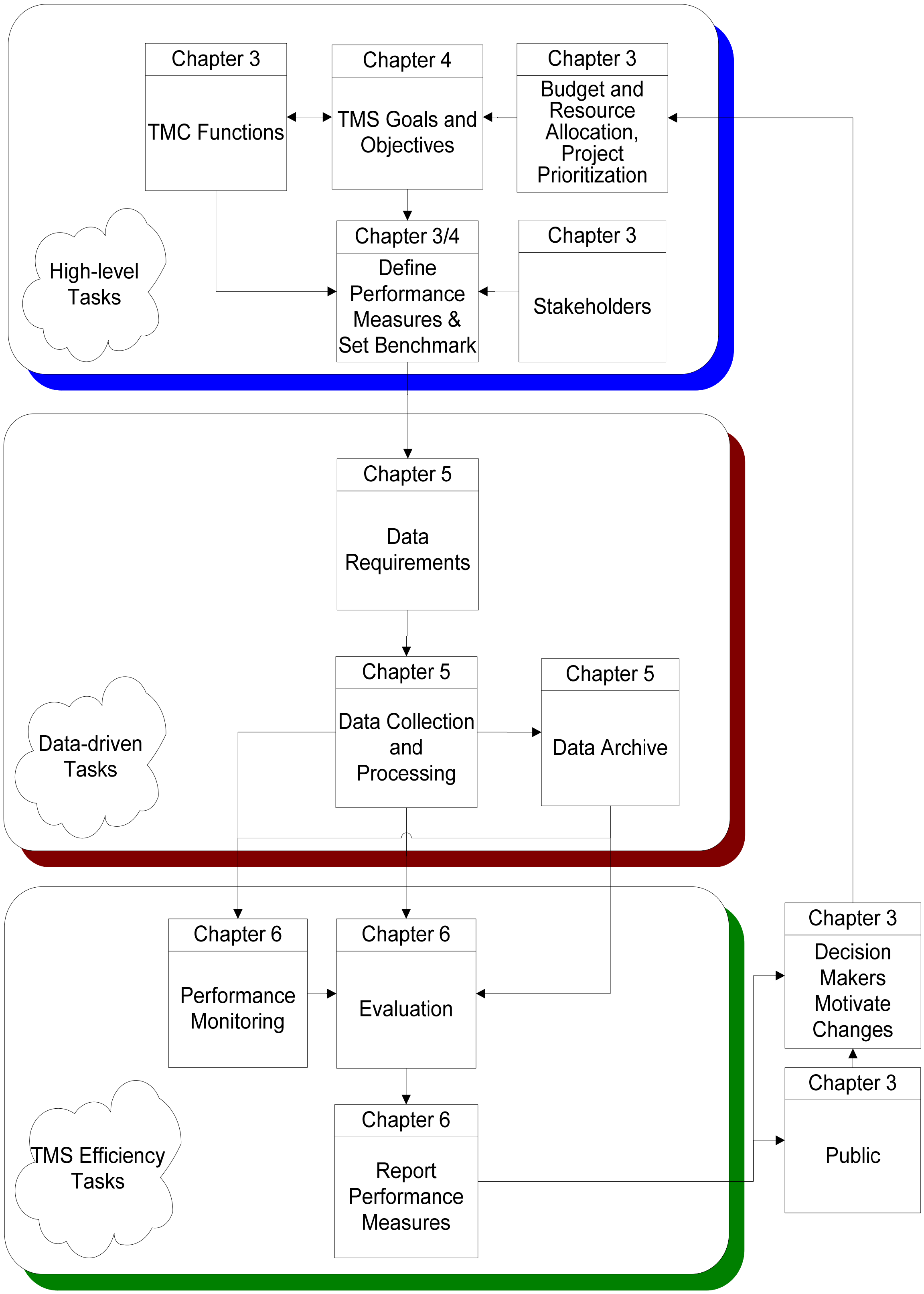


Figure 2-1. Diagram of Performance Measurement Program

As illustrated by the flow chart, the tasks can be categorized into three groups: high-level tasks, data-driven tasks, and TMS efficiency tasks. All these tasks evolve over time for any agency, to represent the latest understanding of the various aspects. The high-level tasks refer to the components of the performance measurement program that capture the "big picture". The data tasks include the components that handle the data used to evaluate the system. The TMS efficiency tasks refer to the components that help determine how well the TMS is doing in an operational context and in terms of meeting its goals. The remainder of this section investigates these groups more closely.

2.1.1 High-level Tasks

An agency can take one of different approaches when initiating a performance measurement program. With the conventional, top-down approach, performance measures first are aligned to the vision, then to the mission, then to the agency goals and finally to the objectives (ICDN 2005). To determine the efficiency of the system, the agency compares its results to a previously determined goal. An agency goal is the end means that the agency desires to achieve with the proposed projects or systems. The purpose of the goal is to allow the agency to keep perspective on the reason why they are creating this system. The agency devises its goals by determining the needs of the public. The agency goals should be written at a high level, encompassing broad objectives. A goal also should be attainable. The goals must incorporate measurable results because these results will determine if the goals have been met. The individuals who help define the agency goals are the stakeholders, the planners, the project designers and any other key personnel involved with the project. Once the goals are agreed upon, performance measures are needed to determine if the goals and objectives are being met.

Daniela Bremmer, the project leader of Washington State Department of Transportation's Strategic Assessment, points out that the traditional approach can become too complex too quickly. With this traditional approach, an agency attempts to link the performance measures to a variety of goals, which in turn attempt to meet the needs of the majority of the stakeholders. Consequently, the agency could end up creating numerous measures that are unnecessary and meaningless. Bremmer recommends using just the performance measures that effectively communicate the efficiency of the system.

The second (bottom up) approach is realistic for practical implementation in a huge and complex system. And the first one (top down approach) is more logical for smaller sub-systems that are easily manageable. When the performances of all sub-systems are effectively tracked, both the approaches are likely to come up with very similar results and measures. Once the approach for a system or sub-system is determined, the performance measures need to be defined.

A performance measure is defined as an indicator that helps determine how well the system is doing and demonstrates the agency's accountability (ICDN 2005). Performance measures should reflect the satisfaction of the transportation service user and the concerns of the system operator. NCHRP 311 defines performance measurement as

> "…a process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program activity

compared to its intended purpose), and the effectiveness of government operations in terms of their specific contributions to program objectives."

Performance measures have multiple purposes. They help monitor the effectiveness of a system by comparing the results to benchmarks, or target results. Through this monitoring the performance measures can detect and correct problems. For example, CHART (Chesapeake Highway Advisories Routing and Traffic system) uses an indicator of the average response time it takes from the time the incident call is received to the time emergency response units arrive to the incident site. It records this time in minutes and compares the result to values of previous years to determine if the system is improving (Chang et al. 2001). Performance measures also help document accomplishments of the system (FWHA 2004, as is the case with the Atlanta Highway Emergency Response Operator (HERO) program. Its operators patrol the highway keeping a look out for emergencies. One performance measure for this program is the total HERO assists by route (Amodei et al. 1998). This performance measure lets the Atlanta agency determine if its operators are patrolling areas with the highest rates of incident. The results on operational effectiveness will also help the planners prioritize projects, refine goals and objectives, and allocate funds and resources. As previously noted, performance measures are created based on the goals and objectives of a specific project or system. Thus, there should be multiple performance measures that gather information on different aspects of the system, including resources used and effectiveness of the system.

An agency does not need to incorporate every performance measure imaginable, however. It must narrow down the performance measures to only those that capture the crucial characteristics. Performance measures should:

Be understandable and easily communicated. The clarity of the performance measure is important because:

- An analyst will later use the data collected for the performance measure. The analyst should be able to understand precisely what the performance measure is evaluating.

- The information derived by the analyst will be made available to the public and agency decision makers. This audience should be able to understand what this information means.

- Because multiple personnel will be working with these performance measures, they must be understandable at all levels of expertise.

Provide frequent updated information. Although it is difficult for agencies to acquire real-time information, this type of information gives more accurate results on the effects of certain components of the system (ICDN 2005). An example is the program called Dashboard, implemented by the Virginia DOT. This program tracks current construction projects to illustrate project completion relative to their projected schedule. This program is used primarily by internal management for considering allocation of funds (VDOT 2003).

Be adaptable. Selected performance measures must be capable of responding to "critical political and system needs" (ICDN 2005), as they could be important to the decision-making process. For example, the California Transportation Plan (CTP) has a goal of enhancing public safety and security. Its crime rate performance measure allows CTP to judge if they are meeting this goal.

Show a trend. Trends help illustrate how the system is improving or where recurring problems exist. NCHRP Synthesis 295 gives an example of an analysis of collision trend. This performance measure determines "patterns in collision experience that may indicate that specific highway features should undergo safety investigation (Persaud 2001)."

Create agency accountability. In recent decades the public has expressed interest in the accountability of the agencies (Shaw 2003). Both the public and decision makers desire to know if their needs are being met. Thus, performance measures must be able to convey valuable information to this audience. For example, the Washington State Transportation Commission and the Washington DOT has devised new congestion measures that address the "above-average commute times (TPCB 2003)." Benefits of these measures are two-fold: They assess highway congestion, and they determine the success of the DOT's tools and actions.

The users of the system are primarily interested only in improvement of the outcomes (the results of a system). The managers, decision makers, and elected officials are equally interested in the output measures (the direct products and services delivered by a system). An understanding of all the systemic components and their efficiencies alone will enable the operators and decision makers to implement the most-efficient system for the situation, for the budget available. Also, the outcome measures (and their data) are collected using the TMS operation system. Unless this system performs properly, the degree of belief associated with the outcome measures will remain unknown. For this reason, reliable output measures form a predecessor to reliable outcome measures.

Performance measures, in essence, should capture the functions of a transportation management center (TMC). The Institute of Transportation Studies defines a TMC as "the hub of a TMS, where information about the transportation network is collected and combined with other operational and control data to manage the transportation network and to produce traveler information (ITS 2003)." Most TMCs can categorize their functions into three groups: (1) traffic monitoring, (2) travel information programs and (3) managing events (Baxter 2002).

1. **Traffic monitoring** includes functions where transportation systems must be monitored in real-time, such as traffic flow monitoring and evaluating traffic conditions.

2. **Travel information** programs refer to programs available to the public that provide information on current traveling conditions. For example, the Variable Message Sign (VMS) is an electronic display providing real-time information to motorists. Another example is the Advanced Travel Information Unit found at Colorado DOT.

3. **Managing events** consists of three types of events: (1) random events, (2) recurring events and (3) scheduled events. Random events refer to unplanned incidents, such as traffic accidents or failures in the transportation equipment. Recurring events are unplanned yet happen on a regular and predictable basis, such as traffic congestion. Scheduled events refer to planned events that will cause transportation challenges, such as the traffic flow before and after a National Football League game.

The performance measures are used in order to evaluate the effectiveness of each function. Thus, it is essential for the TMC to identify its functions early so that they can be compared to measurable results. Wye (2002) points out that "discussions about performance measures often get bogged down in issues concerning empirical or statistical validity." Where it is possible to get statistically representative sample, it is good to do so. Both the management and the public are often primarily interested in obtaining performance indicators towards the trends in the system, rather than mathematically precise formulations and extensive budgets for data collections.

2.1.2 Data Tasks

The success of the performance measures relies heavily on the quantity and quality of the relevant data collected. In order to achieve success, data requirements first must be defined. A data requirement is a prerequisite that specifies a mandatory data type of an application, application domain or component. For example, the purpose of the Highway Safety Program of the Safe, Accountable, Flexible, Efficient Transportation Equity Act of 2005 (SAFETEA) is to help prioritize safety needs. Thus, the data requirements for this program are number of fatalities, number of incapacitating injuries, vehicle miles traveled (VMT) and rural population (Hu 2004).

Data collection is a process of recording measurements. The data collected must be reliable and accurate. In terms of a TMS, these measurements are grouped into three categories:

1. Facility use and performance: These measurements refer to the effectiveness of the TMC. This data determine if the TMC and its systems are being used to their full capabilities. An example of this type of measurement used at the Hampton Roads Smart Traffic Center (HRSTC) is the number of incidents detected by their Freeway Incident Response Teams (FIRT) (HRSTC Newsletter, June 2004). The FIRT operators drive on the road to identify incidents as soon as possible, and clear them out, to minimize their effect on traffic.

2. Staff activities and resource use: The purpose of these measures is to maximize the efficient use of the agency's resources. Human resource management is an extensive topic that is not dealt with in this handbook. The focus of this handbook is on systemic performance of TMS equipment and the transportation network.

3. Events and incidents that disrupt "normal" freeway conditions: Event and incident data refer to the data collected during planned or unplanned events in which significant differences in traffic congestion exist. Some techniques identified by NCHRP 311 that used to collect data from these categories are traffic sensors, incident/event reports, visual images and road/environmental sensor station data.

As the data are collected, it should be archived. An archive is a collection of data that is stored in a database for a long period of time. Archives allow data to be compared from year to year to determine any noticeable trends or changes. The location and accessibility of the archived data, as determined by the agency, also are important. For example, the Performance Measure System (PeMS) developed by Caltrans relies on distributed data that are located at each district TMS. PeMS makes this data available on the Internet (Varaiya 2002).

"Performance Evaluation and Monitoring" section (4-17) in the Freeway Management and Operations handbook identifies four primary reasons to archive data (additional clarifications are provided in the parenthesis, based on the interpretation of this project team):

1. It provides more and better information for managing and operating the system. ('more and better' information comes from the archives, as compared to just the real time monitoring information, otherwise. The archives also help in filling the short-time gaps in monitoring data.)

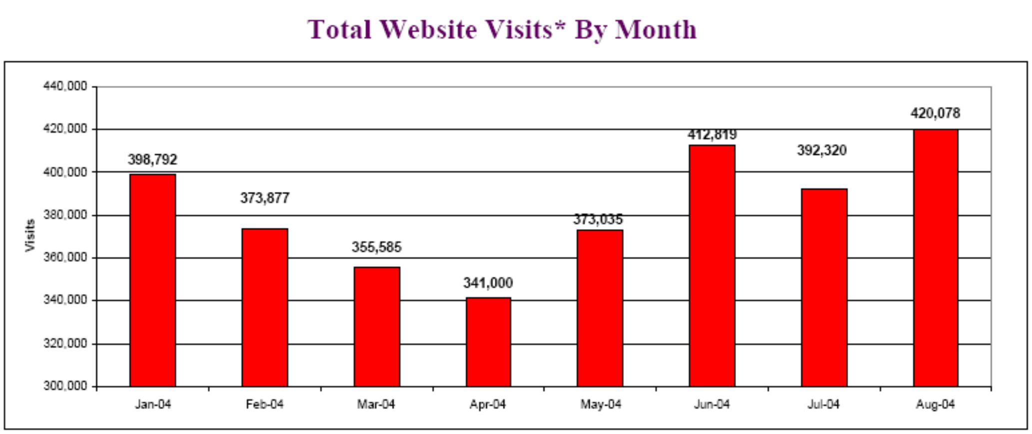
2. It maximizes cost-effectiveness of data collection. ('Cost-effective,' since the same data collected once is reused again and again for various purposes such as traffic analyses, performance measurement, planning etc. after the initial online use of traffic surveillance.)

3. It is much less expensive than manual data collection. (This point is related to the above one. If additional data needs to be collected later for any purpose, using manual data collection proves to be quite costly. On the contrary, usage of data archives removes this additional burden on the budget.)

4. It establishes business practices in other industries such as the retention and analysis of data. (Most industries and businesses already archive as much data as possible for later analyses. Archiving data in transportation will give us the same leverage as the business practices existing in these other industries currently.)

Once the data are collected and archived, instances when either data are missing or an entry is invalid will occur. Such problems could be caused by equipment malfunction, computer software failure, communicating failure or road reconstruction that result in milling out of loop detectors embedded in the road. Thus, screening the data is necessary. By screening the data the invalid or missing entry will be flagged and stored within a database. The flagged entry subsequently will be excluded during calculations or analyses. It is possible to completely remove the entry from the dataset. Doing so, however, brings up data-tampering issues. Removing the entry also could affect later calculations. An alternative method would be to estimate the missing value. However, it is important to identify these entries in the instance where they might need to be excluded from subsequent calculations or analyses. The reason behind this exclusion is that the estimated value may provide incorrect calculations.

The data analysis does not adhere steadfastly to a precise methodology. The analyst does follow general steps, however. First, the analyst should gain a comprehensive understanding of the data with which he/she will be working. For example, the analyst may want to look at the mean, mode, maximum and minimum values of the data set. This information can be obtained either by calculations or with a box plot. The analyst also will want to determine how many data entries are invalid or missing, which may affect how the data set can be analyzed. Next, the analyst will want to look for trends. These observations can be obtained through several graphical methods, such as scatter plots and histograms. Figure 2-2 is an example histogram. It illustrates the number of visits to the NaviGATOR Web site (Chang et al. 2003).



* A visit is a series of actions when a visitor views their first page from the server, and ends when the visitor leaves the site

Figure 2-2. Histogram of Website visits

2.1.3 TMS Efficiency Tasks

Three important outputs for the successful implementation of a performance measurement program are performance monitoring, evaluation and reporting. The Guidelines for TMS Maintenance Concepts and Plans defines performance monitoring as "regular[ly] checking [the] metrics and budgets against the projections [plan]." Another way to define performance monitoring is as an "ongoing" internal process of examining the actual system condition through observed data. Performance monitoring often involves the following three functions:

- Examines the incoming streams of data,
- Compares them to the expected data, and the existing goals and policies, and
- Flags any outliers for further study (detailed evaluation).

An operator is likely to monitor traffic on some sections or corridors, on a minute-by-minute basis. A supervisor is likely to monitor traffic at the network or regional level regularly, with emphasis on specific sections on an ad hoc basis. A TMC manager is likely to review the system and policy level attributes of the region on daily basis, with special emphasis within a day when necessary.

Data fusion is an integral part of both the monitoring and the evaluation processes. In data fusion, an analyst combines data from multiple data streams or databases to identify any important trends. An example would be combining data about traffic incidents with data about traffic flow. The information gained from this fusion would be, "how long traffic is delayed during traffic incidents."

The next step in the performance measurement program is evaluation. Evaluation is the process in which the collected data are analyzed, and the results are usually compared to benchmark performance measures. The purpose of performance evaluation is to determine how well goals are met so that appropriate changes can be made to the TMC operations (such as policy, planning, maintenance, etc.). The evaluation process also is helpful in selecting alternative procedures and refining management techniques.

The performance measures being monitored can raise three significant concerns to an agency:

- Were the correct investments made?
- Are demands of the public and state legislature being met?
- Are agency goals and objectives being met?

This step in the process also identifies areas for system improvement and provides information that later will be reported to decision makers and the public. An example is the Highway Performance Monitoring System sponsored by Caltrans. The data collected from this system are used to determine (State of California 2003):

- Allocation of funds to the policies
- Travel trends and future transportation forecasts
- Environmental Protection Agency (EPA) air quality conformity tracking

Once the best procedures are determined from the evaluation process, the results need to be reported. Reporting provides visual information about the data. The frequency of reporting (i.e., weekly, quarterly, or annually) varies from agency to agency. The report gives feedback on the planning and decision-making process, on trends in system performance, accomplishments and areas of needed improvement. Using this information, the analyst can recommend changes to policy goals and objectives, performance targets and performance measures.

2.2 Overview of Best Practice Examples

The concepts introduced in this chapter are illustrated throughout this handbook using several TMCs that have been identified as best-practice examples. The TMC examples identified provide examples of best practices in several aspects of performance monitoring, evaluation, and reporting.

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Chapter 3. Performance Measurement Program

Chapter Purpose: This chapter discusses the motivations of a TMS performance measurement program and recommended functional components. It also discusses how a TMS performance measurement program influences the agency vision, goals, objectives, concept of operations, services provided, program components and resource allocations. Chapter 4 further discusses typical performance measurement goals of TMS related agencies and also addresses, in more detail, the challenges that these agencies face with regards to a TMS performance measurement.

3.1 Motivations for Creating a Performance Measurement Program

All organizations, whether public or private, are interested in developing and implementing effective performance measurement programs, since it is only through such programs that organizations can maintain efficiency. President William J. Clinton conveyed this point upon signing the Government Performance and Results Act of 1993:

> "…chart a course for every endeavor that we take the people's money for, see how well we are progressing, tell the public how we are doing, stop the things that don't work, and never stop improving the things that we think are worth investing in."

In a broad context, performance measurement is the use of quantifiable indicators of program effectiveness and efficiency to determine progress toward specific, predefined organizational goals and objectives. Financial and non-financial indicators should be used to measure performance in terms of: cost per output (goods and services), cost per outcome (the results of a program activity compared to its intended purpose) and customer-oriented indictors of quality, such as timeliness and customer satisfaction (National Performance Review 1997). For example, in the restaurant business performance may be measured in terms of monetary costs and profits. One such business may measure its performance in terms of cost towards food and labor (output), profits earned using current business model (outcomes) and number of complaints and suggestions (customer-oriented indicators). Likewise, performance measures related to transportation systems can be grouped into three categories: input, output and outcome measures. Input measures address the supply of resources available to implement a program; output measures quantitatively address the delivery of transportation programs, projects and services; and outcome measures address the degree to which the transportation system meets policy goals and objectives. A specific example is shown in Table 3-1 (FHWA 2004).

Table 3-1: Examples of Types of Measures

Measures	Traditional Capacity	Maintenance and Operations Oriented
Input	Capital projects budget	Number of incident response patrols
Output	Miles of roadway built	Response time to incidents
Outcome	Reduced miles of congestion	Change in incident-related delay

Performance management encompasses setting the agency/program goals appropriately and revising them as needed. Figure 3-1 illustrates some important aspects of performance measurement and their relation to performance management (ICMA 2005).

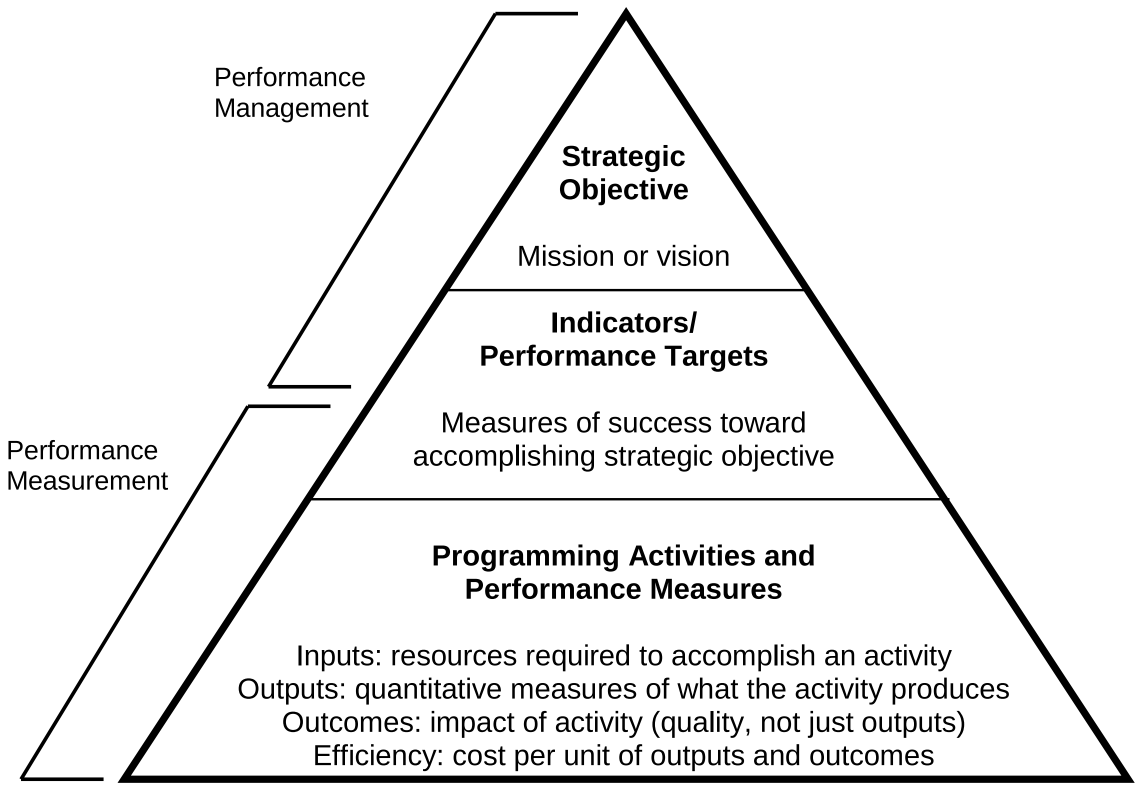

Figure 3-1: Linking Performance Management to Performance Measurement

A performance measurement program can be applied to a Transportation Management System (TMS). A transportation management system (TMS) consists of software systems, computer hardware and communications and surveillance technologies that service freeway and arterial systems. The integrated system also includes the Transportation Management Center (TMC), which is the building or room monitoring command and control of the automated system.

A TMS needs a performance measurement program for many reasons. Federal and state statutes are requiring the implementation of a performance measurement program (Transportation Research Board 2001). Stakeholders such as legislative decision makers and the taxpayers are rightly inquisitive about how their tax dollars are spent in the transportation domain. A performance measurement program also is needed to provide performance trends over time and ultimately strategic feedback for decision makers. Box 3-1 highlights the motivations (or potential benefits) of a performance measurement program as mentioned in NCHRP Synthesis 311.

Motivations of a Performance Measurement Program

Accountability: Performance measurement provides an increased accountability of public expenditures for internal and external purposes. Performance measures allow the determination of efficient or inefficient resource allocation dependent upon pre-identified priority needs via performance reporting. They also allow for the quantification of program benefits and can ultimately increase agency visibility and incoming funding.

Efficiency: Performance measures focus actions and resources on organizational outputs and the process of delivery. Performance measurement is an internal management process.

Effectiveness: Performance measurement encompasses planning and goals achievement. It also serves to link outcomes of policy decisions and immediate actions of transportation agencies, as well as strategic planning to resource allocation.

Communications: TMS performance results must be shared with customers in order to obtain their support for current and future investments. A performance measurement program provides better information to customers and stakeholders on progress made toward desired goals and objectives, as well as deterioration of performance if applicable.

Clarity: Performance measurement serves to clarify the purpose of an agency's actions and expenditures.

Improvement: A performance measurement program allows for periodic refinement of programs. Taxpayer money must be spent as efficiently as possible in efforts to improve how agencies provide transportation (Transportation Research Board 2003).

Box 3-1: Motivations of a Performance Measurement Program

The remainder of this chapter specifically relates to transportation performance measurement. The performance measurement process starts by defining the services that the organization promises to provide, including the quality or level of service (e.g., timeliness, reliability, etc.) that is to be delivered.

Performance measures are used to prioritize projects, provide feedback on the effectiveness of long-term strategies, refine goals and objectives and improve processes for the delivery of transportation services. Performance measures reflect the concerns of the transportation service user as well as the system operator. The measures provide useful information to managers and decision makers on how well the system is performing (FHWA 2005).

3.2 TMS Performance Measurement Elements

This section discusses the core high-level elements of a TMS performance measurement program. Figure 3-2 divides a TMS performance measurement program into three components: high-level tasks, data-driven tasks and TMS efficiency tasks. This chapter touches on all of these elements and elaborates on the following high-level components: TMC functions; budget and resource allocation and project prioritization; defining performance measures and setting benchmarks; and identifying stakeholders, decision makers and the public. Chapter 4 details defining performance measures and setting benchmarks, as well as TMS goals and objectives. Data-driven tasks and TMS efficiency tasks are detailed in Chapter 5 and Chapter 6, respectively.

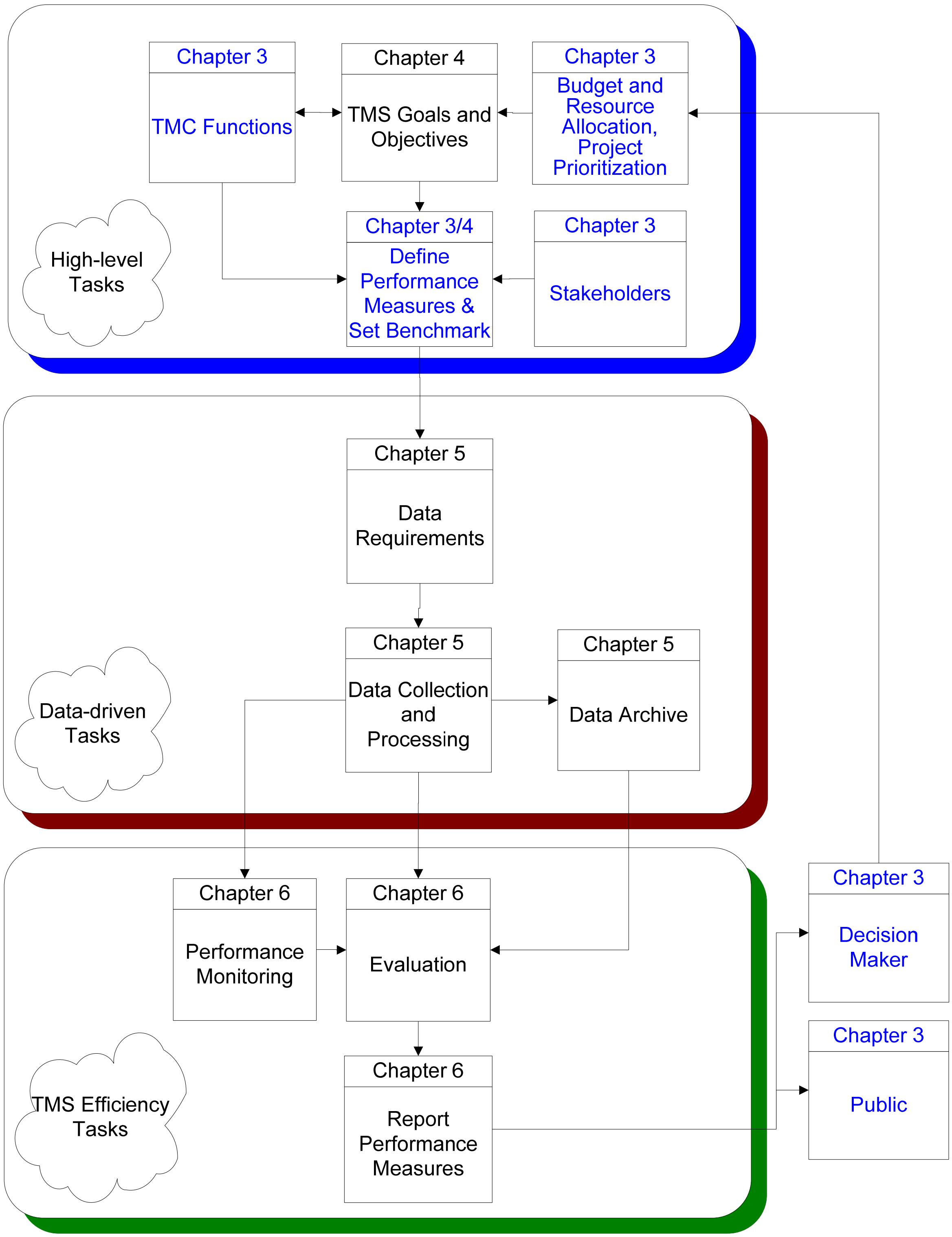

Figure 3-2: An Overview of a TMS Performance Measurement Program

Figure 3-2 illustrates the components forming the basis of a TMS performance measurement program. However, many of these components are difficult to quantify in terms of performance - such as monitoring, evaluating and reporting, as well as how well the program interacts with other agencies and affected stakeholders. A self-assessment tool is included in Chapter 7 of this handbook to help address this difficulty.

The key steps in establishing a performance measurement program include (FHWA 2003):

- Identify the vision, goals and objectives of the agency. It is best to involve stakeholders in defining these three items.
- Identify intended users and audiences.
- Develop TMS performance measures that relate to respective programs.
- Identify performance benchmarks.
- Collect complete, accurate and consistent data and monitor this data in a way that supports decision making.
- Analyze and evaluate data.
- Report results to stakeholders in a useful manner.
- Identify action areas and communicate them to stakeholders.

3.3 High-Level Tasks

The following begins the discussion of TMS performance measurement elements. To view the relationships among elements, refer to Figure 3-2: "An Overview of a TMS Performance Measurement Program."

3.3.1 Transportation Management Center (TMC) Functions

A Transportation Management Center (TMC) requires accurate, real-time monitoring of the freeway's performance, and how that performance compares to "normal" (using performance measures over time to define "normal"). The TMC manager and operators monitor the performance of the facility to assess existing conditions for short-term non-recurring events and for longer term recurring congestion, determine and implement operational plans, and inform freeway users of existing and predicted near-term conditions. The freeway manager also uses the results of the performance monitoring to identify deficiencies in the physical freeway system, and provides planners and designers with the necessary information and input to incorporate into the planning and design of future improvements to the facility. Similarly, an Integrated Transportation Management System (ITMS) also requires real-time monitoring information, aggregated over the entire region, to address the performance of the entire surface transportation network (with data obtained from multiple TMCs and other sources). The real-time information may be used to implement and monitor region-wide response plans. The data may also be archived and evaluated later to either modify existing response plans or create new ones. (FHWA 2003)

Box 3-2 describes the functions of the Minnesota Department of Transportation's TMC as well as Houston's TranStar program, both of which are known for its successes.

Minnesota's Regional TMC

The Minnesota Department of Transportation (Mn/DOT) initiated one of the first TMCs to manage the freeway system in the Twin Cities metro area. It is one of the most successful TMCs in the country. The purpose of the Regional Transportation Management Center (RTMC) is to integrate Mn/DOT's Metro District Maintenance Dispatch and Mn/DOT's Office of Traffic, Security and Operations with the Minnesota Department of Public Safety's State Patrol Dispatch. The integrated system allows for effective communication for transportation management on metro freeways during normal commuting periods, as well as during special events and major incidents. "The RTMC's traffic management systems help optimize the use of available freeway capacity." With nearly 300 closed-circuit televisions (CCTV) cameras, RTMC staff is able to confirm traffic incidents over 200 miles of freeway. Incident information is available to travelers through radio, television, various Internet sites, a telephone service and electronic message signs placed throughout the freeway system. "RTMC staff also uses cameras to verify that 430 ramp meters are responding to real-time traffic conditions. The RTMC's 3,700 loop detectors (traffic sensors) give computers the information needed to determine ramp meter timing. Loop detectors also measure traffic speeds, which are displayed on a graphics map on traffic TV and various Internet sites" (MDOT).

Houston TranStar

"The Houston TranStar center is part of a national effort to establish an Intelligent Transportation System (ITS) throughout the nation." It employs many technologies including: "Closed Circuit Television Cameras (CCTV), Dynamic Message Signs (DMS), Synchronized Traffic Signals, Speed Sensors, Highway Advisory Radio, and other high-tech devices." It was also the first to develop and adopt a common traffic signal controller (Advanced Transportation Controller) and common center software (ICONS) for joint use among several controlling jurisdictions.

This was the first center in the nation to combine Transportation and Emergency Management centers. These agencies include Harris County, Metropolitan Transit Authority of Harris County (METRO), Texas Department of Transportation (TxDot), and City of Houston. "The center uses state-of-the-art technologies to address emergency situations which include the Automated Flood Warning System, Doppler Radar Imagery, Satellite Weather Maps, Road Flood Warning Systems, HAM Radio, the Regional Incident Management System (RIMS) and much more. When emergency conditions occur such as hurricanes, floods, industrial explosions or terrorist attacks, the Emergency Operations Center (EOC) housed at Houston TranStar is activated." Representatives from all four partner agencies collaborate to coordinate a quick and efficient response.

The Houston TranStar's Transportation Management activities had led to many benefits which include a net reduction in travel times and fuel consumption as well as the promotion of a cleaner environment by reducing the amount of exhaust emissions. The emergency related activities have reduced the number of injuries, deaths, and extensive property damage caused by weather-related events (Houston TranStar).

Box 3-2: Best Practices of TMCs

3.3.2 TMS Goals and Objectives

Performance measures are needed at the statewide/regional level to help drive policies, goals and objectives. The objectives and goals capture how a TMS should operate relative to how it operates today. These objectives and goals are further embodied in performance evaluations and analytical assessments of TMS performance, such as before-and-after studies (FHWA 2003).

The visions and goals of some agencies across the United States are highlighted in Box 3-3.

<u>Examples of Goals and Objectives that Acknowledge the Importance of the Transportation System</u>

North Carolina Department of Transportation (NCDOT) – NCDOT's mission is to provide and support a safe and integrated transportation system throughout the state. NCDOT fulfills this mission through two major thrusts. First, NCDOT directs, plans, constructs, maintains and operates the second largest state-maintained transportation system in the nation to include aviation, ferry, public transportation, rail and highway systems. Second, NCDOT licenses and regulates the citizens and motor vehicles that utilize these transportation systems (NCDOT).

Oregon Department of Transportation (ODOT) - ODOT's mission is "to provide a safe, efficient transportation system that supports economic opportunity and livable communities for Oregonians." The agency's goals are to "Improve safety. Move people and goods efficiently. Improve Oregon's livability and economic prosperity" (ODOT).

Vermont Agency of Transportation (VTrans) - VTrans' vision is "to preserve, develop, and enhance an integrated transportation system to support Vermont's quality of life and economic well-being." VTrans' mission is "to work cooperatively to plan for and accommodate the need for movement of people and commerce in a safe, reliable, cost-effective, environmentally responsible, and equitable manner." The agency goals are to:

Support and maintain Vermont's transportation system and promote efficient operations of that system;

- Promote and support the use and connection of appropriate forms of transportation;
- Support Vermont's economy by providing appropriate transportation access to all areas of the state;
- Cooperate with Vermont residents, towns, regions, other state agencies, and interested parties in making transportation decisions that balance the needs of the human and natural environments;
- Seek adequate, stable funding and staffing to support mission requirements;
- Provide employee training and skills enhancement to build a strong, professional work force;
- Encourage and recognize innovation, flexibility, and excellence;
- Foster communication and promote teamwork (VTrans).

Box 3-3: Visions and Goals of Transportation Agencies

Florida's DOT also is noteworthy. "The Florida Transportation Plan explicitly states that performance measures will be used in revising goals and objectives, and that indicators of progress will be used to measure progress toward long-range objectives" (Artrip 2004). Performance measurement has influenced the agency's annual short-range performance report, which provides a yearly update on progress toward achieving its long-range goals and objectives.

> "The short-range plan relates performance to FDOT's three strategic goals summarized as follows: 1) preserve and manage a safe, efficient transportation system, 2) enhance Florida's economic competitiveness, quality of life and transportation safety, and 3) pursue organizational excellence. An annual performance report that relates directly to the long-range plan helps motivate planners to consider the short-term tools that can contribute toward transportation goals. Such reports also provide a mechanism by which management and operations staff can see how they are contributing toward long-term objectives, thereby increasing their stake in the planning process" (FHWA 2004).

3.3.3 Budget and Resource Allocation and Project Prioritization

Performance measures help spend dollars wisely. With a limited pool of resources, performance measures can be used to help identify areas needing improvement so that money is spent prudently.

> "freeway management and operations—particularly ITS-based improvements—are increasingly funded through the use of regular sources. … [The need for funding] necessitates the integration of freeway management and operations into the established transportation planning process, where freeway management strategies and systems can be evaluated both against, and in combination with, conventional transportation components such as major road widening and new facility construction. It is critical that the associated benefits and costs are known and compared in an equitable manner (i.e., using the same set of performance measures and criteria), thereby providing an economic justification for the implementation of freeway management systems and operational strategies" (FHWA 2003).

Performance measures also are used for project prioritization. These measures must be detailed and specific in order to distinguish the effect of investing in one project versus another and to provide decision makers information about the likely impact and outcome of different combinations of investments and/or budget plans among different projects (FHWA 2003). "Moreover, incorporating performance measures helps to ensure that regional transportation system management and operations programs receive adequate attention in prioritization of projects for funding" (FHWA 2004).

According to a Washington state DOT staff person: "The Secretary felt that by building the state DOT's accountability, the agency could attract more funding. The Secretary focused on making the case that WSDOT is on top of things. The best way to do that was through operations data because it gets at aspects of the system that the public cares about" (FHWA 2004).

> "Often, measures of performance are used to set maintenance levels or even as the basis for maintenance budgeting. These are very useful techniques; however, this approach can sometimes miss the bigger picture. For example, a maintenance goal of keeping 95 percent of all CCTV cameras available at all times does not answer the bigger picture of why are

> CCTV cameras needed in the first place, since there is no traceability back to the original concept of operations" (FHWA 2002).

Boxes 3-4 and 3-5 highlight how Florida and Phoenix have used performance measures to aid in budgeting.

Florida DOT

The Florida DOT has been very cautious in developing budget program measures that link the expenditure of state dollars to program performance and agency actions. "Establishing causality between program investment and performance measures becomes a critically important technical and political issue." The Florida DOT has had one of the earliest performance-based plans in the country partly because the Florida state government focuses on accountability in the use of state dollars (Cambridge Systematics, Inc 1999).

Box 3-4: Florida DOT Best Practice on Budget and Resource Allocation

Phoenix, AZ

"Another way Phoenix has used performance measures to allocate resources is in the budget process. The Neighborhood Services Department gave the example of when they feel they need more inspectors. When the department approaches Budget and Research to request more inspectors, they don't just take cost information. Response time and cycle time information is presented to show the need for the added resources (Artrip 2004)."

Box 3-5: Phoenix, AZ Best Practice on Budget and Resource Allocation

3.3.4 Define Performance Measures

The range of needs and uses of potential performance measures must be well understood before an agency can determine which performance measures to implement. A good, worthwhile measure is defined clearly and is directly related to predefined goals and objectives. It is understandable, logical and allows for repeatability. It also allows for data collection and shows trends (National Performance Review 1997). Further, these measures should be reviewed according to the following criteria (Hack 2005):

Criteria for Defining Performance Measures

Purpose: Is the measure worth collecting and does it aid in decision making?

Validity: Does the measure actually measure its intended purpose?

Precision: Does the measure return consistent values with each measurement?

Accuracy: Does the measure match the true value of the attribute?

Cost-effectiveness: Is the required evaluation and reporting of the measure within budget?

Box 3-6: Criteria for Defining Performance Measures

Many of those interviewed in Diane Artrip's Case Study: City of Phoenix, Arizona in Use and the Effects of Using Performance Measures for Budgeting, Management, and Reporting stated that the usefulness to both the city and citizens was an important measure of quality for performance measurements. In other words, they did not want to measure for the sake of measuring. The case study mentions some characteristics for a measure to be useful. Foremost, all audiences must easily understand a measure because different audiences may interpret the measure differently and possibly incorrectly. Secondly, the data must be trustworthy. "There needs to be some assurance that the data are correct." Many people did not necessarily assume that the data were not reliable but felt they could not be sure. Third, whatever is being measured needs to be flexible. For example, "what is valuable and helpful to measure today may not be applicable to measure next year" (Artrip 2004).

Furthermore, M.D. Meyer for the Georgia Institute of Technology has concluded, "performance measures should relate to outcomes describing cause-and-effect relationships that involve owners and users. Outcome measures relate to the quality of life, safety, environmental quality, and economic opportunities. Performance measures should also relate to output measures, which are indicators of the direct production of an organization, such as lane-miles constructed" (Transportation Research Board 2003).

External pressure has been mounting upon the Florida DOT for the development of output measures that provide program accountability. On the other hand, there is also growing pressure from stakeholders to develop outcome measures that relate transportation system performance to quality of life issues and economic development. The DOT understands the importance of such measures but is hesitant to adopt measures to study the accountability of such issues in which they have little to no influence (Cambridge Systematics 1999).

A performance measurement program also is dynamic. Continually evaluating and updating the program allows for improvements in measures. For example, future project objectives could warrant new measures. In addition, as system components are better understood, finer measures more sensitive to this new understanding should be developed (FHWA 2003).

Some common TMS performance measures are (FHWA 2003):

- Total or average hours of incident related delay
- Consistency of peak and off-peak travel times
- Extent of real-time information provision (e.g., lane miles or intersections for which information is available; number of ways to access such information)
- Transit on-time performance
- Percent of signal systems coordinated across jurisdictional boundaries
- Frequency of work-zone accidents
- Number of signals with preemption capabilities
- Number of travel information Web site hits

A more extensive list of commonly used TMS related performance measures is found in Chapter 4 in Tables 4-1 through 4-3.

3.3.5 Set Benchmarks

Benchmarking is the study of another agency's practices in order to improve the performance of one's own agency. Setting benchmarks is a powerful way of using performance measures to influence decisions (FHWA 2003). "A baseline or benchmark is necessary for determining whether a particular performance is good or bad… Benchmark and goals must be attainable… Baseline data was defined as data that represents an initial measurement of performance for a service delivery area. Baseline data is often collected to measure the incremental change or improvement over time of specific outcomes or measures." For instance, Phoenix established a baseline when tracking crime rates over time (Artrip 2004). Benchmarking and baseline data lead to trade-off analyses. In other words, performance targets are set for a policy or system plan when the trade-offs involve different objectives (i.e., safety and system preservation). These benchmarks should reflect the interests of the public, decision makers and agency employees (FHWA 2003). The topic of stakeholder involvement will be discussed further in the next section.

3.3.6 Stakeholders, Decision Makers and Public

The Victoria Transport Policy Institute defines stakeholders as "individuals or groups that are affected by a decision and have an interest in its outcome" (VTPI). With respect to a TMS, stakeholders are interest groups who benefit from, or are otherwise impacted by, a TMS and its operations. Stakeholders include the following (Transportation Research Board):

- Agency management and staff

- Transportation professionals
  - Transportation providers
  - Transportation system users
- Citizens
- Elected officials
- Policy makers
- FHWA
- State DOTs
- Metropolitan Planning Organization (MPO)
- Municipalities
- Emergency Responders and Management

Stakeholders are interested in performance measures and the associated monitoring, evaluation and reporting processes for the following reasons:

- Improving transportation to serve people and commerce
- Improving management access to relevant performance data
- Improving agency efficiency and effectiveness in terms
- Returning on investment in transportation
- Efficient allocation of investment in transportation
- Accountability of the agency

When establishing performance measures, it is imperative to involve stakeholders such as those involved in freeway and signal systems, planning operations, emergency management, and departments of transportation. The stakeholders should be involved in each phase of a performance measurement program, including the processes of defining performance measures and how they are to be used. Stakeholder support is critical for initial acceptance and continued success of the performance measures. Without stakeholders considering the determined measures appropriate, it is "impossible to use the results of the analysis process to report performance and negotiate the changes needed to improve it. Those who are expected to use the process to shape and make decisions should be allowed to influence the design of the program from the beginning." Those persons accountable for results but who are not necessarily decision makers, such as data collectors, should be involved. Their involvement is necessary to gain their support so that they do not circumvent the process or its intended outcome (FHWA 2003). This topic of stakeholder buy-in is further discussed in the section entitled "Data Collection and Processing."

As mentioned earlier, a very important group of stakeholders are the citizens, or transportation system users. Accordingly, agencies need to focus on measuring citizen satisfaction and communicating these results to the group (FHWA 2004). For example, customer satisfaction may be measured from the results of focus groups and surveys. The City of Phoenix, AZ, has shown great success in involving stakeholders, decision makers and citizens in its performance measurement program. Box 3-7 highlights this best practice. Its tactics and strategies can easily be transferred to a TMS performance measurement program.

Phoenix, AZ

As a pioneer in the public sector in the area of performance measures, Phoenix, AZ, is no stranger to the concept of a performance measurement program. One of the city's visions states: "We focus on results. The belief and commitment in results information has taken time to grow and mature. The city of Phoenix credits its success in measurements to citizen input." In the 1990s the City Auditor Department began to develop indicators to reflect inputs, outputs, efficiency and outcomes. Though these indicators were helpful, some management questioned the purpose of performance measurements. In 1991 "citizens were able to attend one of several focus groups held around the city to give their input as to what was important to them about Phoenix." These focus groups helped develop results indicators and their purpose, clarifying "discrepancies between what managers thought citizens wanted in terms of service delivery and citizens' actual expectations." Over 450 citizens participated in these brainstorming sessions.

Many city departments use a more direct approach for citizen feedback. "For example, the Police Department will gather a group of citizens and tell them, 'You're our customer, we're the service provider, we spend lots of money. Where should we be focusing our effort? What's important to you?' They keep it very simple. From these conversations, the department can determine what they should be focusing on and, thus, what they should be measuring."

To reach out to citizens, other means of communicating performance measurements were developed in reporting. "Performance measurement did not become a way of life at the city of Phoenix until customer feedback began to be compiled on what was important to measure. Department management cares about satisfying the customers, and if performance measures can be used as a tool to accomplish this, managers will take the time to use them. Managers stressed that it is important for them to know that they are not just measuring for the sake of measuring; or tracking a certain measure just because the data are easy to get."

"Employees are seen as an important group of people to include in the development process. This includes front-line staff, supervisors, and all the way up the chain. It was often mentioned that they strive to get employee buy-in before implementing measures. Many times employees were included in focus groups when the City Auditor Department was helping departments develop performance measures. One of the reasons cited for getting the employees involved is to gain their buy-in to the whole process. Employees are the ones who will end up gathering, calculating, and maintaining the data needed for measures. Because of this, interviewees felt that it is vital that employees see the importance of the process (Artrip 2004)."

Box 3-7: Phoenix, AZ Best Practice of Stakeholder, Decision Maker, and Public Involvement

3.3 Best Practice Examples

This chapter has addressed TMC functions; budget and resource allocation and project prioritization; defining performance measures and setting benchmarks; and stakeholders, decision makers and the public. These elements will vary by program type and its associated goals, size of agency and system, available funding and so forth. Chapter 4 discusses the remaining high-level tasks including defining performance measures and setting measures, as well as TMS goals and objectives, in more detail.

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Chapter 4. Agency Goals and Performance Measures

***Chapter Purpose*:** The previous chapter discussed how a TMS performance measurement program influences an agency's vision, goals, and objectives. Chapter 4 further discusses typical performance measurement goals of TMS related agencies and also addresses, in more detail, the challenges that these agencies face with regards to a TMS performance measurement program. This chapter presents typical goals of TMS related agencies including state departments of transportation, metropolitan planning organizations, and transportation management centers. It also presents a list of performance measures organized by TMS type. Figure 4-1, on the next page, illustrates the components forming the basis of a TMS performance measurement program and shows Chapter 4 in relation to the rest of the handbook.

4.1 TMS Related Agencies and Their Goals

This section identifies how TMS functionality may influence typical goals and measures used by public agencies, service providers, and other stakeholders. Because "a consensus does not exist and technical guidance has not been developed regarding the appropriate measures" variation exists in the performance measures used from one TMS to another (Transportation Research Board, *NCHRP Synthesis 311* 2003).

4.1.1 Departments of Transportation

The job of a DOT is to plan, build, maintain, and improve the state's transportation network (Georgia Department of Transportation 2005). Typical goals of a DOT include improving efficiency, capacity, and safety. Some goals specific to state DOTs are listed in Box 4-1.

4.1.2 Transportation Management Centers

The functions of a TMC include incident response, traveler information, traffic management, and video surveillance (Hudson Valley Transportation management Center). The overall purpose of a TMC is to improve mobility and safety; the general goal is to reduce incident response time and incident rates, especially secondary incidents (Sreedevi 2003). "The overall goal of [the] Transportation Management Center is to maximize the use of the existing transportation network" (Washington State Department of Transportation 2005).

Because TMCs manage a transportation network, improved ITS and inter-agency cooperation are typical goals. Houston TranStar, for example, is a partnership of four public agencies: the Texas DOT, Harris County, the Metropolitan Transit Authority of Harris County, and the city of Houston (Houston TranStar). Minnesota created a Regional TMC to serve as a "unified communications center" for the State Patrol Dispatch, Maintenance Dispatch, and Traffic Operations to meet their coordination needs. Hudson Valley TMC, on the other hand, "recognizes that the private sector will play a critical role in ITS implementation. A priority element is to promote opportunities for ITS public/private partnerships through active participation mechanisms like ITS-AMERICA and to pursue innovative means to accomplish these new partnerships" (Hudson Valley Transportation management Center).

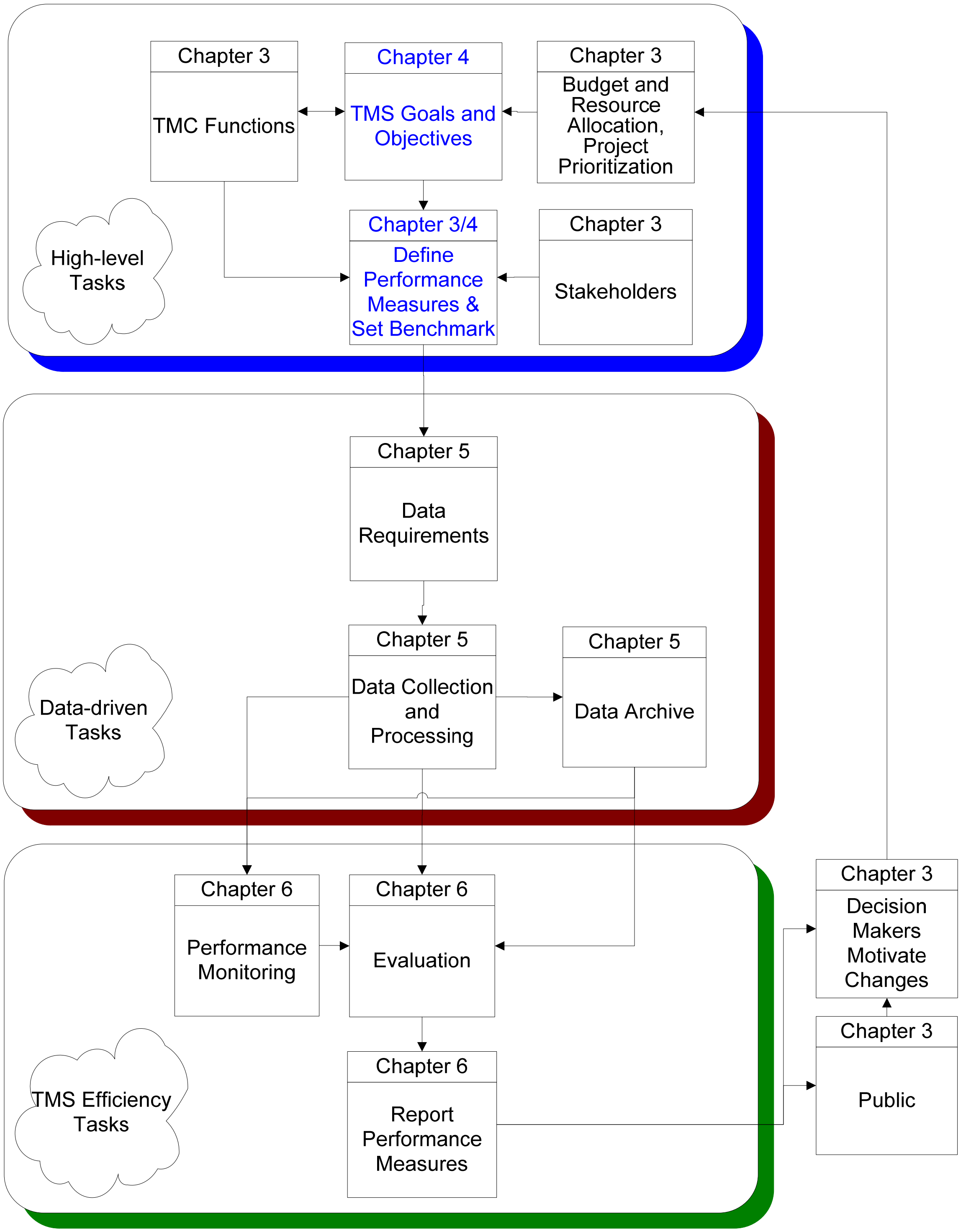

Figure 4-1: An Overview of a TMS Performance Measurement Program

DOT-Specific Goals	
NYSDOT	One of the goals of the NYSDOT is to maintain a facility that is protected from external dangers and potential abuses.
ODOT	Ohio's mission is to create a transportation network that connects them to the global economy.
VDOT	Virginia specifies the overall goal of achieving results on time and on budget.
RIDOT	Part of RIDOTs mission is to provide a transportation network that, in addition to meeting general goals such as safety, is both "aesthetically and culturally sensitive."
UDOT	One of the Utah DOT's four main goals is to increase the capacity of their transportation system.
ODOT	Improving the livability of their state through its transportation system is one of Oregon's visions.

Box 4-1: DOT-Specific Goals (DOT individual websites)

4.1.3 Metropolitan Planning Organizations

Transportation planning with the intention to secure federal funding is the main function of an MPO. A typical goal of an MPO is "to provide comprehensive, coordinated and continuous ("3C") transportation planning for the safe and efficient movement of people and goods consistent with the region's overall economic, social and environmental goals. Special emphasis is placed on providing equal access to a variety of transportation choices and effective public involvement in the transportation planning process" (San Antonio Bexar County 2005).

FHWA has recommended to MPOs the goals of accommodating bicyclists and pedestrians (Pekow), of instituting freight planning, and of improving analytic models. In general, FHWA has found MPO goal setting to be vague and there is "insufficient application of objective performance-based criteria" (Federal Highway Administration, *Breakout Session Summary Session* Comparison).

4.1.4 Comparison

The functional difference between a DOT and an MPO accounts for different goals and corresponding performance measures. While a DOT is concerned with the maintenance of a system, an MPO may use measures that focus more on the community, such as sustainability. Similar rifts occur between urban/rural and passenger/freight interests. For instance, while predominately rural agencies use traditional performance measures, urban agencies look for "mode-neutral" performance measures to invalidate the notion that highway investments are of a higher priority (Cambridge 1999).

The rift between urban and rural performance measure programs is partly because of size. "Agencies in larger (population) areas are more likely to have a performance measure program in place. This may be a result of the resources available to larger agencies or that these agencies have more complex congestion and mobility issues to manage that may not be adequately addressed by more traditional measures of effectiveness such as LOS." NYDOT, for example, is concerned with "external threats" to target areas along its transportation network that most rural DOTs wouldn't consider. Regional differences will also occur in areas such as weather management. The agencies in areas receiving snow and ice will be concerned with roadway conditions during bad weather and may set corresponding goals (Transportation Research Board, *NCHRP Synthesis 311* 2003).

All agencies are concerned about their ability to effect improvement in an area of measurement; however, various agencies view certain performance measures and goals more applicable than others. The importance of such measures varies across dimensions (i.e. State versus MPO, urban versus rural, passenger versus freight, etc.) "This raises the question of how to provide guidance that is both specific enough to be useful to those who already are using a performance-based approach and at the same time broad and flexible enough to be valid across such a range of perspectives." The various interests of a TMS create the added challenge of defining performance measures that are appropriate for a range of functions without losing their existing application (Cambridge 1999).

Further complication occurs when measures are imposed on a TMS by stakeholders. External obligations may interfere with an agency's own idea of important measures, even if they are flexible. One solution to this conflict of interest is to overlap sets of measures so that one set satisfies the external requirements and the other meets internal needs. Inherent in this method is an added degree of complication and confusion (TransTech 2003).

In general, it is inevitable that performance needs will vary. When conflicts occur between various performance measures, they should be acknowledged and balanced if possible. Regardless of function, agencies share the common goal of accountability. For this reason, an agency's measures should be clear and focused. They will help an agency set policies and make them more accountable their stakeholders. It is also important that selected performance measures reflect the goals of a TMS; the goals and objectives should not be influenced by the performance measures. The end result will be a measure of success that will accurately reflect the achievement of a defined objective (Neudroff et al. 2003). Box 4-2 below highlights the goals of the Utah Department of Transportation's performance-based program.

"Quality Transportation Today, Better Transportation Tomorrow."

This is the Utah Department of Transportation (UDOT)'s motto. Each year UDOT reviews and revises their list of goals to keep on top of the current needs in their state. UDOT recently vamped up their commitment to goal setting. By asking themselves three pointed questions—Who are we? What is our focus? What do we do and how do we do it?—UDOT was able to establish four specific goals: take care of what we have, make the system work better, improve safety, and increase capacity.

Each strategic goal is subcategorized into focus areas. "Take care of what we have," for example, is broken down to the preservation of pavement, the preservation of bridge structures, and overall maintenance efforts. Performance measures, including the performance target, are then outlined.

UDOT also initiated a Statewide Transportation Improvement Program (STIP) and is looking as far ahead as 2030 with a long range plan, Utah Transportation 2030, based on its four strategic goals. UDOT represents an agency that effectively uses goals and measures to make progress (Utah Department of Transportation).

Box 4-2: Example of the application of performance measures to achieve goals (Utah Department of Transportation)

4.2 Typical TMS Performance Measures

This section provides standard measures that can be applied to typical TMS functions in order to meet the goals and objectives of a TMS. Tables 4-1, 4-2, and 4-3 are categorized by TMS type and its respective functions. Three types of TMSs are considered: freeway, arterial, and transit. They are organized further by functions and also by input, output, outcome, and external measures. Please see Figure 4-2, on the next page, for a holistic view of the TMC types and functions. It is noted that some of performance measures presented in this section can be used independently, while some measures need to be used with conjunction with other performance measures. For example, the measure of the number of cameras itself is useless. However, it becomes meaningful when used with the coverage miles.

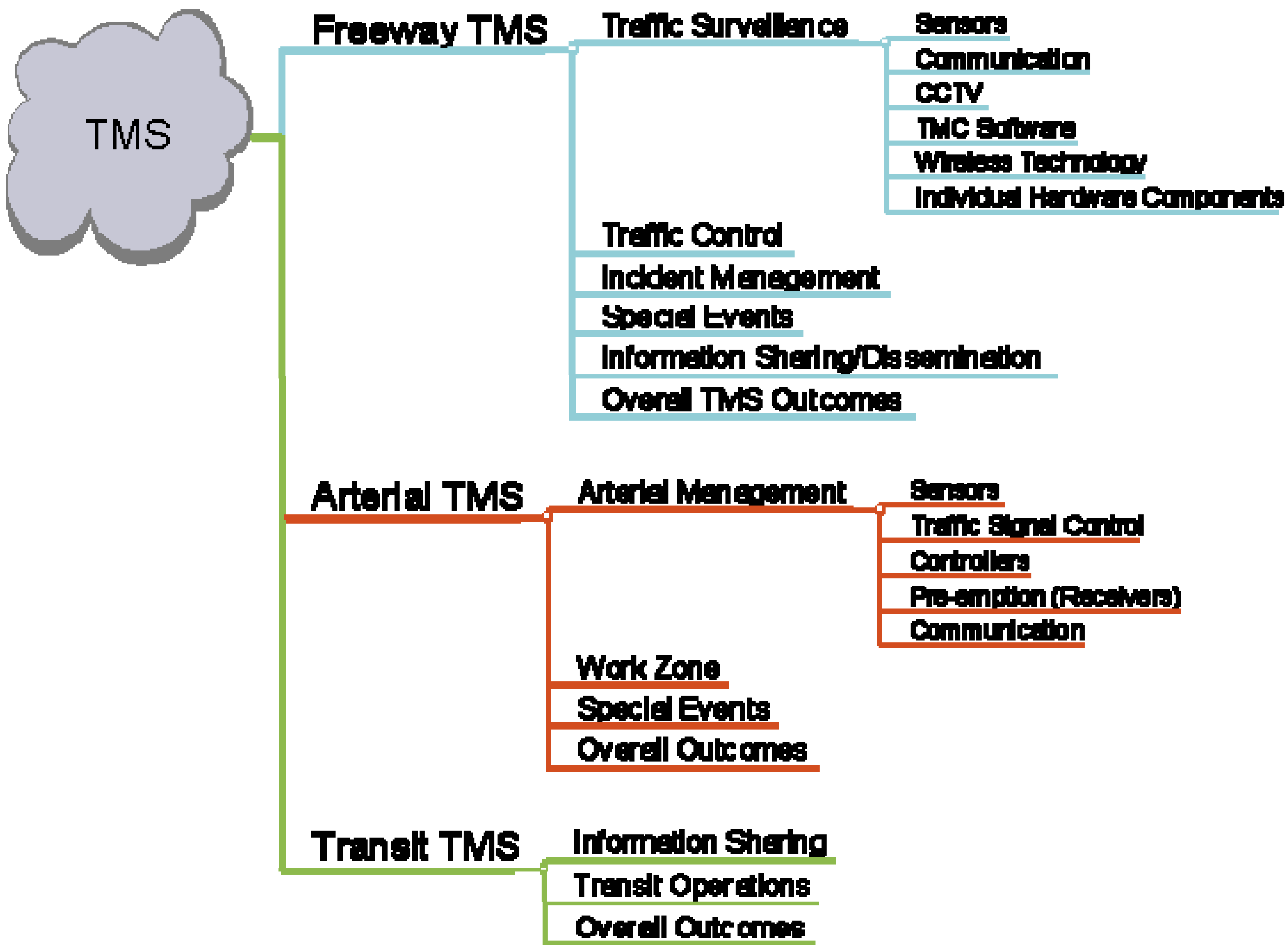

Figure 4-2: Overview of TMSs by Type and Their Respective Functions

Table 4-1: Performance Measures Corresponding to a Freeway TMS

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Traffic Surveillance	Sensors	Person-hours spent working on installation / maintenance	Input		
		Percent time working properly	Output		
		Percent freeway miles with electronic data collection	Output	Can be an external factor for analysis	$\frac{\text{Freeway Miles With Data Collection}}{\text{Total Freeway Miles}} \times 100\%$
		Number of loop/video/AVL/AVI readers working properly	Output	Can be an external factor for analysis	
		Spacing between sensors	Output	Can be an external factor for analysis	Average for n spacings, $\frac{\sum_{i=1}^{n} Spacing_i}{n}$
		Data quality, reliability by detector, other hardware, software algorithms, sensor type	Output		
	Communication	Efficiency of bandwidth	Input		$Efficiency = \frac{Bandwidth}{CycleLength} \times 100\%$
		Speed[8]	Output		see page 29
		Number of bits lost (i.e. noise)	Output		
		Number or percentage of time of failures	Output	Defined as complete loss of communication	
	CCTV	Person-hours spent working on CCTV system	Input		
		Percent time working properly	Output		
	Software at TMC	Person-hours spent working on TMC software maintenance and upgrades	Input		
		Flexibility	Output	Ease/cost of expansion to include new VMS, sensors, CCTV, etc.	
		Interoperability	Output	With other software used frequently at the TMC such as internet, etc.	
		Reliability[10]	Output		see page 31
		Other issues (maintainability, security, integration etc.)	Output		
		Number of service calls related to software	Output		

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Traffic Surveillance	Wireless Technologies	Market penetration	Output	Can be an external factor for analysis	
		Number and location of readers by type (AVL, license plate, toll tags etc.)	Output		
	Individual Hardware Components	Person-hours working on component monitoring and maintenance	Input	Can also use dollars spent as measure	
		Frequency of checking the status of the sensors	Output	Including sensors, readers, CCTV, video walls, hardware/software components, switches, routers, computer stations, servers, communication lines	
		Percent of time, and number of components working properly	Output		$\frac{\text{Time Component Works Properly}}{\text{Total Operation Time For Component}} \times 100\%$
		Equipment Downtime	Output	Percent time component not working, and percent time component working incorrectly (to help diagnosis)	$\frac{\text{Time Equipment Broken}}{\text{Total Operation Time For Equipment}} \times 100\%$
		Mean time between equipment failure	Output		$\frac{\sum_{i+1}^{n} \text{Time Between Failures}_i}{n}$
Traffic Control	General	Person-hours spent working on system	Input		
		Total/Percent freeway miles with electronic data collection	Input	Output for traffic surveillance	
		Number of loop/video/AVL/AVI readers	Input	Output for traffic surveillance	
		Spacing between sensors	Input	Output for traffic surveillance	Average for n spacings, $\frac{\sum_{i=1}^{n} \text{Spacing}_i}{n}$
		Data quality, reliability by detector, other hardware, software algorithms, sensor type	Input	Output for traffic surveillance	

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Traffic Control	HOV/Ramp Metering/Other Controls	Person-hours spent toward HOV/ramp metering/other management	Input		
		Percent of equipment (sensors, ramp meters, etc.) in "good" (working) condition	Output		$\frac{\textit{No. of Pieces Working}}{\textit{Total No. of Pieces}} \times 100\%$
		Percent time VMS working properly	Output		$\frac{\textit{Time VMS Working}}{\textit{Total Operation Time}} \times 100\%$
		Percent time RHOV (or HOV) gates working properly	Output		$\frac{\textit{Time RHOV Gates Working}}{\textit{Total Operation Time}} \times 100\%$
		Percent time Lane Control Systems (LCS) working properly	Output	Where lane control opens/closes lanes/shoulders for use	$\frac{\textit{Time LCS Working}}{\textit{Total Operation Time}} \times 100\%$
		Number of hours that ramp metering is in operation	Output		
		Percent time ramp metering working properly	Output		$\frac{\textit{Time Ramp Metering Working}}{\textit{Total Operation Time}} \times 100\%$
		Frequency of ramp metering software algorithm review/evaluation	Output	To measure currency/outdatedness	
		Frequency of updating ramp metering rate	Output		
		HOV vs. general purpose travel time	Outcome		
	Evacuation	Number of evacuation events	External		
		Extent of coordination with other agencies	Input	i.e., law enforcement and EMS	$\frac{\textit{No. Incidents Managed Jointly}}{\textit{Total No. Incidents Managed}} \times 100\%$
		Available number of personnel trained in evacuation operations	Input	In field and in TMC	
		Number of signs (both VMS and Static) - installed, checked, maintained in working condition	Input/output		

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Traffic Control	Evacuation	Time required to disseminate information to VMS/HAR	Output		Average for n disseminations, $\frac{\sum_{i=1}^{n} Time\ to\ Disseminat\ e_i}{n}$
		Frequency of update/review of evacuation plans/routes/signs	Output		$No.\ Update/Review\ per\ Quarter\ or\ Year$
	Weather	Hours, lane-miles, lane-mile-hours affected by (applicable) severe weather (rain, snow, ice, surface ice, high winds, fog, dust, smoke)	External	For before-and-after studies	
		Person-hours spent toward weather events	Input		
		Lane-miles pre-treated/plowed per hour/day (for snow events)	Output		$\frac{No.\ Lane\ Miles\ Treated}{Hour\ or\ Day}$
		Percent of equipment (e.g., snow plow) working	Output		$\frac{No.\ of\ Pieces\ Working}{Total\ No.\ of\ Pieces} \times 100\%$
		Number of messages displayed on changeable message signs, per weather event	Output		Average for n events, $\frac{\sum_{i=1}^{n} No.\ of\ Messages_i}{n}$
		Number of weather events for which messages were displayed vs. total weather events	Output		$\frac{No.\ of\ Events\ With\ Messages\ Displayed}{Total\ No.\ of\ Events}$
	Human Component	Turnover rate	External/output	Depends if the quality of work environment is objective of agency	$\frac{No.\ People\ that\ Left\ Job}{Total\ No.\ People\ at\ Job} \times 100\ \%$
		Person-hours working	Input	In field and in TMC, by job description	$No.\ People\ Working \times \frac{Avg\ Working\ Hours}{Day\ or\ Year}$
		Job experience/skills	Input		
		Dollar amount spent on employee training	Input	Summed over time (per month, per quarter, per year), or an average dollar amount per employee	Average, $\frac{Total\ Dollars\ Spent\ On\ Training}{No.\ of\ Employees\ Trained}$

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Traffic Control	Human Component	Quality of Training provided for personnel	Input	For multi-tasking, interpersonal coordination with other agencies, customer service, other traffic control reviews	
		Number of human errors	Output		
Incident Management	General	Number of incidents, by severity (e.g., fatal, injury), by type (e.g., crash, stalled vehicle)[2]	External	See page 26	
		Person-hours working for TMS Incident Management System	Input	Both in field and in TMC	
		Number of responded crashes versus total number of crashes	Output	Responded crashes are crashes responded to by State Safety Patrol or Freeway Incident Response Team	$\frac{\textit{No. of Responded Crashes}}{\textit{Total No. of Crashes Reported}}$
		Response time to incidents[1]	Output	See page 26	
	Sensors	Percent time working properly	External	Also an output for traffic surveillance	
		Percent freeway miles with electronic data collection	External	Also an output for traffic surveillance	$\frac{\textit{Freeway Miles With Data Collection}}{\textit{Total Freeway Miles}} \times 100\%$
		Sensor Downtime	Input	Percent time component not working, and percent time component working incorrectly	$\frac{\textit{Time Sensor Not Working}}{\textit{Total Operation Time}} \times 100\%$
	Calls	Number of employees/person-hours answering calls	Input		
		Incident-related calls	Input/output	Input for incident, output for calls	
		Number of incidents detected and/or verified with calls vs. the total number of incidents detected and verified	Output		*Total No. Incident Calls - ...* *- [Duplicate + False Alarm Calls]*
	Incident Detection Algorithms (Software)	Percent time component working properly	Input	Output for traffic surveillance	$\frac{\textit{Time Component Working}}{\textit{Total Operation Time}} \times 100\%$
		Incident detection Rate[3]	Output	see page 26	
		False Alarm Rate (FAR)[3]	Output	see page 26	

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Incident Management	Incident Detection Algorithms (Software)	Mean Time to Detect (MTTD) incidents	Output		For n incidents, $\frac{\sum_{i+1}^{n} Incident\ \ Detection\ \ Time_i}{n}$
	CCTV	Number of surveillance cameras	Input	Output for surveillance	
		Roadway coverage	Input	Output for surveillance	$\frac{No.\ of\ Lane\ Miles\ Monitored\ \ By\ CCTVs}{No.\ of\ Lane\ Miles\ Managed}$
		Percent of time CCTVs working properly	Input	Output for surveillance	$\frac{Time\ \ CCTVs\ \ Working}{Total\ \ Operation\ \ Time} \times 100\%$
		Number of identified incidents using CCTV	Output		
	EMS & Safety Patrol	Total number of EMS/Safety Patrol vehicles	Input	Need to define coverage hours (by time of day, day of the week, or special event)	
		Safety vehicle mileages per year	Input		Total for n safety vehicles, $\frac{\sum_{i=1}^{n} MileageofSafetyVehicle_i}{Year}$
		Average duration of lanes, shoulders closed by incident type/severity	Output	Correlates to the system's relibability (important for budgeting resources and response procedures) Example: plot the likelihood of lane closure by location and by hour of the week to organize responder resources	Average for n incidents, $\frac{\sum_{i=1}^{n} Duration\ \ Lanes,\ Shoulders\ \ Closed_i}{n}$
		Response time by incident type/severity[1]	Output	see page 26	
		Clearance time by incident type/severity[5]	Output	see page 27	
		On-scene time	Output	The time EMS and/or safety crew spends at the incident site	
	VMS/HAR/511	Percent of time VMS working properly	Input		$\frac{Time\ \ VMS\ \ Working}{Total\ \ Operation\ \ Time} \times 100\%$
		Time required to program a new VMS message	Output	The time taken to post an incident-related message	Average for n messages, $\frac{\sum_{i=1}^{n} Time\ \ to\ Program\ \ Message_i}{n}$
		Effectiveness of message	Output	From customer surveys/calls	

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Incident Management	Verification	Person-hours working on verification	Input		
		Verification time[4]	Output	see page 27	
	Outcomes	Total or average hours of incident-related delay	Outcome		
		Number of secondary crashes per primary crash	Outcome		
Special Events	Planned Events	Number of events per month	External		
		Number, duration of lanes/shoulder miles closed, by event type	External		Average duration for n events, $\frac{\sum_{i=1}^{n} \text{Duration Lanes, Shoulders Closed}_i}{n}$
		Person-hours working on planned event management	Input		
		Volume of traffic on major routes, alternate routes	Output		$\frac{\text{No. Vehicles on Major/Alte rnate Route}}{\text{Hour}}$
		Volume of traffic entering and exiting the site and parking areas	Output		$\frac{\text{No. Vehicles Entering/E xiting}}{\text{Hour}}$
		Number of event patrons and participants utilizing transit to and from the event	Output		
		Average vehicle occupancy	Output		For n vehicles, $\frac{\sum_{i=1}^{n} \text{Vehicle Occupancy}_i}{n}$
		Percent time VMS working properly (and other VMS related measures)	Output		$\frac{\text{Time VMS Working Properly}}{\text{Total Operation Time}} \times 100\,\%$
		Number of messages displayed per VMS, and time periods of messages	Output	To evaluate the locations of VMSs (usefulness) Example: find optimal number of messages and length of time they are displayed so that they can all be read, and optimal location to get travelers' attention	Average for n messages, $\frac{\sum_{i+1}^{n} \text{Time Between Failures}_i}{n}$ $\frac{\sum_{i=1}^{n} \text{Time Message Displayed}_i}{n}$
		Clarity, accuracy, timeliness of messages, per event	Output	Customer surveys	

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Special Events	Planned Events	Number of messages broadcast on highway advisory radio or other media	Output		
		Number of messages transmitted among agencies	Output	Indicates coordination, clarity of messages	
		Frequency of evaluating/changing regular traffic signal timing for special events	Output		
		Number of times a ramp(s) was closed and time/duration of closure(s)	Output		Average duration for n closures, $\frac{\sum_{i=1}^{n} Amount\ of\ Time\ Closed_i}{n}$
	Work Zone	Number, lane miles, time periods of work zones, by type	External		
		Miles, hours of lanes/shoulders closed due to work zones, by type and capacity reduction	External	Average, range (minimum, maximum), median, and variance	
		Work zone configuration	External/output	Time of day, partial closures, etc.	
		Person-hours spent working on system	Input	Can also use dollars spent as measure	
		VMT exposed to work zones of different types	Output		
		Average time for work completion, by work zone type	Output		For n work zones of one type, $\frac{\sum_{i=1}^{n} Time\ to\ Complete_i}{n}$
		Number of work zone crashes	Output		
	Outcomes	Number of reduced crashes	Outcome		
		Travel times	Outcome		
		Hours of delay	Outcome		
		Capacity reductions	Outcome		$\frac{Vehicles\ per\ Hour}{(Vehicles\ per\ Hour)_{max}} \times 100\%$

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Information Sharing/ Dissemination	General	Person-hours spent on overall information sharing/dissemination	Input		
		Amount spent on hardware/software system components	Input		
	Real-Time	Person-hours spent on real-time information sharing/dissemination	Input		
		Frequency of data sharing (crash, planned events, weather, traffic) with EMS, transit, and signal system TMS	Output	i.e. how often is applicable information shared Example: informing EMS of a concert event so they can mobilize resources	$No.\ of\ Data\ Sharing\ per\ Month\ or\ Year$
		Number of agencies that receive information	Output	For identification and inclusion of agencies wanting traffic-related data	
		Extent of real-time information (lane-miles or intersections) available/shared	Output		$\frac{Real\ Time\ Coverage\ (Lane - Miles)}{Total\ Coverage\ (Lane - Miles)}$ $\frac{No.\ Intersections\ with\ Real\ Time\ Information}{Total\ No.\ Intersections}$
		Frequency/duration of radio broadcasts	Output		Average duration for n broadcasts, $\frac{No.\ of\ Traffic\ Broadcasts}{Time} \times 100\%$ $\frac{\sum_{i=1}^{n} Time_i}{n}$
		Individuals receiving traveler information by source (511, other direct means)	Output	Customer survey	
		Percent of road closures communicated to public within certain period of closing	Output		$\frac{Communicated\ Road\ Closures}{Total\ Road\ Closures} \times 100\%$
		Hits per day on traveler information web site	Output		Average for n days, $\frac{\sum_{i=1}^{n} No.\ of\ Hits_i}{n}$
		Information quality perceived by customers	Output	Real-time and off-line	

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Information Sharing/ Dissemination	Off-Line	Person-hours spent working on off-line activities	Input		
		Frequency of offline system update	Output	On an as-needed basis	
		System update frequency by components	Output		
		Number of newsletter subscribers	Output		
		Number of ways to access information	Output	Improved on an as-available technological basis	
		Number of people/organizations accessing information	Output		
		Speed of results returned for a query	Output	Qualitatively measured as acceptable or unacceptable speeds	Average for n queries, $\frac{\sum_{i=1}^{n} Time\ to\ Return\ Results_i}{n}$
		Number of users/visits to websites	Output		
		Number of queries	Output		
		Total amount of data queried	Output		
	Outcomes	Reduced overall travel time	Outcome		
		Reduced overall delay	Outcome		
		Customer satisfaction	Outcome		
Overall TMS Outcomes	Mobility6	VMT by congestion level	Outcome		
		Delay due to congestion (total or by vehicle)[7]	Outcome		see page 28; Average for n events, $\frac{\sum_{i=1}^{n} Delay/Lost\ Time_i}{n}$
		Level of service or volume-to-capacity ratios	Outcome	Classified A (best) to F (worst)	$\frac{Volume}{Capacity}$
		Duration of congestion (lane-mile/hours in LOS E or F)	Outcome	The maximum length of time a segment of the facility is congested	
		Percent of system congested	Outcome	Often correlates with LOS E or F	$\frac{Lane\ Miles\ Congested}{Total\ Lane\ Miles} \times 100\%$
		Percent of miles operating in desired speed range	Outcome		
		Average speed[8]	Outcome		see page 29
		Travel time[9]	Outcome		see page 30

Freeway System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Overall TMS Outcomes	Mobility6	Travel Time Reliability[10]	Outcome	Variability and range in travel times, percent of acceptable times	see page 31
		Indices such as Travel Time Index, Buffer Index, Travel Rate Index[11]	Outcome	Based on Urban Mobility Program measures	see page 33
	Safety	Total number of crashes (property damage, injuries, fatalitites)	Outcome	Both an external factor and an outcome, based on whether or not avoidable by a TMS	
		Construction-related fatalities	Outcome		$\frac{\text{No. of Fatalities in Work Zones}}{\text{Total No. Fatalities}} \times 100\%$
		Number of secondary crashes	Outcome		
	Customer Satisfaction	Customer perception of safety	Outcome	Customer surveys	
		Customer satisfaction	Outcome	Customer surveys	
		Customer perceptions on travel times	Outcome	Customer surveys	
		Estimated diversion rate	Outcome		$\frac{\text{No. Vehicles Diverted to Alt. Routes}}{\text{No. Cars in Traffic on Route of Interest}}$
		Hours of both recurring and non-recurring delay by mode	Outcome	Non-recurring delay correlates to incident-related delay	
	Quantity of Travel	Total person-hours traveled by vehicle type	Outcome		
		Average delay (total, recurring, & incident – based)	Outcome		
	System Utilization	Density (passenger cars per hour per lane)	Outcome		$\text{No. of Passenger Cars/hour/ lane}$
		Percentage of travel heavily congested	Outcome		$\frac{\text{Miles of Heavily Congested Travel}}{\text{Total Miles Traveled}} \times 100\%$
		V/C ratio	Outcome		$\frac{\text{Volume}}{\text{Capacity}}$
	Queue Characteristics	Queue growth rate	Outcome		$\frac{\text{Cum. Arrival} - \text{Cum. Departure}}{\text{Time}}$
		Queue length (average or maximum)	Outcome		$\text{Cum. Arrival} - \text{Cum. Departure}$

Table 4-2: Performance Measures Corresponding to an Arterial TMS

Arterial System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Arterial Management	Sensors	Total intersections, corridors	External		
		Number of personnel available and hours spent on activities (e.g., operation, maintenace, etc.)	Input		
		Maintenance (hours, cost) spent on field equipment (total and average)	Input		
		Links of coverage vs. total links	Output		
		Data quality, accuracy, reliability by sensor type and other components	Output		
		Equipment downtime	Output	Percent time component not working, and percent time component working incorrectly (helps in diagnosis)	$\frac{Time\ \ Equipment\ \ \ Not\ \ Working}{Total\ \ Operation\ \ \ Time} \times 100\ \%$
		Frequency of checking the status of the sensors	Output		
		Mean Time Between Failures (MTBF) for field equipment	Output		$\frac{\sum_{i=1}^{n} TimeBetwee\ \ enFailure_{\ i}}{n}$
		Number of routine maintenance calls per time period	Output		
	Traffic Signal Control	Cost of updating timing plan, per intersection/corridor	External		Average for n updates, per intersection/corridor, $\frac{\sum_{i=1}^{n} Cost_{\ i}}{n}$
		Person-hours toward traffic signal control	Input	Can also use dollars spent as metric	
		Number of signals to be maintained per person	Input		$\frac{No.SignalsToM\ a\,\mathrm{int}\ ain}{No.PeopleMa\ \ \mathrm{int}\ aining}$
		Number of maintained signals vs. total signals	Output		

Arterial System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Arterial Management	Controllers	Change in intersection approach volumes	External		
		Person-hours spent toward maintaining/operating for controllers	Input	Can also use dollars spent as metric	
		Time taken to replace or repair failed equipment	Input / Output		Average for n replacement/repairs, $\frac{\sum_{i=1}^{n} Maintenance\ Cost_i}{n}$ $\frac{\sum_{i=1}^{n} Time_i}{n}$
		Frequency of reviewing timing plan, per intersection/corridor	Output	Note the difference between reviewing and retiming	
		Number of signals retimed per given time period	Output		
		Frequency of failures (flash mode or complete failure)	Output	Due to power outage or broken lights	
		Frequency of resetting clock due to shifting	Output		
		Time/cost required for uploading new timing plan to controller	Output		
		Utilization of capabilities within controller software (transition logic, transit signal priority, etc.)	Output		
	Pre-Emption (Receivers)	Number of vehicles equipped with receivers	External		
		Person-hours working on pre-emption management	Input		
		Percent of time not working properly	Output		$\frac{Time\ Receiver\ Not\ Working}{Total\ Operation\ Time}$
		Number of actual services/month	Output	Indicated by the actuations on the receiver	
	Communication	Bandwidth	Input		
		Speed[8]	Output		see page 29
		Number of bits lost (i.e. noise)	Output		

Arterial System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Arterial Management	Communication	Number or percentage of time of failures	Output	Complete loss of communication	$\frac{No. Failures}{Day/Month}$
Work Zone		Number, lane miles, turning movement closures, intersection closures, time periods of work zones, by type	External		
		Intersection capacity, lane number, hours or miles, closed due to work zones of different types	External		$\frac{No.\ Lane\ Number/Miles/Hours\ Closed}{Total\ Lane\ Number/Miles/Hours}$
		Number of work zones per month	External		$\frac{No.\ Work\ Zones}{Month}$
		Vehicles, VMT exposed to work zones	External/output	Type depends on the use of work zone configuration	
		Average (duration, length) of work zones by types	External/output	Type depends on the use of work zone configuration	Average for n work zones, $\frac{\sum_{i=1}^{n} Length\ of\ Work\ Zone_i}{n}$
		Average time for work completion, by work zone type	External/output	Type depends on the use of work zone configuration	Average for n work zones, $\frac{\sum_{i=1}^{n} Time\ for\ Work\ Completion_i}{n}$
		Work zone configuration	External/output	Time of day, partial closures, etc.	
		Work zone requests	Input		
		Person-hours spent on work zone configuration & implementation	Input		
		Frequency, number of work-zone crashes	Output		$\frac{No.\ Work\ Zone\ Crashes}{Day/Month}$
		Percent time VMS working properly (and other VMS related measures, where applicable)	Output		$\frac{Time\ VMS\ Working}{Total\ Operation\ Time} \times 100\%$
Special Events		Number of events	External		
		Duration of event	External		
		Person-hours toward special event work	Input	Can also use dollars spent as metric	

Arterial System					
Function Category	**Components**	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Special Events		Frequency of evaluating/changing timing plans for special events	Output		*No. reviews per event*
		Number of special event signal operations by time of day, day of week and event types	Output		
		Coordination level with freeway TMSs and other jurisdiction signal systems	Output	Depending on the need to review	
Overall Measures		Total lane-miles being managed	External		
		Person-hours toward arterial management	Input		
		Number of cycle failures, per intersection/corridor	Output	Classified by cause of failure (poor timings or excessive demand)	$\frac{\text{No. Cycle Failures}}{\text{Day/Month}}$
		Efficiency of bandwidth	Output		$Efficiency = \frac{Bandwidth}{CycleLength} \times 100\%$
		Travel time delay[7]	Outcome		see page 28
		Maximum queue length	Outcome		*Cum. Arrival - Cum. Departure*
		Customer satisfaction	Outcome		
		Number of positive/negative feedback calls vs. total calls	Outcome		$\frac{\text{No. Feedback Calls Received}}{\text{Total Calls Received}}$
		Average speeds along corridors	Outcome		Average for n vehicles, $\frac{\sum_{i=1}^{n} Speed_i}{n}$
		Travel time reliability[10]	Outcome		see page 31
		Level of service by intersection/corridor	Outcome		

Table 4-3: Performance Measures Corresponding to a Transit TMS

Transit System				
Function Category	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Information Sharing	Person-hours spent on information sharing	Input	Can also be in dollars spent	
	Number of VMS signs capable of providing information on arrivals, & % working units.	Output		$\frac{\textit{No. VMS Capable of Displaying Arrivals}}{\textit{Total No. VMS}}$ $\frac{No.VMSWorking}{TotalNo.VMS} \times 100\%$
	Coordination with regional TMS (Freeways, arterials, and other transit)	Output		
	Percent of time information is accurate	Output		
	Percent of time information is timely	Output		
	Percent of time information is useful	Output		
Transit Operations	Number of passengers/time period	External		
	Person-hours spent on transit operations	Input		
	Frequency of scheduling update	Output		
	Average occupancy	Output		
	On-time percentage	Output	An output in terms of systematic inefficiencies, an outcome from the customer perspective	$\frac{\textit{No. On-Time Routes}}{\textit{No. Routes per Day}}$
	Number of incidents, & preventive maintenance undertaken	Output		
	Percent of AVL equipped buses	Output		$\frac{No.BusesWithA\ VL}{TotalNo\ .Buses} \times 100\%$
	Proportion of buses with signal priority	Output		$\frac{\textit{No. Buses with Signal Priority}}{\textit{Total No. Buses}}$

Transit System				
Function Category	**Metric**	**Type**	**Supplementary Notes**	**Calculation Example(s)**
Transit Operations	Number of intersections/routes equipped with transit signal priority equipment versus total number on transit routes	Output	Requires coordination with the city/county/MPOs	
	System penetration of transit signal priority	Output		$\frac{\textit{No. Intersections/Routes with Signal Priority}}{\textit{Total No. Intersections/Routes}}$
	Number of buses out of service/route	Output		
Overall Outcomes	Customer satisfaction	Outcome		
	Travel time reduction	Outcome		
	Delay savings	Outcome		

1) *Response time* is the time it takes to activate, coordinate, and dispatch the necessary personnel, equipment, and communications once the occurrence of an incident is verified. The time ends when the first responder arrives on the scene of the incident (Neudroff et al. 2003). The relation of response time to incident management overall is shown in Figure 4-3. The time it takes to respond to an incident can be broken down by the type and severity of an incident. (This measure should have the review and recommendations of legal department before implementation to limit vulnerability to litigation.)

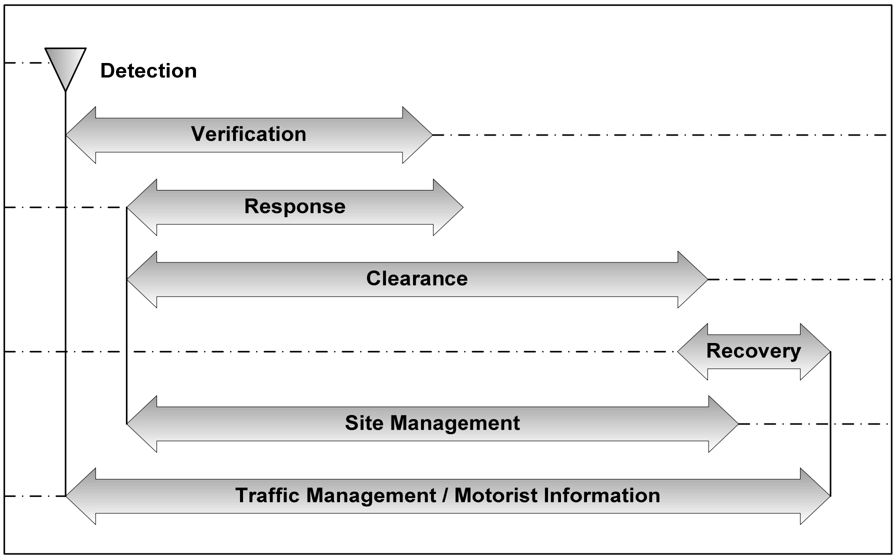

Figure 4-3: The Stages of Incident Management (Neudroff et al. 2003)

2) An incident is anything that interrupts the usual flow of traffic and can vary in type from vehicle breakdowns, to vehicle crashes, to obstructions in the roadway, such as cargo spills or fallen debris. Crashes can be subcategorized into single vehicle crashes, multiple vehicle crashes, crashes involving trucks, and weather related crashes. Severity is based on injuries and fatalities (ITS Decision 2003).

3) *Incident detection rate* and *false alarm rate* (FAR) are used to measure the performance of incident detection algorithms. The detection rate can be taken as the percentage of incidents detected by the software versus the number of incidents that occur. The FAR can be taken as the percentage of false alarms versus the number of tests run by the software. Factors that may affect the performance of an incident detection algorithm include: the operating conditions of the roadway (at or below capacity), the duration and severity of the incident, the geometric characteristics of the roadway (grade, change in the number of lanes, presence of ramps), weather (including the condition of the road surface as wet or dry), detector spacing, the location of the incident with respect to a detector, and the diversity of the traveling vehicles (ITS Decision 2003).

4) *Verification time* is the time it takes to confirm an incident has taken place and to then communicate the location and nature of an incident to the appropriate agency (Neudroff et al. 2003). Verification can generally be considered complete when the first response team arrives at the scene. An exception is when hazardous material is involved (PB Farradyne 2000). Its relation to incident clearance is shown in Figure 4-3. To measure verification time accurately, times should be recorded by TMC field personnel and by a reliable, non-TMC source for comparison.

5) *Clearance time* is measured as the time it takes to clear the vehicles, wreckage, or other obstructions that are disrupting traffic flow to return the roadway to its normal flow pattern. This may include repairs to the roadway (PB Farrdyne 2000). Clearance time should be measured according to the type and severity of the incident; the expected clearance time for a minor incident should be under 30 minutes, between 30 minutes and 2 hours for an intermediate incident, and over 2 hours for a major incident. Details of an incident are an important consideration because variables such as "truck involvement, overturned vehicles, trailer or tanker damage, fuel spills, cargo spills, fatalities, police crime scene designations, weather, travel lanes affected, and volume of passing traffic" can greatly affect the clearance time (Transportation Research Board, NCHRP Synthesis 318). In measuring clearance time, an agency may use notification time, actual time, or verification time as the start time. It's simply important to define these parameters. Clearance can be considered complete when the traffic bottleneck has cleared.

6) "*Mobility* is defined as the ability to satisfy the demand to move a person or goods and can be described by four parameters:

- Quantity of travel (number of persons served)
- Quality of travel (travelers' satisfaction with travel).
- Accessibility of travel (ability to reach the destination and mode choice).
- Utilization of a facility or service (the quantity of operations with respect to capacity)" (Transportation Research Board, NCHRP Synthesis 311 2003).

Table 4-4 is an example of Florida's Mobility Performance Measures Program and specifically the mobility performance measures in place there (Florida 2000). Some of these measures are discussed in more detail in the remainder of this section. *Mobility* measures have been used for many purposes, "ranging from site-specific operations analysis to corridor-level alternative investments analysis to area-wide planning and public information studies. Transportation agencies have adapted a wide range of mobility performance measures and these have been reviewed to develop the performance measures most appropriate for national mobility monitoring" (Battelle et al., 2002).

Table 4-4: Florida's Mobility Performance Measures for Highways (Florida 2000)

Dimension of Mobility	Mobility Performance Measures	State Highway System	Florida Intrastate Highway System	Florida Intrastate Highway System Corridors	Metropolitan Highway Systems	Definitions[1]
Quantity of Travel	Person miles traveled	•	•	•	•	AADT * length * vehicle occupancy
	Truck miles traveled	•	•	•	•	AADT * length * % trucks
	Vehicle miles traveled	•	•	•	•	AADT * length
	Person trips				•	Total person trips
Quality of Travel	Average speed	•	•	•		Average speed[2] weighted by PMT
	Delay	•	•	•	•	Average delay
	Average travel time			•		Distance / speed[2]
	Average trip time				•	Door to door trip travel time
	Reliability			•	•	% of travel times that are acceptable
	Maneuverability			•		Vehicles per hour per lane
Accessibility	Connectivity to intermodal facilities	•	•	•	•	% within 5 miles (1 mile for metropolitan)
	Dwelling unit proximity		•	•	•	% within 5 miles (1 mile for metropolitan)
	Employment proximity		•	•	•	% within 5 miles (1 mile for metropolitan)
	Industrial/warehouse facility proximity		•			% within 5 miles
	% miles bicycle accomodations	•			•	% miles with bike lane/shoulder coverage
	% miles pedestrain accomodations	•			•	% miles with sidewalk coverage
Utilization	% system heavily congested	•	•	•	•	% miles at LOS E or F
	% travel heavily congested	•	•	•	•	% daily VMT at LOS E or F
	Vehicles per lane mile	•	•	•	•	AADT * length / lane miles
	Duration of congestion	•	•	•	•	Lane-miles-hours at LOS E or F

[1] Definitions shown are generally for daily analysis. Calculations for the peak are based on prevailing conditions during the typical weekeday 5:00 to 6:00 PM peak.
[2] Speed based on models using the HCM or field data.

7) *Delay* is added travel time caused by congestion. It can be calculated as:

Equation 4-1

$$\textit{Total Segment Delay (veh-min)} = [\textit{Actual Acceptable Travel Time (min)} - \textit{Actual Travel Time (min)}] \times \textit{Volume (veh)},$$

$$\textit{Total Delay (veh-min)} = \sum_{i=1}^{n} \textit{Segment Delay}_i$$

Acceptable travel time for expected conditions is generally based on the posted speed limit, but may "be calculated using a congestion threshold speed established from local performance goals for mobility." "Acceptable travel conditions" are usually free-flow (Federal Highway Administration 2002).

Another method is to measure the divergence of the actual travel time from the expected travel time. Equation 4-2 can be used to calculate delay over a set of links assuming free-flow conditions.

Equation 4-2

$$D = \sum_{i=1}^{n} L_i \times F_i(t) \times \left[\frac{1}{V_i} - \frac{1}{f_i} \right]$$

Where,

L_i = The length of the ith segment holding the ith TMS, which can be derived from adjacent TMS' locations marked by milepost value

$F_i(t)$ = The total volume at the ith TMS site for the specified period t

f_i = The free-flow speed at the ith segment (Martin 2003)

8) *Average Speed* is the arithmetic average of all vehicles for a specified period of time. The simplest calculation is to take distance over time: total distance traveled divided by the total time to travel "x" distance. Because TMS data is collected by lane, weighting factors based on the volume in each lane are used to determine the average speed at a given point in all lanes. The lane with the highest volume is given the highest weight. Equation 4-3 represents this method (Martin 2003).

Equation 4-3

$$V^i = \frac{\sum_{m=1}^{n} F^i{}_{Dm} V^i{}_{Dm}}{\sum_{m=1}^{n} F^i{}_{Dm}}$$

Where,

V^i = Weighted average speed at the ith TMS site for the specified period

$V^i{}_{Dm}$ = Average speed at the mth detector of the ith TMS site for the specified period

$F^i{}_{Dm}$ = Total volume at the mth detector of the ith TMS site for the specified period

n = Number of detectors at the ith TMS site (Martin 2003)

Equation 4-4 can be used to calculate speed for a specified period of time where weight is the ratio of total volume in time of *t* to total volume in time of *T* (Martin 2003).

Equation 4-4

$$V^i_T = \frac{\sum_{k=1}^{n} F^i_{tk} V^i_{tk}}{\sum_{k=1}^{n} F^i_{tk}}$$

Where:

V^i_T = Weighted average speed at the ith TMS site for the specified period T

V^i_{tk} = Average speed at the ith TMS site for the specified period t

F^i_{tk} = Total volume at the ith TMS site for the specified period t

n = The number of t intervals included in the T (Martin 2003)

An alternate method of calculating speed is shown below:

Equation 4-5

$$SA = \frac{3600L}{TR} + D$$

SA = Average Travel Speed

L = Segment length (miles)

TR = Total Running Time for each segment (seconds)

D = Average stopped delay during PM peak hour traffic (seconds) (Sellsted)

9) *Travel Time* is the time takes to travel a measured distance on a segment or corridor. It is calculated using average speed over a segment of a given distance. The average five-minute speed is usually applied, as shown in Equation 4-6. The process is shown in Equations 4-6 to 4-9. Over a link, real time speed can be used to calculate the precise travel time (Martin 2003).

Equation 4-6

$$T_i(t) = \frac{L_i}{V_i(t)}$$

Where:

$V_i(t)$ = average speed in a five-minute interval at the ith TMS at time t when vehicles travel over the ith segment

L_i = the length of the ith segment holding the ith TMS, which can be derived from the adjacent TMSs' locations marked by milepost value (Martin 2003)

"Assuming $x_i, x_2, \ldots x_n$ as locations of n TMSs on a directional roadway, L_i is calculated as follows:

Equation 4-7

$$L_i = \frac{x_{i+1} - x_{i-1}}{2}$$

"The lengths of the first and last segments are:

Equation 4-8

$$L_i = (x_2 - x_1), \quad L_n = (x_n - x_{n-1})$$

"Equation 4-9 shows that travel times are aggregated over a set of links to find the total travel time *T* for an entire or specific section of a route" (Martin 2003).

Equation 4-9

$$T = \sum \frac{L_i}{V_i(t)}$$

10) *Reliability* is defined as:

- "The likelihood of a traveler's expectations being met. Reliability is measured as the variability between the expected travel time (based on scheduled or average travel time) and the actual travel time (due to the effects of nonrecurrent congestion).
- The range of travel times experienced during a large number of daily trips.
- The impact of nonrecurrent congestion on the transportation system, estimated as a function of the variation in the duration, extent, and intensity of traffic congestion on a system" (Transportation Research Board, *NCHRP Synthesis 311* 2003).

Many techniques have also been reported for measuring reliability. It is generally measured in terms of the variability of travel time, characterized by the various travel times associated with a given trip. "The range of travel times can be obtained by calculating the mean and standard deviation of travel times within a sample. For example, an uncongested facility might have a trip time reliability of 12 to 15 minutes for 85% of all trips, whereas on a congested facility the reliability might be between 20 and 30 minutes." This way of calculating reliability was used to study the benefits (travel time savings) of high-occupancy vehicle

(HOV) lanes versus freeway main lanes. This method can be applied to a single roadways, corridors, and area wide networks, but should be used to compare travel times along one facility (Transportation Research Board, *NCHRP Synthesis 311* 2003).

A higher standard deviation in the sample travel time correlates to higher variability and therefore less reliability. When using equation 4-10 to calculate standard deviation, a large sample size should be used (Martin 2003).

Equation 4-10

$$s^2 = \frac{\sum (T_i - M)^2}{n-1}$$

Where,

- s = the estimate of travel time standard deviation
- T_i = the travel time of the ith travel crossing a specific route
- M = the mean travel time of a set of samples
- n = the number of sampling travels (Martin 2003)

Figure 4-4 contains an algorithm for calculating variability and reliability. Travel time and expected number of trips are input from TMS data (Martin 2003).

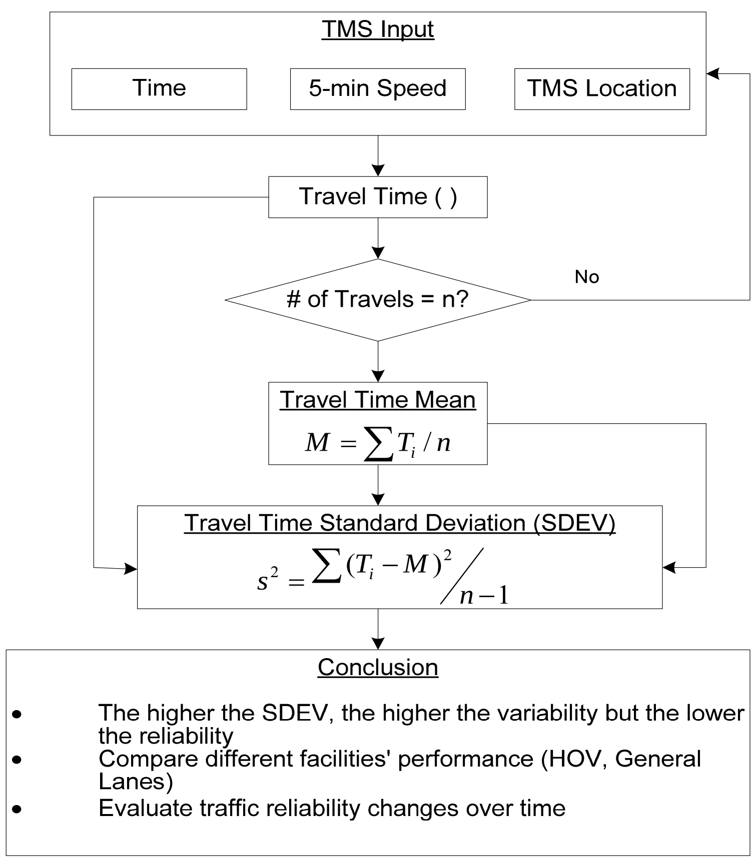

Figure 4-4: Traffic Variability and Reliability Algorithm (Martin 2003)

A reliability performance indicator, *R*, was theorized by Ikhrata and Michell. It is the probability that travel time will either meet or exceed the expected travel time, based on previous trips. Equation 4-11 shows how to calculate *R* using data from commuter surveys (Transportation Research Board, *NCHRP Synthesis 311* 2003).

Equation 4-11

$$R = 1 - (\%trips_{within} - \%trips_{exceed})$$

Where,

$\% \, trips_{within}$ = percent of trips in which users arrive at their destinations at the expected (average) travel time or less; and

$\% \, trips_{exceed}$ = the percent of trips in which users do not arrive at destinations within the expected (average) travel time

> "A preliminary investigation of this methodology revealed that because the indicator is based on the average travel time, approximately one-half of the observations will always fall within the average value and one-half will exceed it. Using this methodology, the reliability performance indicator will always have a value in the range of 0.9 to 1.1." The index will increase with decreasing reliability (Transportation Research Board Synthesis 311 2003).

A "reliability buffer index" was established in the Texas Transportation Institute's Urban Mobility Report: 2000. The index represents "the difference between the average travel time and the 95th percentile travel time as the extra time that has to be budgeted for a trip compared with the average travel rate to define a reliability index" (Transportation Research Board, NCHRP Synthesis 311 2003).

Equation 4-12

$$Buffer\ Index\ (BI) = \frac{95th\ Percent\ Confidence\ Rate - Average\ Travel\ Rate}{Average\ Travel\ Rate} \times 100\%$$

Due to significant variability during peak hours, 2 minutes per mile should be added to the buffer (on top of the average travel time of 1.5 minutes per mile) (Transportation Research Board, *NCHRP Synthesis 311* 2003).

Reliability can also be measured as the difference between incident-related delay and nonincident-related delay using Equation 4-1 (Transportation Research Board, *NCHRP Synthesis 311* 2003).

How Florida Calculates Reliability

"The Florida's Reliability Method report (Jackson et al. 2000) went further to derive a methodology for determining reliability from the Florida DOT's definition of the reliability of a highway system as the percent of travel on a corridor that takes no longer than the expected travel time plus a certain acceptable additional time. In this context, it is necessary to define the three major components of reliability.

1. Travel time—The time it takes a typical commuter to move from the beginning to the end of a corridor. Because speed is determined along each segment as the traveler moves through the corridor, this travel time is a function of both time and distance. This is representative of the typical commuter's experience in the corridor.

2. Expected travel time—The median travel time across the corridor during the time period being analyzed. The median is used rather than the mean so that the value of the expected travel time is not influenced by any unusual major incidents that may have occurred during the sampling period. These major incidents will be accounted for in the percentage of how often the travel takes longer than expected, but will not change the baseline to which that unusually high travel time is being compared.

3. Acceptable additional time—The amount of additional time (Δ), beyond the expected travel time, that a commuter would find acceptable during a commute. The acceptable additional time is expressed as a percentage of the expected travel time during the period being analyzed. Times 5%, 10%, 15%, and 20% above the expected travel time are currently being considered. However, Florida practice recommended that preference surveys be conducted to determine how much difference from the expected commute a traveler would find acceptable.

"The threshold when travel exceeds the acceptable additional time beyond the expected travel time is obtained using the following equation:

$$\text{Acceptable } TT = x + \Delta$$

where

x = the median travel time across the corridor during the period of interest; and

Δ = an additional travel time estimated as a percentage of the median travel time during the period of interest or value, used to establish the additional time beyond the expected travel time that a traveler would find acceptable.

"The percent of reliable travel is calculated as the percent of travel on a corridor that takes no longer than this acceptable travel time. A comparative analysis was conducted using traffic flow data for the following three study corridors: (1) I-95 in Jacksonville, (2) I-95 in Broward County, and (3) I-4 in Orlando. Two test corridors were also included in the project. The first test corridor was I-95 from south of Hallandale Beach Boulevard in Broward County to north of Yamato Road in Palm Beach County. Data for this corridor were collected as part of a 1999

Continued on next page

How Florida Calculates Reliability (continued)

Interstate Traffic Data Survey. The second test corridor was a 23-mi segment of I-405 in Seattle, Washington. The reliability results suggest that the Florida Reliability Method is well suited for measuring reliability because it characterizes reliability as an indicator of how well conditions on the corridor meet travelers' expectations by establishing an acceptable travel time unique to the corridor. This definition matches well with the reliability definitions provided by operations researchers and used in other commercial transportation applications such as aviation (ontime arrivals), rail (on-time arrival), and integrated logistics (on-time or just-in-time delivery). Other methods describe the variability of travel time but do not report directly on reliability from this perspective. The following recommendations were made regarding data collection for reliability measurement:

- For the calculation of reliability using the Florida Reliability Method, the acceptable additional time should be based on a fixed percentage of 15 or 20% of the expected travel time. However, it is recommended that preference surveys be conducted to determine how much difference from the expected commute a traveler would find acceptable.
- Reliability should be measured for a consistent peak hour (such as 5 to 6 p.m.) rather than the peak period for a corridor. This allows comparisons between facilities, and also enables annual monitoring of reliability on the same facility, because the peak period may change from year to year.
- The interval for collecting speed and volume data should be less than the travel time under free-flow conditions.
- The optimum data collection period for the reliability measurement is a 6-week period using data collected at intervals of 5-min or less based on the travel time under free-flow conditions as noted above.
- Data collected over a 4-week period at 15-min intervals is the minimum recommended to provide an adequate sample size" (Transportation Research Board Synthesis 311 2003).

Box 4-3: How Florida calculates reliability

11) *Travel Time Index* (TTI) is "the ratio of peak period travel time to free-flow travel time. It represents the ease of getting to a destination." TTI can range from 1 to infinity, where a large number indicates congestion. For example, a TTI of 1.3 means that a trip taking 10 minutes during off-peak hours will take 13 minutes during peak hours. TTI can be applied to segments of the roadway or the entire system. Equation 4-13 shows how TTI is calculated (Martin 2003).

Equation 4-13

$$TTI = \frac{\sum \frac{l_i}{V_i(t)}}{\sum \frac{l_i}{f_i}}$$

Travel rate index is the increase in travel time and is calculated in the following ways (Transportation Research Board Synthesis 311 2003):

Equation 4-14

$$\frac{\text{Travel Time Under Congested Conditions}}{\text{Travel Time Under Uncongested Conditions}}$$

Equation 4-15

$$\frac{\frac{60/Speed_{Freeway}}{60/Freeflow\ Speed_{Freeway}} \times VMT_{Freeway} + \frac{60/Speed_{Arterial}}{60/Freeflow\ Speed_{Arterial}} \times VMT_{Arterial}}{VMT_{Freeway} + VMT_{Arterial}}$$

Chapter 5 will provide a detailed view of important data requirements and concerns related to these performance measures mentioned in this chapter. The next chapter serves as a bridge between Chapter 4 on Agency Goals and Performance Measures and Chapter 6 on Performance Monitoring, Evaluating, and Reporting.

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Chapter 5: Data Requirements, Collection, and Archiving

Introduction

Data is an individual fact or multiple facts, or a value, or a set of values, but is not significant to a business in and of itself. Giving data context, or meaning, turns it into information. Without this context, the data is useless to the business. (Ministry of Forests, 2000)

"Performance measures" are the information of interest to the readers of this handbook. The decision makers and the public alike use these measures to analyze a project or program progress. Data, the focus of this chapter, provide the facts for creating this information. The previous chapter (Chapter 4) explains the relevant performance measures and their calculations. The next chapter (Chapter 6) explains how to use the measures effectively, in performance monitoring, evaluation and reporting practices. This chapter provides a detailed view of several important facets related to data, ranging from the assessment of data requirements for particular measures, to archiving for later usage. The relationship of this chapter to the rest of this handbook is presented in Figure 5-1.

Section 5.1 maps the performance measures identified in the previous chapter to their data requirements. Section 5.2 relates potential issues associated with these data requirements. Section 5.3 provides an overview of the vast number of data collection techniques and their details. The need for and details of data screening and archiving are explained in Section 5.4. Section 5.5 describes a number of issues related to data, such as data quality, reliability, availability etc. Section 5.6 concludes the chapter by providing examples of best practices in existing TMS data management programs.

With the data as the central idea or focus of attention, the related major topics of this handbook, and sub-topics of this chapter are presented in Figure 5-2.

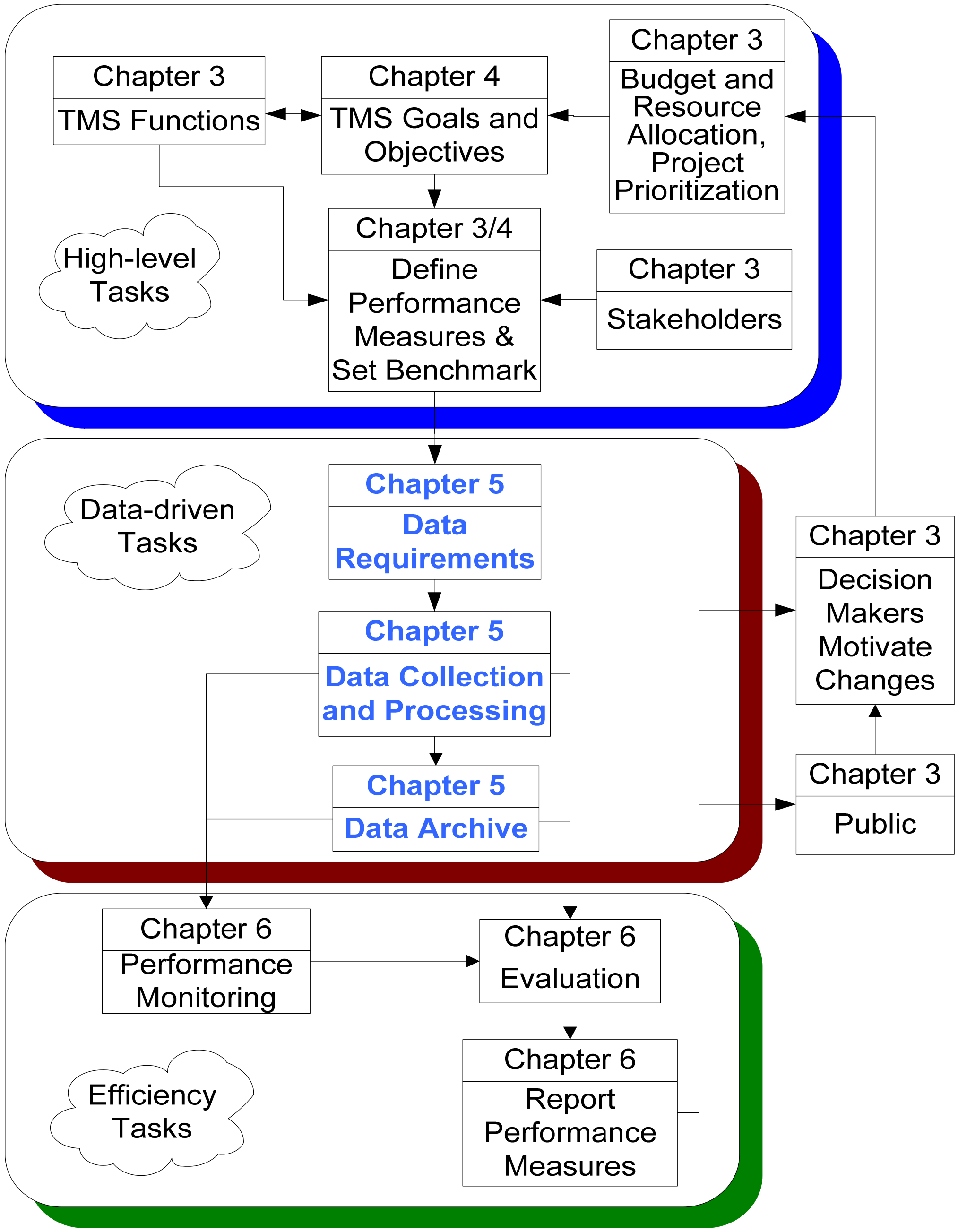
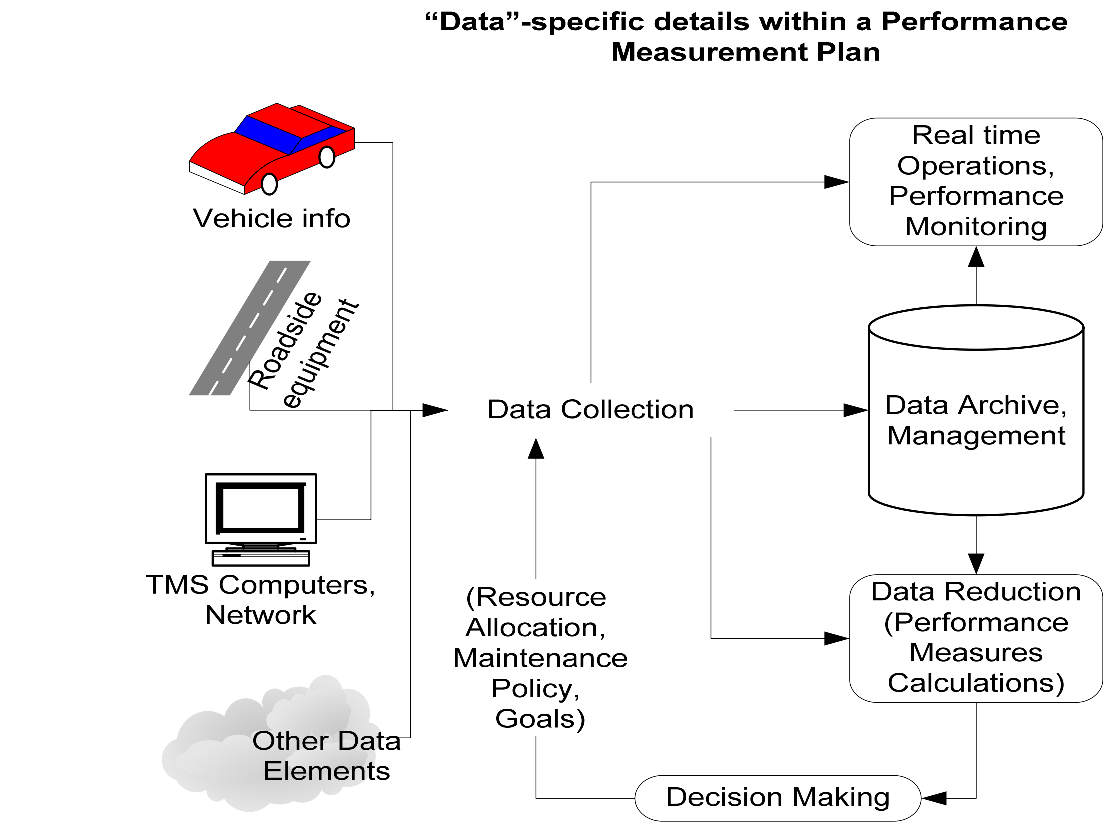


Figure 5-1. Data-Driven Tasks of Performance Measurement



Note 1: The same real time data is used in archiving, performance monitoring, and even some performance measure calculations that are similar to monitoring.
Note 2: Archived data provides the historic context to real time operations, and performance monitoring.
Note 3: Arrows indicate the direction of data flow.

Figure 5-2. Key "Data" Specific Aspects of Performance Measurement

5.1 Data Requirements for Performance Measures

TMS data is collected as event logs (e.g., incidents, hardware/field device monitoring, etc.), or in a specific format as determined by specific needs (e.g., travel time study, turning movement counts, etc.). Table 5-1 maps a list of the common data elements to TMS performance measures and programs explained in other chapters. As appropriately stated by Varaiya (1997),

The list of transportation system performance measures and outcomes is endless. Once you include such indirect impacts as economic development, community well being, and land use patterns, it becomes obvious that nothing can be excluded from the list.

The NCHRP report 311 (Shaw, 2003) alone catalogs a long list of about 70 performance measures for the operational effectiveness of highway segments and systems. Compiling a comprehensive matrix associating all the measures with all possible data sets is practically infeasible, and is likely intimidate the reader. As an alternative, the following matrix presents select measures (or TMS programs) and data sets. The matrix columns represent the frequently deployed TMS programs (or their performance measures). The matrix rows represent the frequently collected datasets (or promising ones, based on upcoming technologies). The intention here is to provide an example for individual agencies to follow. Each agency should tailor this matrix for their specific programs, and measures. The relevant stakeholders should also be involved in the consensus building process (to select programs, goals, measures etc).

A number of potential issues related to assessing data requirements for particular performance measures exist. These issues are addressed in the next section.

5.2 Potential Issues Related to Data Requirements

Data requirements assessment for performance measurement is as much an art as it is a science. Considering the measurement of mobility as an example, the occurrence of two concurrent incidents in a region is likely to disrupt traffic mobility much more significantly than just a single incident. This may be the case, even if the second incident did not occur along the corridor or region of interest. Another example is the indirect effect of local economic factors on any of the transportation system. These effects also usually vary significantly from one time period or region, to another. For these reasons, broad guidelines are provided here to tackle these potential issues.

Data should be relevant, timely, and cost-effective in order to be useful. Absence of any of these facets would pose a burden to the data-collecting agency. Relevance of the data depends directly on the needs. Only data assessed as a requirement for some purpose should be collected. If an incident management program is being evaluated, data related to incidents for time periods before, during, and after its occurrence are likely to be required. If the data during an incident could not be collected, the relevance of even the available data would be lost. The relevance of data elements should account for spatial relevance, temporal relevance, and normalcy for the region. One report (Turner et al, 2004) states data relevance succinctly: "…to be effective, performance monitoring must also gather information on activities and events that can affect system performance."

Table 5-1. TMS Programs, Measures and the Relevant Data Needs

Data \ Performance Measure/Program	Traffic Surveillance	Mobility-travel time (Congestion)	VMT	Safety-incidents	Incident Management	Information Dissemination	HOV study	Ramp Metering	Arterial Mobility	Transit TMS	Special Events	Other TMS Outputs	Environment Analysis
Traffic volumes	X	X	X	X	X		X	X	X		X		X
Speeds	X	X			X		X	X	X	X	X		X
Vehicle Classification	X	X	X	X			X						X
Probe data (AVL, GIS, AVI), and scheduling	X	X				X			X	X	X		X
Incident/Event log (VMS, HAR, 511, HOV/RHOV open time logs)	X	X		X	X	X	X	X	X	X	X	X	X
Travel time	X	X			X	X			X	X	X		X
Maintenance log		X	X	X	X	X		X		X		X	
Signal data (light times, offsets, queues, preemption)	X				X			X	X	X	X	X	
Weather data	X	X		X	X	X					X		X
Video or image stream	X				X	X					X	X	
Air/Water/Noise pollution						X							X

Notes: This table maps data to a variety of TMS-wide measures, specific program measures, and even entire TMS programs. Agencies should perform a similar mapping for their specific measures, and programs, with active participation from relevant stakeholders. ♦ Metadata (defined as data or context describing the data) is often given low priority or not even collected properly. This is very important for **all** later uses, when the persons, equipment, weather are all not available to collect data again. Metadata is therefore an important component of all programs and measures.

Timeliness requires that the data be collected, reduced, formatted, and so forth within the schedule allowed, so that performance evaluation and reporting are not delayed. Such delays usually indicate bad performance on the part of the agencies. However, such situations could also arise sometimes due to funding or personnel availability constraints, poor definition of data requirements, or lengthy procedures for collecting and processing the data. Cost-effectiveness of data collection is not limited only to the associated short-term dollar value. In-house staff resources, equipment availability and time schedules are some important factors to be considered by an agency before deciding on the particular method of data collection or on an external contractor. Further, involving a contractor at any stage of a system development or operation, including data collection/archiving have very similar advantages and disadvantages. These issues from the TMS maintenance concepts (Vick and Sumner, 2002) are presented in Box 5-1.

TMS Category	Agency		Contractor	
	Pros	Cons	Pros	Cons
Control Center	In-house system skills remove dependencies on possibly unstable businesses. Gives career path to employees.	Difficult to keep and reward competent programming staff. Long hours not popular.	Already has system knowledge and can more readily deal with software bugs. Wider skill range. Not subject to union restrictions. More flexibility in staffing choices.	Expensive. However, true cost comparisons need to include all costs, pensions, benefits, etc.
Roadside	Agency often owns much of the needed equipment. Can coordinate schedules with other Agencies.	Requires a staff increase sometimes institutionally unacceptable. Private contractors can be more responsive.	Reduces Agency staff needs. Provides wider range of skills. Can more readily operate outside of office hours.	Pricey and the Agency can loose some control over job priorities. Contractor needs real estate and plant.
Communications	In-house skills provide more job satisfaction for Agency employees	Difficult to keep and reward competent staff. Specialized equipment, expensive and little used.	Has system knowledge and likely to be more timely in response. Can rent specialized services and equipment quickly.	Expensive.

Box 5-1: Issues of Using In-house vs. Contractor Employees

Another issue particularly relevant to data collection is the sensor coverage. Adequate and representative sensor coverage of the region is required to obtain all the relevant data. Some performance measures are focused at one point in a geographic region, such as volume of traffic crossing a bridge. These do not require further sensors other than for back up, in case of the failure of the primary sensors. Other performance measures are based on intersection volumes, such as turning movement counts. Yet other performance measures such as corridor or regional level mobility and safety demand adequate data from several representative locations. For example, a freeway corridor should be monitored at the ramps, basic freeway sections (regions between ramp and weave sections) and specifically at the bottlenecks, at a minimum, to provide a representative picture of the corridor mobility. Depending on the geographic area (point, corridor, region, etc.) covered by the performance measure, corresponding representative sensor coverage is necessary.

5.3 Overview of Data Collection Techniques

It should be noted, before diving deep into the data collection details, that a number of potential issues exist in this area. These are explained in section 5.6, and readers interested in data collection techniques are urged to at least browse that section before proceeding further.

Data can be obtained using three distinct instruments (Turner et al, 2004):

- Data Archives (including information sharing with external agencies)
- Modeling and Estimation
- Manual or Automated Data Collection

Data archival and retrieval is a broad and important instrument to obtain data, topics that are discussed separately in Section 5.4. Wherever data from external agencies (such as police departments) are obtained, either from their archives or through direct data transfers in real-time, sufficient additional information such as metadata, definitions, data quality, and coverage should be obtained by the TMC. Wherever feasible, the agencies utilizing the data usually should share the budget for collecting the data and maintaining the equipment. One report (Zimmerman et al, 2001) details a number of issues related to data sharing and how various agencies cope with the issues/concerns such as data ownership, data-sharing policies, revenue sharing and so forth. Excerpts from this report are presented in Box 5-2.

The term "data" here encompasses digital, video, and verbal forms of information.

- Agencies have two major objectives in sharing their data with private sector and other public sector recipients: improving transportation operations through better interagency coordination and optimizing the use of the transportation system by providing information to travelers. Enhancing interagency coordination was the top-ranked motive for data sharing.
- Even though their motives are different, public and private sectors are active participants in use of traveler information as a transportation management tool. Almost all agencies directly provide information to the public typically with VMS, HAR, kiosks, and interactive voice response telephones. Although agency data are a fundamental source, private providers generally need to enhance public data before they are marketable. The most common types of information provided are traffic and road conditions, incident information, and planned construction information. Transit data are generally less useful to private providers, and only a third of them report transit delay information.
- Agencies who have data to share protect their interests by placing restrictions on access to data, but firms generally do not find these conditions to be onerous. Two or more conditions on access are common, the most frequent being acknowledgement of the agency as the source of the data when distributed to the public.

continued on next page

Continued from previous page

- Formal policies on data sharing were reported by half the surveyed agencies, and several more have plans to issue one. The principal advantage of a formal policy is that it provides a process for handling requests for agency data.
- In addressing the costs associated with the data-sharing process, agencies frequently employ two or more cost recovery mechanisms in data-sharing relationships. Most frequently agencies require the receiving party to cover its own cost, such as hardware, software and communications cost to connect to agency data sources. The second most popular mechanism involves a private firm sharing its "value-added" information with the agency.
- The two most controversial topics in the private sector's relationships with agencies regarding agency data are revenue sharing and exclusivity.
- The idea of revenue sharing is optimistically viewed by many agencies, although in practice it has not had much success. The private sector tends to oppose revenue sharing either because of practical difficulties in administering it or because it violates the principle that public data should be available to all taxpayers for free.
- Exclusivity: A few agencies see value in assigning to some other entity the burden of dissemination of agency data. Private firms are generally opposed to exclusive arrangements because they constitute monopolistic, anti-competitive franchises and because they violate the principle of right of access to data collected at taxpayer expense.

Box 5-2: Summary Details of Some Important Data Aspects

Modeling and estimation, especially from simulations, is another broad and important topic for data generation. The necessary calculations are usually built into the models to output the measures. Modeling and simulations also require a vast amount of data for setting up the network, calibrating and validating the models. The network data are obtained from the inventories maintained by the TMC regarding the roadway geometry and assets such as sensors, VMS signs and so forth. The traffic data for calibration and validation are similar to other data used for measuring performance, all of which are explained below in detail. Some of the modeling and simulation details are covered in section 6.3.

Collecting data from the field directly encompasses a number of different methods:

- Manual collection systems
  - Events, and maintenance reports
  - Accident reports
  - Surveys and assessments (customer satisfaction, evaluating a performance measurement system)

- Short term traffic data

- Automated detection systems
  - Data logging systems (hardware, field device, network conditions, data quality)
  - Traffic data (volumes, speeds, travel times, vehicle classification)
  - Weather and Environmental sensors

Field data collection made for transportation management can be classified broadly into manual and automated data collection systems. Most of the data elements could require or encompass both the manual and automated systems, but are classified based on their predominant nature of being acquired. For example, a number of scheduled maintenance details may be filled in by an automated system, yet is likely to require supervisory human intervention before filing to improve data integrity. Further, for all the data elements, proper metadata should always be identified and collected, which could be either a manual process or an automated process.

Manual Data Collection

Information regarding events, metadata of all data/equipment, maintenance reports, accident reports, surveys and short time traffic data are all usually collected on an as-needed basis. These data elements sometimes present a wide range of variability over time and space, and consequently, their automation is almost impossible. Details regarding these data elements are presented in this subsection.

For manual as well as automated data collection systems, the data elements to be collected and their formats depend on the overall primary goals of the TMS. Both planned and unplanned events that disrupt traffic networks as well as the extent of spatial and temporal disruption should be recorded for accurate performance measurement and reporting. These event-related data elements are similar to the accident data elements explained later in this subsection.

Metadata encompasses all the data pertaining to the context of the collected data. Metadata are important to monitoring and fixing potential deficiencies. Metadata also usually involve the spatial locations of the sensors and the time relevance of particular data elements. Spatial details should be preserved in GIS or other comparable digital formats that allow expandability, scalability and analysis capabilities.

Vick and Sumner (2002) clearly explain the need for a well-organized and efficient maintenance program for a TMS, irrespective of the actual nature of the maintenance system itself. They further explain details of an Asset Management System (AMS). Although barcodes, tags and automated event logging are all recommended, a number of these elements require manual intervention to collect and upkeep the data. They also recommend that the agency maintain an inventory down to the lowest level of device repair or replacement. For more detail, read Guidelines for Transportation Management Systems Maintenance Concept and Plans.

Accident reports usually are collected by emergency personnel and/or incident management teams and are archived for later purposes. The data elements that are collected vary broadly from place to place, depending on the time and resource availability, as well as the reporting needs stipulated by the agency for specific purposes. At a minimum, the transportation agencies should attempt to collect the following data elements:

- Dates of incidents as well as their start and end times
- Agencies responding to the incident and the response times (Note that there are several definitions for these response times, and for other data streams like traffic speed. Although it is desirable to have all the agencies collect similar data, for comparison and effective benchmarking purposes, the definitions employed in any locality depend finally on the goals and measures deemed important by those local agencies, elected officials, and the public.)
- Number of vehicles involved
- Accurate location of the incident, and possibly the extent of subsequent traffic disruption (Note that this is again a very broad area. Traffic volumes, speeds, delays (travel times), lanes/shoulders/median affected, queue lengths, secondary incidents, capacity reduction due to rubber-necking, signal coordination disruption, signal cycle failures etc. are a few of the several possibilities. The particular data collected depends on the agency goals, measures and resources available.)
- Injuries and fatalities
- Nature of the incident (hazardous materials, fires, minor incidents, multi-vehicle incidents, bridges/tunnels, etc.)

VDOT is in the process of measuring the performance of incident-related activities of a TMC (Wilbur Smith Associates, 2004). Based on this compilation of the existing data collection standards in many regions, the aforementioned data elements are proposed as a minimum for all TMCs. Most emergency agencies are required to collect many more data elements because of legal needs.

Surveys and assessments (both internal and external) usually are conducted on an as-needed basis. The focus of these surveys is to measure the customer satisfaction of agency performance in various programs and goal areas, such as mobility (congestion), safety, information services, incident management and so forth. Recently, customer satisfaction has become a high-priority goal for a number of agencies (Hyman, 2004). Many surveys can be found in published reports on the World Wide Web (WWW). For example, George Mason University (GMU) conducted a survey for the Partners in Motion Program to evaluate the customer satisfaction from the SmarTraveler (Web-based traffic information dissemination program) in the Washington, D.C., area (SmarTraveler survey). The broad areas covered by this survey are presented in Box 5-3. Another example is the customer survey cards maintained by the safety patrol (Freeway Incident Response Team – FIRT) in the Hampton Roads region, presented in Box 5-4 (FIRT Consumer Feedback cards).

- How customers became aware of the SmarTraveler Web site.
- How often customers access the Web site to get information before leaving for work, before leaving office and for non-work trips.
- How often customers access the Web site for information, for various reasons/circumstances such as road construction, bad weather, running late, rush hour and so forth.
- How customers characterized the information, such as current, accurate, ease of obtaining information, details, coverage of highways and so forth.
- How customers react based on the information obtained, such as change trip time, trip mode, destination, trip route and so forth.
- Benefits observed by the customers, such as travel time, reduction in frustration and so forth.

Box 5-3: Example Customer Survey Questions

- For what reason did you need assistance?
- How did FIRT driver know you needed assistance?
- How long did you wait for the FIRT driver?
- Did the FIRT driver assist you in a courteous manner?
- Overall, how would you rate the FIRT service?
- What value would you place on the service you received from the FIRT program?
- Should this service be expanded to cover more freeways in Hampton Roads?
- Additional Remarks

Box 5-4: Example Customer Survey Questions

Periodic assessments also are required for evaluating and improving the performance measurement program, which is covered in Chapter 3 of this handbook.

Short-term traffic data also are collected manually, wherever automated equipment is not available or to calibrate automated equipment in the field. These types of data usually include traffic volumes (including turning movements at intersections), vehicle classification, vehicle speeds and travel times. Many traffic-engineering books (e.g., Garber and Hoel, 2001; Roess et al, 2004) explain the various traditional methods/equipment for obtaining these data elements. Manual counting in the field or through video archives and pneumatic tubes are popular ways of obtaining traffic volumes. Floating-car technique, average speed technique, moving vehicle technique, license-plate observations, video data and Laser/Lidar (Laser expands to light amplification by stimulated emission of radiation; Lidar expands to Light detection and ranging) guns are some of the popular methods of obtaining speed and travel time information. Brief descriptions of these methods of data collection follow:

Manual volume data collection could be done using pencil and paper, mechanical counters or advanced electronic counters. Advance electronic counters can sort the information into bins as required by the user and usually keep track of time.

Pneumatic tubes are laid on the road and secured to obtain volumes, speeds, vehicle classifications, axles and so forth depending on the configuration and the capabilities of the electronic counters associated with them. Video streams of the traffic also could be archived for later manual interpretation at the office.

In the floating-car technique, the test car is driven along the test section so that an observer sees that the test car "floats" with the traffic. The driver of the test vehicle tries to pass as many vehicles as those that pass the test vehicle. The time taken to travel the section is recorded a number of times because a statistical distribution of this data is necessary to obtain the travel time.

In the average speed technique the driver drives the test car along the test section at a speed that, in the opinion of the driver, is the average speed of the traffic stream. Large data sets and statistical considerations are observed as in the above case.

Two observers with synchronized clocks review the license plates (or the video archives) for the locations at the beginning and the end of the test section. A sample size of 50 matched license plates is recommended for reasonably accurate results.

Video imaging with detectors drawn on the display also can provide average speeds of the traffic stream.

Lidar/Laser guns work on the Doppler principle and are similar to the speed-measuring guns used by the police. These can be used to obtain average speeds of the vehicles.

Usage of tag-readers or other automated vehicle identification (AVI) techniques at the beginning and the end of the test section also will provide travel time data. Geographic Positioning Systems (GPS) or cell-phones could alternately be used as probes in obtaining short-interval travel time or speed information. These probe-based solutions are new technologies that have yet to work out all standard procedures similar to the traditional approaches. Interested readers should review the Travel Time Data Collection Handbook for many more details on these techniques and also other emerging techniques such as aerial photography and so forth. (Turner et al, 1998). Portable data collection equipment such as the Smart Travel Van, based on advanced video detection, also are worth considering for a number of these purposes (Smart Travel Van documentation).

Two other valuable references for manual data collection for a TMS are the Manual of Transportation Engineering Studies (4th Edition) and the AASHTO Guidelines for Traffic Data Programs (1992). The former document is recommended by the Freeway Management and Operations Handbook for its extensive information regarding human resources needed, methods of data collection, types of equipment used, the amount of data required and the techniques available to reduce and analyze the data. Information relevant to statistics also is covered in this manual. The latter is in the process of being updated.

Reliable automated systems are not available for many other TMS data elements usually collected by people, such as vehicle occupancy, seat belt usage and so forth. These data continue to be visually collected by people either in the field or from a video archive.

5.3.1 Automated Data Collection

A number of important TMS data elements are collected in an automated manner. *The Freeway Management and Operations Handbook* (Neudorff et al, 2003) clearly states this:

> … the detection and surveillance subsystem of a Freeway Management System represents a potentially valuable data source for performance monitoring. Typically, the FMS generates massive amounts of data about the state of travel that are used by transportation authorities to effectively operate and manage their transportation systems, including traveler information. … These same data may also be applied at the state/regional tier, being incorporated into the transportation planning process for analyzing and evaluating alternative transportation improvements.

The same is also true with data from arterial systems. Asset inventory, maintenance data of TMS equipment and facilities and traffic data form the core data elements collected by a TMC. The TMC is the ideal place for collecting and archiving the work zone and event information for the region—although no specific examples have been found in the reports. Maintenance information, for schedules and actual breakdowns, including down times also should be collected by the agencies (Vick and Sumner, 2002). Traffic data from the sensors have been traditionally maintained by the TMCs. The traffic data collected by the sensors in an automated manner are based on the roadside and in-vehicle sensors, most of which have been mentioned in the manual data collection process as portable equipment. The Minnesota DOT tested a number of roadside traffic surveillance technologies/equipment under the Minnesota Guidestar program (Minnesota DOT, 2002). The report also presents the costs and deployment issues for these various technologies. The detector-testing procedures could be adapted to other similar traffic data-collection equipment.

Technologies such as cell phone probes, GPS and other wireless data are still emerging. They are likely to provide more information, in terms of spatial coverage and data elements recorded. But complete methodologies to reliably obtain information from all these sensors are not yet available. Hence, stakeholders and agencies should use discretion in adopting these technologies at this point in time.

Interest in weather data is increasing within the Transportation community (TRB, 2004). Weather and environment sensors are sometimes maintained by the TMC—as Road Weather Information Systems (RWIS). The real-time data used for traffic control, roadway maintenance, evacuation, traveler information and so forth could be archived, along with other important details, for post-event analyses. Data currently collected and used include temperature, precipitation (type and amount), visibility, pressure and pollutant information (including ozone levels). All weather data are usually logged in an automated manner. They can also be obtained from other agencies that maintain weather stations. Nearly 1000 Automated Surface Observing System (ASOS) sites that record regular hourly weather data are located throughout the country, mainly at airports. They also record at shorter intervals during special weather conditions.

Direct data collection (manual collection much more than the automated collection) is an intense, resource-consuming process (including time, funds and human expertise). Therefore, the effort should focus on using existing data, either in-house or external, to the maximum extent possible. The details of data archiving are presented in the next section.

5.4 Data Processing and Archiving

What is archiving? And why should data be archived? Archiving is the technical terminology used for storing, or saving (usually data), for potential later use. Significant uses might include performance measurement (of the system and the data quality), planning applications and reporting purposes.

Several studies have been undertaken in the past to understand the various important components and implementation aspects of archiving data for transportation systems. A forthcoming publication (Smith and Venkatanarayana, 2005) scans and summarizes a comprehensive list of these studies and takes a peek at the future. The important components and issues related to archiving are presented here.

ITS data usually are collected in an automated manner and stored as a data log (technically referred to as Online Transaction Protocol [OLTP]). That is, data are time stamped and recorded as they are generated. Such data logs include traffic data from the detectors (traditionally, the inductance loop detectors), signal controller data, VMS (Variable Message Signs) message logs, incident data, event information (construction, maintenance, work zones, etc.), HAR (Highway Advisory Radio) logs, and so forth. If such data are stored directly as generated, future searching and querying to obtain the data of interest is difficult. For this reason, the data are processed before they are archived. In contrast to OLTP, this improved data archive that allows querying with a focus on analysis is referred to as Online Analytical Protocol (OLAP). Considering the potential uses of data archiving, the ITS National Architecture included the Archived Data User Services (ADUS) and enhanced the field of data archiving within transportation. These services also are referred to as Archived Data Management Systems (ADMS), in which the archived data along with or without further information services are made available to other agencies.

The data logging occurring at the TMC as the raw data comes from the field or are noted by an operator or other personnel is referred to as an Operational Data Store (ODS). This ODS could be in any simple format, such as flat files or simple databases, to facilitate operations. This data is then extracted, transformed as appropriate, and loaded into sophisticated databases that allow much greater analysis capabilities—a process called Extraction, Transformation, and Loading (ETL).

The extraction and loading processes depend directly on the format and technology of the ODS and the final data storage. An extensive treatise on these subjects is beyond the scope of this guidebook. The transformation process involves many other critical details of importance to a TMC. The data transformation is focused mainly around these topics:

- Data staging and segregation
- Data aggregation (both spatial and temporal)
- Data quality screening
- Data imputation
- Data characterization

5.4.1 Data Staging and Segregation

The process of "holding" a data set in a server while all the transformations are performed is called data staging, which may be accomplished using an intermediate database, through the use of comma (or tab) separated text files or any other format. The data format also may be different between the ODS and the final warehouse. It may further be algorithmically easier to maintain the data in a particular format for different processing during the transformation. Data segregation involves the selection of only particular data elements of particular equipment for further processing, which could be necessary due to outdated data fields, decommissioned equipment or even data irrelevant to the programs supported by the ADMS.

5.4.2 Data Aggregation

Aggregation may be defined as combining data from different locations or time periods and presenting (or archiving) as one unit. Data aggregation is performed over the time dimension and/or the space dimension based on the minimum "granularity" of data required for later analysis. For example, a station may be defined as the combination of all the lanes on a roadway, at a particular mile marker and direction. And a link may be defined as a stretch of roadway between two given mile markers. Then, data should not be aggregated to the link or station level in an ADMS if they are needed to support lane-level analyses. The aggregation decision also needs to consider the available server space and speed, although these constraints are increasingly becoming inconsequential with advancements in electronics and computer technology.

Studies have been conducted to investigate the determination of an "optimal" static or dynamic time aggregation interval (i.e., the aggregation intervals vary from one time to another). Statistical procedures to determine the optimal aggregation intervals for different time periods of the day have been studied. This determination depends on whether the variability among the various data elements within a considered aggregation interval is small or large. If the variability is large, smaller or no aggregation is recommended. If the variability is small, higher aggregation, such as 1 hour, is recommended. On the other hand, dynamic aggregation periods like 11 minutes or 26 minutes could make further aggregation or comparison of such data difficult in a fielded ADMS.

Data summarization also is a form of aggregation, where summaries for time periods or spatial regions (e.g., links or corridors) other than the lowest granularity also are maintained in the database. The frequency of user requests for such aggregated data, the ability to standardize such time or space intervals, and the cost of such processing (time delay) during the time of request determine whether summarization is beneficial to the ADMS. For example, transportation professionals often need the average annual daily traffic volume at a location. Creating these measures from the lowest granularity data (such as 1-minute intervals) is quite time consuming. Such well-defined and frequently requested aggregations are better suited for summarization.

5.4.3 Data Screening

The quality of data in an ADMS can be verified only if an alternate, validated source of comparable data is available. Obviously, this requires redundancy in all data elements and is not economically feasible. What is feasible, however, is to check each data element to determine if it is a feasible or reasonable value for the location and time. This form of checking often is referred to as data screening. In addition, it often is incorrectly referred to as data quality screening, when in fact it is the process of screening for feasibility. Several research studies suggest different empirical rules for identifying unfeasible traffic data from point detectors. Detector readings that result in unfeasibly high average vehicle lengths, volume measures with 0 speeds, and high occupancy rates are some of the frequently used screen tests recommended for application. These are easily implemented within an ADMS and serve to effectively remove clearly erroneous data. An agency may adopt more advanced techniques such as "outlier" traffic detection based on fuzzy-clustering, entropy statistic, and so forth depending on the level of comfort among the stakeholders and the applicability to their region.

Finally, given that a fine, indefinable line exists between true outliers and unfeasible data, ADMS's should leave bad quality data as flagged and unaltered in the archives. That is, wherever "bad" data are identified, instead of removing it or replacing with other estimated data, the data should be stored as is and flagged using other fields.

Test 1—Maximum Occupancy Threshold: Occupancies higher than 90 percent are usually infeasible in most traffic conditions.

Test 2—Overall Maximum Volume Threshold: The maximum volume carried by a roadway cannot be more than its absolute capacity.

Test 3—Positive Volume with Zero Speed: This (and other similar) artifacts of the detector/controller/software system need to be monitored on a case-by-case basis.

Test 4—Maximum Volume Threshold with Reported Occupancy of Zero: This test can be applied for other occupancies also. The volume and occupancy should normally show a correlation.

Test 5—Average Effective Vehicle Length Infeasible: Based on the speed, volume, and occupancy reported by a detector, the average vehicle length can be calculated using fundamental traffic flow theory principles. Records exhibiting abnormal average vehicle lengths can be safely discarded as bad data.

Box 5-5: Example Traffic Data Screening Procedure Rules

5.4.4 Data Imputation

Imputation is the process of filling in the gaps that occur from missing data due to equipment, software, or communication failures. Several algorithms and approaches (e.g., time series models, expectation maximization, etc.) have been, and are being, studied to determine the best manner of imputing missing traffic data. Some form of imputation usually is a necessity for using data in further models or simulations. The complexity of understanding these algorithms, applying them, and getting effective results depend on the staff resources available as well as the interests and applications of the stakeholders. The research techniques include simple historic averages, various pair-wise regression models expectation maximization (EM) algorithm, "factoring-up," straight-line interpolation, polynomial and kernel regressions, methods based on genetic algorithms (GA), time delay neural network (TDNN), and locally weighted regression (LWR) models. Interested readers may follow up with material available in the references (Smith and Venkatanarayana, 2005).

Historic average, by individual day of the week or grouped separately as weekdays and weekends, provides a good estimate of traffic behavior in many locations. If one or two minutes of data are missing in an entire day, imputing with historic average provides a complete data set for the day, without distorting the actual picture.

On the other hand, using historic average for imputing data for half the day could severely distort the true picture.

Box 5-6: Example Imputation Procedure

Imputation is not always a preferred form of accounting for missing data. For example, the AASHTO guidelines (1992) do not recommend it. To ensure the principle, Truth-in-Data is followed. Also, reporting data integrity (i.e., the percentage of imputed data) and maintaining original data are good practices. But often, incomplete datasets are not useful in carrying out any analyses at all.

5.4.5 Data Characterization

Data characterization refers to analysis intended to extract and store information from data in the ADMS. An example from ADMS Virginia is provided in Box 5-7. Stakeholders could specify other new forms of data characterization for improved usage of the archives.

In ADMS Virginia, a new characterization referred to as the "normality value" was introduced based on prior research. Based on the historic data obtained for a detector for the particular time of the day and the day of the week, the probability of occurrence of the current traffic data record is determined. This value is used within ADMS Virginia to allow stakeholders to easily identify unusual traffic conditions for further analysis. In addition, the characterization can be used to select only "normal" traffic when building typical traffic patterns through historical averaging.

Box 5-7: Example Data Characterization Procedure

A number of the data transformation functions previously described are specific to traffic data. Yet, these principles are widely applicable to other data streams as well. The final step in the data archiving process involves storing the data, which can be achieved using a number of different formats, including traditional relational databases and other modern formats, such as cube design. An example star-schema of a relational database is presented in Figure 5-3. A central fact table keeps growing over time. The support tables are usually static and explain the variables involved in the central fact table.

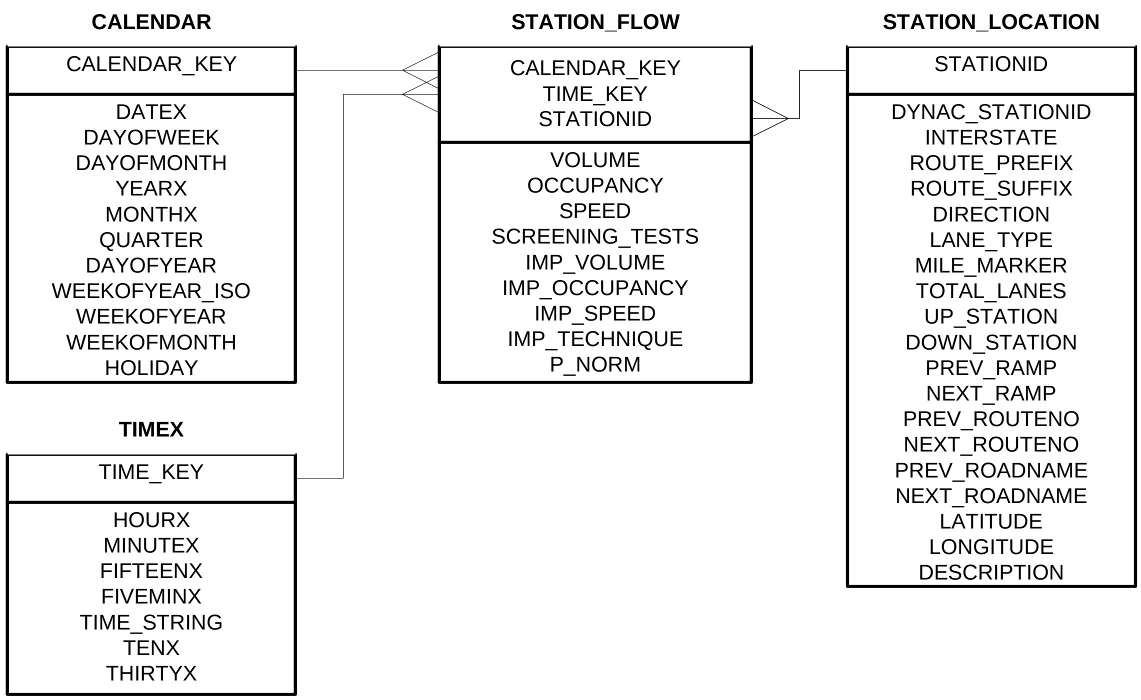


Figure 5-3. An Example Star-schema Design

Shekhar et al (2002) explain the cube design in detail. In summary, the traffic data are archived by time of the day (TTD), day of the week (TDW) and location (S) as the dimensions. Different combinations also allow the selection of month of the year (TMY). This format is shown in Figure 5-4.

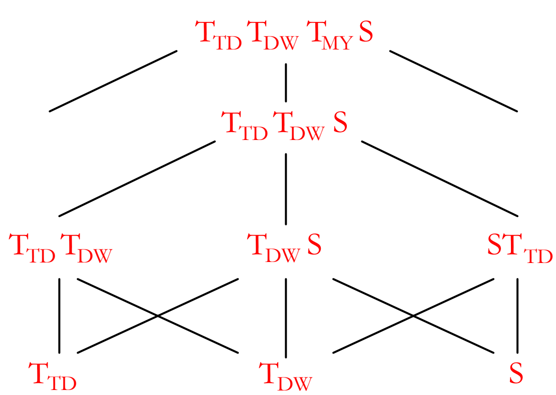


Figure 5-4. Cube Design

The agency should select a format suitable for its purposes. Based mainly on available literature and commercial, off-the-shelf software, as well as available human expertise, a relational database management system (RDBMS) is recommended. Where the experience and expertise of the database personnel greatly exceed average knowledge and know-how, other convenient (but often difficult, due to their uncommonness) formats may be attempted.

The development and maintenance of an ADMS goes one step beyond simple archiving. An ADMS provides a systematic data and information retrieval process for all the stakeholders, using some software for the GUI (graphic user interface) as the front end and the archive as the backend. Once such a system is in place, it helps coordinate activities within and outside the agencies for improved performance monitoring. Data should be made available over the Internet for improved accessibility. The initial development of an ADMS involves considerable stakeholder input, coordination, planning and software development. A number of documents related to ADMS development are available from the Web sites of PeMS (California) and ADMS Virginia (PeMS, ADMS Virginia).

5.5 Data Collection and Archiving Issues

A number of issues pertaining to data collection and archiving should be considered by a TMC or other responsible agency. Various sources (Turner et al, 2002 & 2004; Neudorff et al, 2003) acknowledge these issues, but often do not have immediate solutions applicable to all TMSs. Rather, care should be taken so that none of these issues become significantly prominent and compromise the usefulness of the data. The various potential issues related to a data collection plan, as detailed in the Freeway Management and Operations Handbook (2003) are:

- Data to be collected (focus of the data collection may be a subgroup of the travelers, such as tourists)
- Frequency and schedule (time aspects of data collection)
- Data collection locations (spatial aspects of data collection)
- Data collection responsibilities (staffing issues and responsibility of stakeholders)
- Data management requirements

A number of these issues are best decided mutually by the stakeholders. The temporal and spatial vastness of data collection may be drastically reduced by the application of statistical experimental designs to select representative scenarios/situations. The entire dataset available may not be required for performance measurement purposes. A smaller but strategically positioned dataset might be sufficient. These and other key data-specific issues are listed and discussed as follows:

- Availability: Availability pertains to the amount of data, which usually is not of significant concern for automated data collection. For manual data collection, such as classification, turning movements, crash reports and so forth, if a sufficient amount of data is not collected, proper analysis may not be possible.
- Completeness: Whereas availability looks at the presence or absence of the required data, completeness looks at whether or not all the data elements are collected. If a particular data element is not collected properly, performing analyses and inferring results may become impossible. For example, if the number of vehicles involved in crashes or the exact help rendered by the safety service patrol (e.g., as gas, tire change, jump, etc.) is not recorded, the dataset would be incomplete to calculate the corresponding measures.
- Coverage: Coverage usually is applied to spatial representation of the data. For regional analyses (any amount of space that consists of multiple spatial units), a representative sample of data is

needed from all the spatial units. The non-availability of data from any one or more of these units would render the data and hence the analyses incomplete. A single spatial unit is the smallest amount of space for which a measure is reported. Examples could be a detector location, a corridor or a link between two signals and so forth. One report (Margiotta, 2002) states that only "22 percent of urban freeway miles in the 76 largest metropolitan areas had electronic surveillance in 2000."

- Quality: Data quality often is a serious concern among ITS professionals. Several white papers have been published and workshops conducted to cater to this aspect of data (Turner, 2002; Middleton et al, 2003; Margiotta, 2002; Neudorff et al, 2003). They discuss the implications of bad data quality on the agency/stakeholder usage of the data, causes and solutions to improve the data quality. Some of the causes stated for bad data quality are:
  - Type of equipment
  - Environmental conditions
  - Installation
  - Calibration
  - Inadequate maintenance
  - Communications
  - Equipment breakdown

All these items can be covered by the provision of adequate scheduled/breakdown maintenance and proper contracting for installation. Yet, these causes do arise from new technologies, and the agency should be aware of them to ensure mitigation. Further details are provided on how to detect and correct the errors in the data, which is beyond the scope of this manual. Readers should refer to the white papers published from the data quality workshops (Turner, 2002; Middleton et al, 2003; Margiotta, 2002). A 5 to10 percent error tolerance in the data is recommended for performance monitoring purposes. Agencies should account for proper polling of the data from the field equipment—an important issue since ITS data are collected continuously and data once missed are usually not retrievable. But adequate provision should be allowed in the design of the software, hardware (for cache memory) and databases to tolerate missed polling cycles.

As stated by Varaiya (Choe et al, 2002):

> … there is no substitute for accurate data and any agency installing and operating freeway surveillance systems, which are primarily designed for real-time operating strategies, must have a plan for intensive maintenance of the field and communications equipment.

The same holds true for arterial systems. Formalized maintenance schedule, funding and performance standards are recommended for implementation by the TMC (Margiotta, 2002). Maintenance costs should be included with operational costs during the life cycle development plan of a TMS. Calibration methods and benchmarks also are required for successful installation and functioning of equipment. Finally, the agencies should note that the usage of data could help improve the data quality by identifying problem areas more quickly (Turner et al, 2004).

Specific information regarding the cost of proper detector installation and maintenance is not available anywhere for use by practitioners (Turner et al, 2004). This report suggests improving the information availability in these areas as an action item. In summary, as stated by Dalton et al (2000), the "garbage in, garbage out" concept applies to the data used in a TMS performance measurement system. Quality of data and equipment reliability are very important for an agency to maintain.

- Standards: The various datasets and their elements collected are better standardized for a particular agency, through policy directives, if not for the entire nation. Standardization will allow for uniformity of data collection and hence their comparison over the years—irrespective of the equipment, personnel, changes and so forth. ASTM standard E2259-03a provides guidance for archiving and retrieving ITS-generated data (ASTM, 2003). Another standard regarding the traffic-related metadata "Standard Specifications of Metadata Content for ITS-Generated Data" is in the making. Subscribing to a standard in development is not advised because doing so leads to the purchase of equipment that soon will not conform to the latest standards. Agencies are recommended to consult the available (and even) draft standards for the data elements to be collected and the appropriate protocols for equipment interoperability and interchangeability.
- Reliability: The reliability of equipment or its dataset can be understood as the repeatability of the data collection to get similar results under similar prevailing conditions. Although reliability is closely related to quality and accuracy, it is different and impacts the maintenance requirements for the equipment. For detailed information on the maintenance concepts and plans, readers should refer to the TMC Pooled Fund Study report published by Vick and Sumner (2002).
- Variability: For the same data element (say travel time), different data sources (such as wireless probes, toll tags and GPS-equipped agency vehicles) are likely to produce data with different degrees of precision, accuracy and data quality. Depending on which of these sources are used for different times or locations, the agency could see variabilities in the results obtained, induced by the artifacts pertaining to the data collection source or equipment. Although no specific references confirming such variabilities have been published, agencies should be aware of such possibilities.
- Level of aggregation: On the whole, the TMC should consider an appropriate aggregation interval for its data archives in consultation with all the potential stakeholders who use the data. Wherever such decision has to be temporarily postponed due to the inability to adopt a policy, the raw data may be stored entirely.
- Experimental design: The temporal and spatial vastness of the data collection may be drastically reduced by the application of statistical experimental designs to select representative scenarios/situations. The spatial vastness of the data collection in a region has to be investigated on a case-by-case basis. At the minimum, accident hot spots and congestion bottlenecks have to be included for a corridor-wide or region-wide performance measurement. The agencies and stakeholders should together determine the representative spatial locations. For determining the minimum amount of data to be collected, a specific experimental design may be selected. In general a 2k Factorial design, as explained in Box 5-8, or other appropriate design may be applied. Interested readers can further refer to statistics books such as the one by Montgomery and Runger (2002).

Suppose there are k factors in an experiment, each with two levels. The total number of combinations of these factors is 2k. Although field data collection is not fully comparable to lab experiments, the factors of interest to the data analyst are quite similar. For example, analyses of an incident management system at peak times and off peak times, during normal weather and severe weather form an experiment with two factors, each with two levels. By considering data from all four possibilities, the individual factors can be effectively analyzed with the least amount of data collection.

Box 5-8: 2k Factorial Design Explanation

- Storage: The amount of data to be stored and the structure of the storage depend on the agency-wide policies and procedures for data management. When constrained by funding and human resources availability, a TMC may be inclined towards storing in the easiest form (such as data logs) or as simple text files. Although doing so works on a temporary basis, more hardware space may be needed, and the difficulty might surface when analyses are later attempted on the data. Universities in the region could alternately provide their expertise in channeling the data streams and providing an archive place, from where further research and other activities could obtain data. University of Virginia, University of California at Berkley and University of Washington are examples where the DOTs and the universities benefit mutually in this manner.
- Metadata are data or the context describing data. Complete metadata should be maintained along with the data, wherever feasible. This would include information such as who collected the data, what date and time the data were collected, any events in the region during the data collection (both planned and unplanned), weather conditions, particular instruments used, and so forth.
- Institutional and data-sharing issues: One report (Margiotta, 2002) informs that most TMCs and transportation departments desire improved data sharing. To achieve this goal, the data must be high quality, be highly reliable and also easily available. It also references another report (Zimmerman, 2001) that details the data-sharing techniques, mechanisms and policies that public agencies use. Important excerpts from these reports are discussed in detail in the performance measurement program in Chapter 3 of this handbook.
- Other: Miscellaneous aspects related to data that should be considered by the responsible agencies to efficiently collect/archive data include: Definitions of the same data may be different from one purpose to another (e.g., vehicle classification is defined very differently for the FHWA reporting purposes and for EPA's pollution modeling). Units of data collected/stored could be different from one agency to another. These differences should be appropriately communicated to produce a stable ADMS. Those in charge of collecting and making data available should be immediately informed of any changes in the performance measurement programs. Failure to do so could result in an agency spending precious resources to collect, reduce and/or archive unnecessary or redundant data. Data archival systems may want to consider optional back up and data retrieval systems as much effort is expended in collecting, processing and archiving important data sets for measuring system and agency performance.

Although a number of potential issues should be considered in collecting, processing and archiving transportation data, Turner et al (2004) state the obviously important point for agencies: "transportation agencies should not wait idly for a 'silver bullet' dataset or collection technique." They further suggest embarking on a performance measurement program (and indeed data collection, archiving, etc., to build upon their ideas) with the available resources and to improve upon the process in an evolutionary manner.

5.6 Best Practice Examples of Existing TMS Data Management Programs

It is very difficult, if not impossible, to specify best practices for any data-related activity because such objectivity rests on various factors not controllable by a TMC. The budget available for data activities, the personnel resources available during specific times and weather are some of these important factors. For this reason, data activities are a trade-off between what the agency requires, the resources available at disposal and the constraints imposed. For example, for a low-budget project highly accurate data may be necessary, but not feasible monetarily. Or an agency may have to meet a performance-reporting deadline irrespective of the prevailing weather.

Yet, it pays to have a high benchmark in mind based on the best practices with optimal trade-offs. This would allow the professional in charge of providing data with the necessary reins. Wherever adjustments, approximations or estimations have to be made, they can be adequately justified.

Some of the best-known and most widely used ADMS systems are PeMS (Performance Measurement System in California), TDAD (Traffic Data Acquisition and Distribution based in Washington State), DataLink (based on TransGuide system in San Antonio, Texas) and ADMS Virginia (based in the state of Virginia) (Smith and Venkatanarayana, 2005). Interested readers may want to obtain log-ins to these systems and assess the data and information services available therein (ADMS Virginia; DataLink; PeMS; TDAD).

California PeMS (Performance Management System) - California Transportation (Caltrans) and researchers at the University of California at Berkeley created PeMS, a freeway Performance Measurement System, that gathers raw freeway detector data in real-time from several of its participating districts. The calculation process is summarized below:

(1) "Aggregates 30-second flow and occupancy values into lane-by-lane, 5-minute values"

(2) "Calculates the g-factor for each loop, and then the speed for each lane. Most detectors in California are single loop, and only report flow and occupancy. PeMS adaptively estimates the g-factor for each loop and time interval."

(3) "Aggregates lane-by-lane values of flow, occupancy, and speed across all lanes at each detector station. PeMS has flow, occupancy, and speed for each 5-minute interval for each detector station (one station typically serves the detectors in all the lanes at one location)."

(4) "Computes basic performance measures such as congestion delay, vehicle-miles traveled, vehicle-hours-traveled, and travel times."

(5) The data archives are available through a password-protected Web site on-line at http://transacct.eecs.berkeley.edu. A user of the Web site can view various district maps and select an origin and destination. PeMS displays 15 shortest routes and travel time estimates for each for the current time as well as a future time, using an algorithm that integrates historical and real-time data. The travel time prediction algorithm combines historical and real-time data.

continued on next page

California PeMS (continued)

The data archive of PeMS was mandated by state legislation that required Caltrans to monitor the performance of their transportation system. "Because Caltrans has extensive detector coverage on freeways in several districts, they chose to archive existing data rather than manually recollect system performance data. Caltrans' PeMS data warehouse is unique because it is one of the few statewide operations data archives in existence" (14).

Box 5-9: California PeMS Archiving Data Example

5.7 Summary

This chapter presented data collection, screening and archiving and provided a link between data requirements and performance measures. This chapter also discussed various issues related to data collection, screen and archiving. In addition, best practices examples were presented to help understanding of data management in the TMS operations.

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Chapter 6. Performance Monitoring, Evaluation and Reporting

Chapter Purpose: This chapter provides (i) data analysis methodologies and processes related to performance monitoring and evaluation, (ii) various reporting techniques, formats and frequencies for TMS performance reporting and (iii) best practices on the TMC performance monitoring, evaluation and reporting. This handbook section deals with performance measures that use collected and archived traffic data, providing a more detailed discussion of performance monitoring, evaluation and reporting than that in Chapter 2. Chapter 7 then gives TMCs a self-assessment tool to gauge their performance measurement plans.

Figure 6-1 illustrates the flow of this handbook and highlights the topics for this chapter—performance monitoring, evaluation and reporting. Performance monitoring and evaluation are related to topics discussed in Chapter 5 as the data are used for these processes. Reporting is related to evaluation because the information obtained from the data analysis is reported to the public and decision makers.

As discussed in Chapter 2, performance monitoring, evaluation and reporting are the three crucial functions for the performance measurement program implementation. The outputs of these three functions ultimately determine the efficiency of the TMS. To review, these processes are defined as:

- **Performance monitoring**: Examines the actual system condition through observed data
- **Evaluation**: Analyzes the collected data and compares the results to benchmark performance measures
- **Reporting**: Provides information via various media to decision makers and the public

The function outputs and some important associated techniques are discussed in detail later in this chapter.

Performance Monitoring

Performance monitoring allows for the agency to visualize the system status through certain measures. It provides "current information on the condition and service level of the transportation system" (Cambridge Systematics, Inc. 2004) for the operational level personnel of the agency (e.g., the operators and supervisors). This definition certainly can be expanded to the TMS. This up-to-date information is then used by the agency to make immediate decisions. Furthermore, long-term monitoring (via archived data analyses) provides significant information to assist in planning future maintenance as well as future deployment decisions.

There are different levels of monitoring for each level of management within the agency. While the operators of the system may focus on the day-to-day operations on one section of a corridor or highway, the supervisor may focus on several corridors or the entire region. Managers generally monitor entire systems based on the high-level information provided in daily or weekly reports.

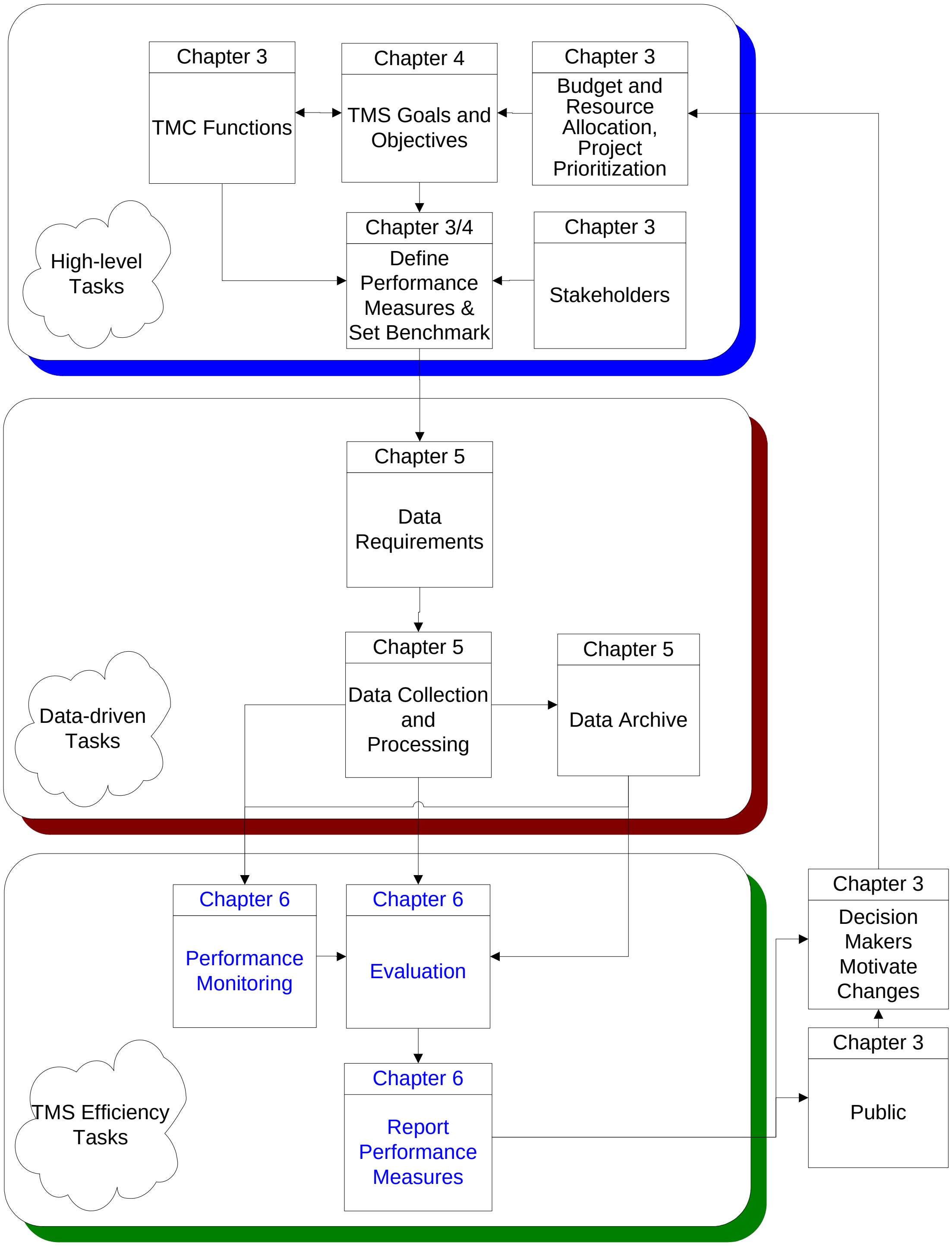


Figure 6-1. An Overview of a TMS Performance Measurement Program

Evaluation

Evaluation refers to the analysis of data, which involves "comparing the results with established performance measures, and assessing the performance of the strategies, policies, systems, and operator procedures that comprise the program" (FHWA 2003). Evaluation allows for the assessment of program effectiveness, identification and justification of areas for improvement and support of requests for additional resources.

TMS initiatives are "planned, designed, deployed, operated, and maintained with public funding" (FHWA 2003). Thus, it is of utmost importance to ensure that these funds are spent efficiently. Evaluation allows for the following actions:

- Determination of the actual improvement in performance
- Identification of problems that result in inefficient system performance
- Analysis and prioritization of alternative solutions
- Estimation of the benefits and costs of the TMS.

Evaluation is an ongoing process that occurs throughout the life cycle of a TMS. Some methods to aid the evaluation process include before-and-after studies and benefit-cost estimates, which are discussed in subsequent sections of this chapter.

Reporting

A good performance measurement program improves communication with decision makers and other agencies involved with the operation and management of a transportation system. Improving communication and tracking progress is possible through reports distributed to internal and external stakeholders, delineating relevant performance results that will aid decision making (FHWA 2003). Reporting practices also create a sense of internal accountability to the performance management program, as employees must meet deadlines for providing updated tracking data (TransTech Management 2003).

Though reporting techniques may differ, reports should clearly and concisely communicate results. The content and context of a report will depend on its purpose, however, the information must provide "a quantity and format suitable for the intended audience" (TransTech Management 2003). Often, different reports are generated for the various audiences the agency is serving. For external audiences a report is "a highly polished document, while internal documents may be more informal" (TransTech Management 2003). Regardless, reports must be presented in a comprehensive manner and should thus include visual displays of data that show trends, performance and data interactions. The frequency of publication varies from weekly to annually, but annual reports are the most common (Transportation Research Board 2003).

6.1 Performance Monitoring

Performance monitoring is primarily an operational task that allows real-time (or immediate) decisions to be made based on the up-to-date information produced by the system. There are multiple purposes for monitoring this information, such as:

- Identifying transportation systems or corridors with poor performance;

- Calculating the degree to which transportation facilities are meeting goals and objectives established for those facilities;
- Determining specific areas of management programs or systems that require improvements. (FHWA 2003).

An example of traffic performance monitoring comes from the Archived Data Management System (ADMS) Web site, which stores and allows access to Virginia traffic data. Figure 6-2 shows graphs from the ADMS Daily Report, which will be implemented in an upcoming build of ADMS. This report provides a way for state transportation officials to monitor the TMS status. The left graph, for instance, gives the Speed Index value, the average percentage of the speed limit traveled on area freeways for the previous week. The middle graph provides an updated incident count, and the right graph shows the percentage of stations available to collect data. Using these three performance measures, TMC officials can monitor system mobility, safety and the effectiveness of field equipment.

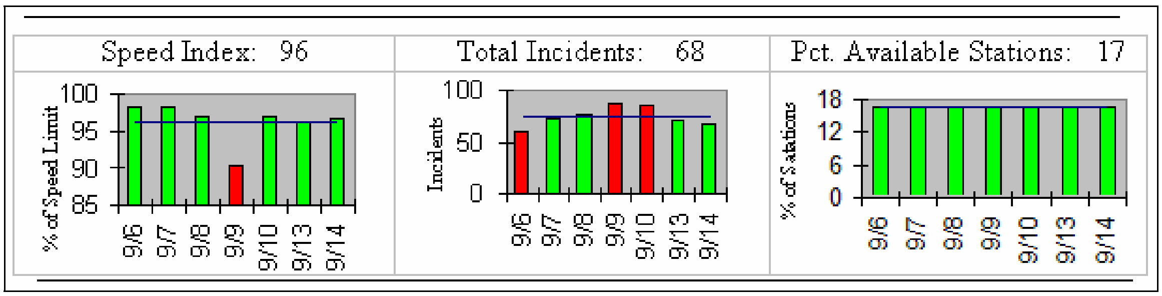


Figure 6-2: ADMS daily report graph examples

Currently, TMC operators as well as the public can monitor the performance of corridors and freeways through images obtained via traffic cameras, where they are available over the Internet, cable TV or other medium. For example, Figure 6-3 shows a screen shot of the New York City TMC's Advanced Traveler Information System. The Web site (http://www.nytmc.org) allows the user to view streaming video or a still image from a number of New York area intersections, thus providing the public with valuable, real-time traffic conditions at points around New York City.

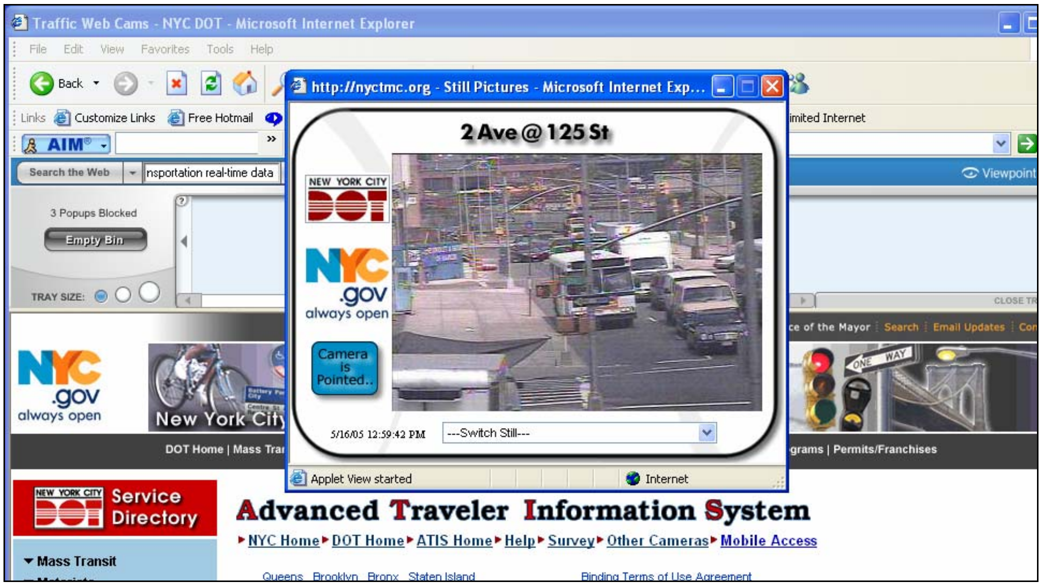


Figure 6-3: Real-time image of an intersection from the ATIS of the NYC TMC

The San Diego TMC displays another type of real-time information to both the public and TMC operators. Figure 6-4 exhibits the TMC's real-time map, which reports the current speed on any given section of highway or freeway.

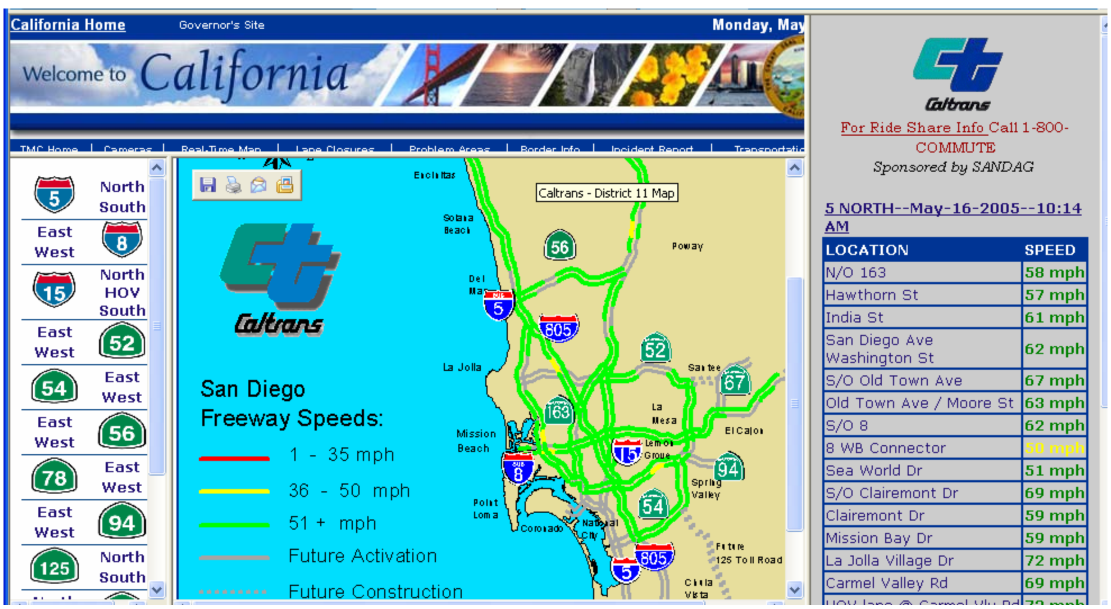


Figure 6-4: San Diego TMC real-time map

In this example, the menu located on the left allows the user to select a specific freeway and direction. Based on this selection, the current traveling speeds at various points on the corridor are displayed on the right side of the screen. A large, speed-based, color-coded map of the area also is displayed in the center of the screen, illustrating where construction will soon occur. In addition, the color-coded map can help operators identify segments where sensors are not working properly or extreme congestion is present.

For TMS or TMC managers, performance monitoring can be accomplished via a regularly released report. Such reports update transportation officials on the condition of specific TMS components (e.g., traffic sensors, signals, etc.) and overall system performance. For instance, officials in Northern Virginia are currently working to produce a daily report on the condition of the high-occupancy vehicle (HOV) facilities in the area, along I-95 and I-395. The report displays the previous weekday's speed and volume data for both morning and afternoon peak periods in the HOV lanes compared to the average speed and volume from the previous month. Figure 6-5 shows a typical data table from this HOV daily report.

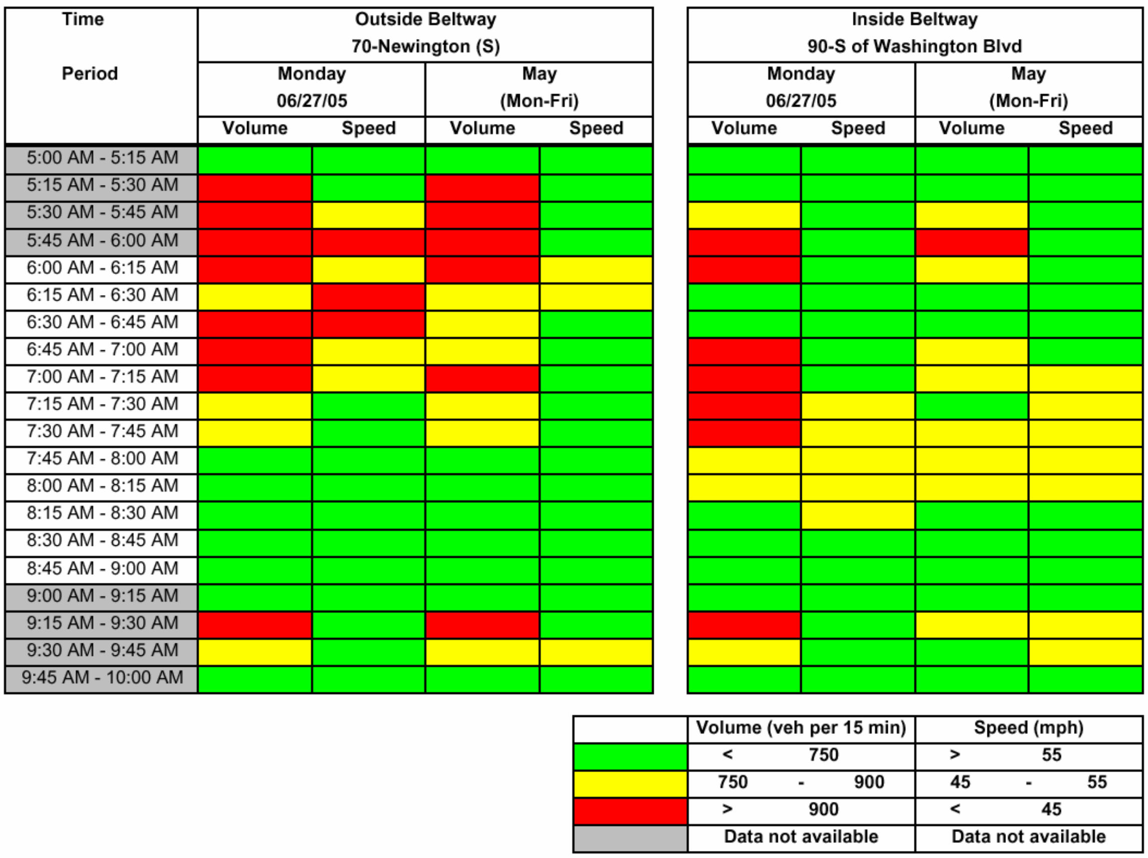


Figure 6-5: Analysis for HOV 3+ restrictions during morning peak in Northern Virginia

6.2 Evaluation

Performance evaluation is the analysis and manipulation of data to determine the conditions and effectiveness of the TMS. Different techniques, such as before-and-after and trend analyses, can help TMCs assess their performance and the ultimate results of their work. This section addresses various evaluation techniques and ways that TMCs use them for self-assessment.

6.2.1 Statistical Analysis and Comparison

Data analysis methods are an important part of performance evaluation. Agencies should consider the following criteria when selecting an analytic tool to evaluate their systems:

- Identification of the analysis context for the task at hand (i.e., planning, design or operations/construction).
- Determination of the appropriate geographic scope or study area for the analysis, including isolated intersection, single roadway, corridor or network.
- Capability of modeling various facility types, such as freeways, high-occupancy vehicle (HOV) lanes, ramps, arterials, toll plazas, etc.
- Ability to analyze various travel modes, such as single-occupancy vehicle (SOV), HOV, bus, train, truck, bicycle and pedestrian traffic.
- Ability to analyze various traffic management strategies and applications such as ramp metering, signal coordination, incident management, etc.
- Capability of estimating traveler responses to traffic management strategies including route diversion, departure time choice, mode shift, destination choice and induced/foregone demand.
- Ability to produce direct output performance measures such as safety (crashes, fatalities), efficiency (throughput, volumes, vehicle-miles of travel (VMT)), mobility (travel time, speed, vehicle-hours of travel (VHT)), productivity (cost savings) and environmental (emissions, fuel consumption, noise).
- Tool/cost effectiveness for the task at hand, mainly from a management or operational perspective. Parameters influencing cost-effectiveness include tool capital cost, level of effort required, ease of use, hardware requirements, data requirements, animation, ability to automate all or part of the process, etc. (FHWA 2003).

Although there are numerous methods to analyze the data, this subsection focuses on the more successful and frequently practiced techniques. These techniques include before-and-after evaluations, benefit-cost evaluations, analysis of trends and comparison group evaluations.

6.2.1.1 Before-and-After Evaluation

The most common method to evaluate the effectiveness is the before-and-after evaluation. This methodology studies the transportation network before and after the implementation of the new strategy or system (FWHA 2002). The same performance measures are used in the "before" and "after" conditions. An example of this type of evaluation is a study on the use of a strobe light in the red lens of a traffic signal. The purpose of the strobe light in this system is to draw the driver's attention to the traffic signal. The before-and-after study helped determine if this new technology prevents accidents (Cottrell 2005). The Freeway Management & Operations Handbook identifies several limitations to this evaluation method. These limitations include:

- Difficulty in distinguishing the effects of an individual improvement when multiple improvements were made at one time.
- Time required for drivers to adjust their travel behavior after the system or strategy is implemented. Thus, the true effects of the changes may not be measured if the "after" data are collected too soon.
- Susceptibility to errors caused by time-related factors because of the often long time lag between the "before" and "after" condition.
- Fluctuation of a performance measure over time until an extraordinary value is observed, which causes the performance measure to return more typical values. This tendency is called *regression to*

the mean. If the "before" or "after" condition exudes this tendency, it hides the true performance of the system.

Box 6-1 highlights a best practice case in which San Antonio TransGuide used the before-and-after analysis to evaluate their data.

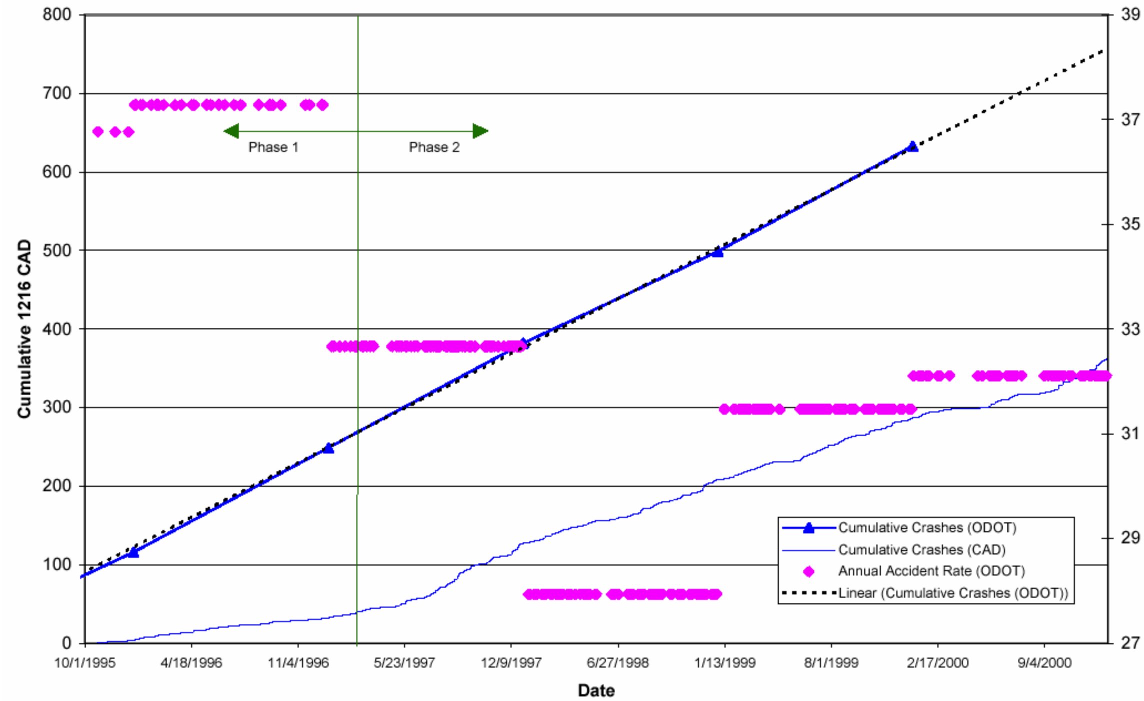
Best Practice: An example of this type of study was performed by the San Antonio TransGuide. There was a report created in 1997 by Russell Henk et al. entitled *Before-and-After analysis of the San Antonio TransGuide System*. This paper documents the impact of the system on crashes and incident response times during the first five months of operation and reports the findings of a survey investigation into driver response to the TransGuide system. Compared to the time period when the system did not exist, the study found that the system reduced primary accidents by 35 percent, reduced secondary accidents by 30 percent, reduced inclement weather accidents by 40 percent and reduced overall accidents by 41 percent.

Box 6-1: Best Practice of Before-and-After Analysis (Henk 1997)

6.2.1.2 Analysis of Trends

A prerequisite to trend analysis is that the data must be archived so that trends can be identified over time by graphical means or other statistical functions. An example is the INFORM system in Long Island, New York, and the way it tracks the percentage of devices online and maintains a trend analysis (Baxter 2002). This type of analysis is also beneficial because it indicates which aspects of the problem are benefiting from the investments made in the system. Box 6-2 illustrates a best practice of trend analysis performed by Oregon DOT.

Best Practice: The Oregon DOT performed a trend analysis with its incident data. These data were filtered, and trends were studied over time. An example of the results from this analysis is shown below.



This graph compares the Highway 18 observed accident frequency from the computer-aided dispatch (CAD) data with the accident rates reported by the ODOT Crash Analysis Unit (referred to as ODOT data). It displays the cumulative numbers of filtered accidents between 1995 and 2000 for both data sources. This trend analysis is thus able to show the different results obtained by the two accident data collection methods. For instance, while the ODOT method yields a constant accident rate (slope of the cumulate crash line), the CAD method shows a significant increase in the accident rate around September 1997.

Box 6-2: Trend Analysis Best Practice (Bertini 2001)

6.2.1.3 Comparison Group Evaluation

This type of evaluation creates a comparison group with untreated sites, making it a control for other factors in the evaluation. This method makes it easy to see how effective the strategy or new technology is at accomplishing the objective. Often, this comparison group is then applied to the before-and-after evaluation.

Best Practice: In 2002 the Minnesota Department of Transportation (Mn/DOT), with help from the Federal Highway Administration (FHWA), conducted a study of non-intrusive traffic data collection technology. Specifically, Mn/DOT evaluated nine different traffic sensors on various criteria, which included cost, performance, ease of setup, etc. The following table shows the study results.

Sensor Model	Technology	Freeway Test Site			Ease of Installation	Ease of Calibration	Reliability
		Speed Performance	Volume Performance				
			Peak	Off Peak			
Autosense II	Active Infrared	+	+	+	+/-	+	+
3M Canoga	Magnetic	+	+	+	-	+/-	+
ECM Loren [1]	Microwave			+	+/-	-	-
SmarTek	Passive Acoustic	+	+/-	+	+	+	+
ASIM IR 254 [2]	Passive Infrared (PIR)	+/-	+/-	+	+	+/-	+
ASIM DT 272 [3]	PIR/Ultrasonic	N/A	+/-	+	+	+	+/-
ASIM TT 262	PIR/Ultrasonic/Radar	+	+	+	+	+	+/-
Autoscope	Video	+	+	+	+	+/-	+
Traficon	Video	+	+	+	+	+/-	+

(1) The ECM Loren did not function in the test. No data available.
(2) ASIM IR 254 was difficult to calibrate for sidefire installation because of alignment complications.
(3) Data collection problem presented difficulty in fully evaluating the ASIM DT 272.

Notes: + Denotes a sensor that performed satisfactorily in the stated condition. ♦ +/- Denotes a sensor that meets some but not all the criteria for satisfactory performance in the stated condition. ♦ - Denotes a sensor that does not perform satisfactorily in the stated condition.

Box 6-3: Comparison Group Analysis Best Practice (Minnesota Department of Transportation/SRF Consulting Group, Inc., 2002)

6.2.1.4 Root-Cause Analysis

Root-cause analysis (RCA) is performed after an error occurs while collecting data, such as a loop detector producing incorrect readings. RCA determines the data collection problem so that it can be corrected. Prior to performing this type of analysis, it should be confirmed as being cost beneficial. It is ineffective to determine the root cause of every occurrence. General causes, like operator error, should not normally be investigated because the purpose of this analysis is to fix the problem unless, however, operator errors are a chronic occurrence. In that case operational issues should be investigated (ex. Staff size, training, or work procedures). There are four major steps to this analysis (Rooney and Heuvel 2004):

1. **Data collection**: The purpose of this step is to gain more information about the event that is being investigated.
2. **Causal factor charting:** Causal factors are "those contributors (human errors and component failures) that, if eliminated, would have either prevented the occurrence or reduced its severity." The final product of this step is a sequence diagram with logic tests that describes the event leading up to the occurrence. Figure 6-6 shows an example of this sequence diagram, where the cause of

an imaginary accident is examined. Preparation of this chart by drawing a simple skeleton of the diagram should begin as soon as information is gathered about the occurrence. As more information is learned about the occurrence, more details are then added to the chart. This chart drives the data collection process by narrowing down which information is relevant and should be collected. Once the investigators are satisfied with their final product, they can continue on to the next step. Often, however, more than one causal factor associated with an occurrence exists. It is also possible that the agency did not identify some of the causal factors, causing the occurrence to repeat itself.

3. **Root cause identification:** Once all the known causal factors are identified, then the root cause can be determined. This step involves creating a root cause map, which "structures the reasoning process of the investigators" by addressing questions about why certain causal factors occur. In the end, this process determines the reason for the occurrence.
4. **Recommendation generation and implementation:** Recommendations that address the problem or root cause are generated in this step. These recommendations must be feasible and achievable by the agency. Implementing the recommendations so that the problem will stop and more accurate data will be generated is also an important element of this step.

Documenting this process is important. This documentation can be achieved with root cause summary tables. Each column in the table represents an important step of this analysis process. The first column gives a general description of the causal factor, such as background information. The second column shows the path or paths through the root cause map associated with the causal factor. An example of the map is illustrated in Figure 6-7. Note that LTA states for less than adequate. The example also does not include all considered reasons. Refer to <http://www.asq.org/pub/qualityprogress/past/0704/qp0704rooney.pdf> to find a more detailed description of a root cause map. The third column identifies the recommendations associated with each root cause.

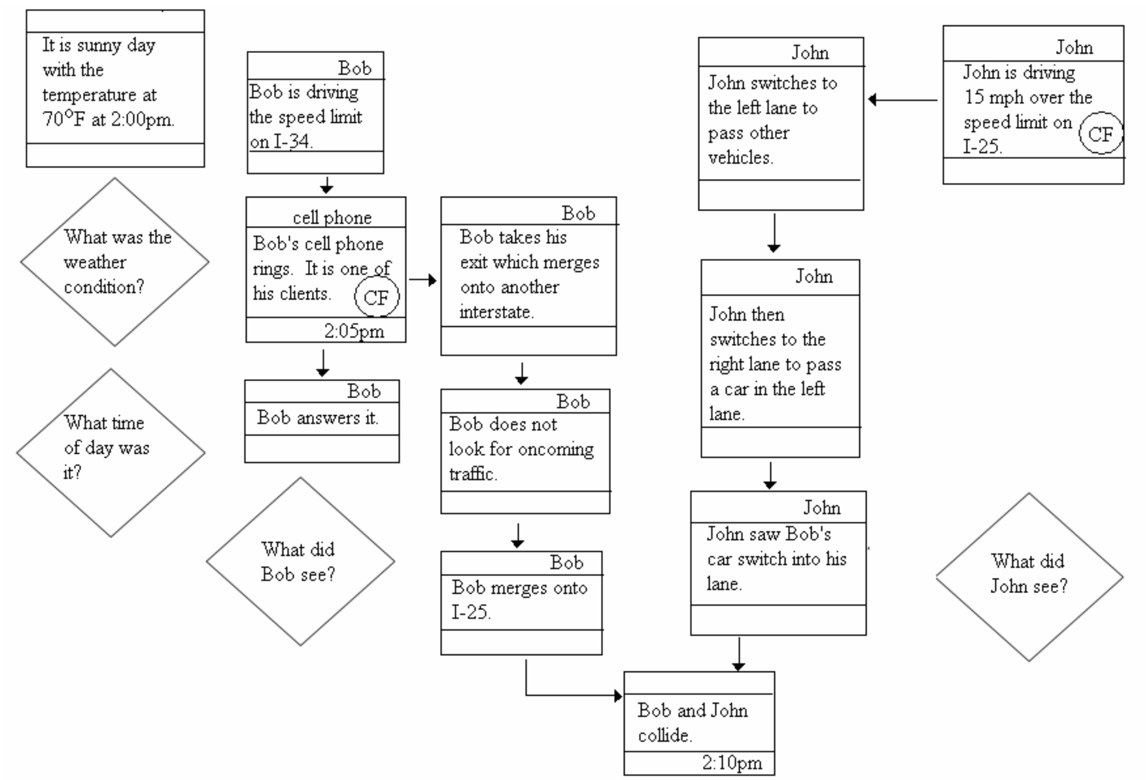


Figure 6-6: Causal Factor of an accident with John and Bob (Rooney and Heuvel 2004)

Table 6-1: Root Cause Summaries (Rooney and Heuvel 2004)

	Description	Paths Through Root Cause Map	Recommendation
Causal factor #1	Bob talks on his cell phone while driving	-Personnel difficulties -Standards, policies, or administrative controls LTA	-Implement policy of either using head set or refraining from using phone
Causal factor #2	John is driving 15 mph over the speed limit.	-Personnel difficulties -Standards, policies, or administrative controls LTA	-Have law enforcement monitor vehicle speeds more carefully -Have harsher punishment for violators

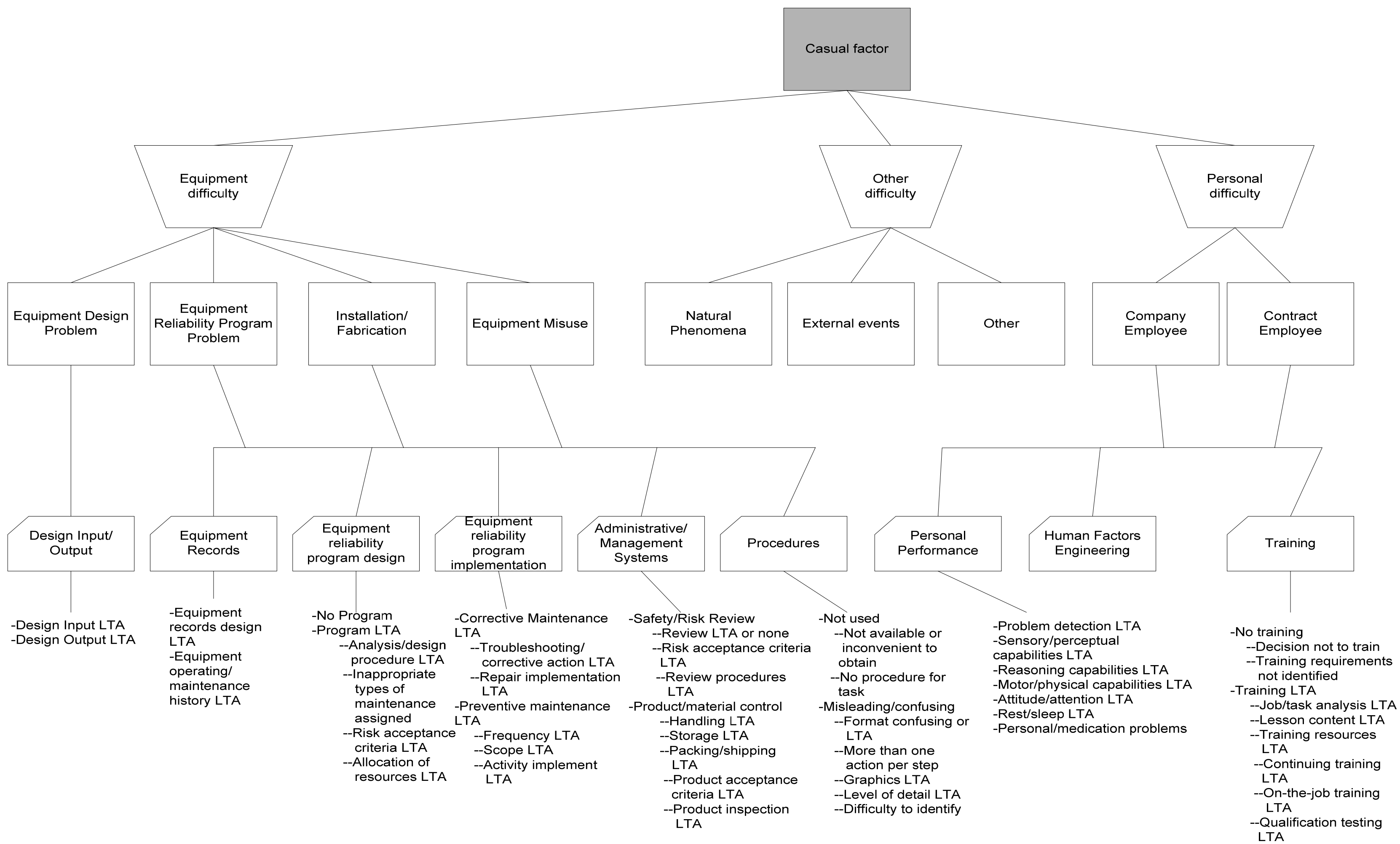


Figure 6-7: Root cause map example (Rooney and Heuvel 2004)

6.2.1.5 Benefit Analysis

Benefit analysis uses statistics to determine whether and to what extent the implemented project positively contributes to the intended audience and the overall system. The benefit-cost analysis is the recommended practice to describe the system benefits to the public and decision makers. At the regional level, the benefit-cost analysis will allow the system to be evaluated against traditional transportation program needs (Amodei 1998). The most practiced benefit analysis is benefit-cost evaluation.

Benefit-Cost Evaluations

This technique is the most widely accepted methodology for evaluating transportation improvement alternatives. The analyst must assign values to possible benefits and disadvantages of the system (such as shorter travel time or increased congestion). The analyst should consult an operations practitioner to ensure that the full range of benefits is captured. By analyzing the alternatives with respect to system costs, the analyst can determine objectively which offers the best benefit-cost ratio. The formula given by the Freeway Management & Operation Handbook is:

B/C = (benefit of alternative i)/(cost of alternative i)

If the benefit of the alternative is greater than the cost, then the improvement in the system is economically justified. This ratio provides a convenient basis for comparison of each alternative.

An incremental benefit-cost analysis should be used if the cost, quantities and complexities of the alternatives' components build upon each other. For this approach the benefits and costs should be analyzed in terms of additional benefits achieved and costs incurred over the next expensive alternative. Doing so determines whether an investment necessary to achieve the next incremental step in the system can be justified in terms of the incremental benefits that would be achieved.

The downside of this method, however, is that not all benefits are easily quantified and not all quantifiable benefits can be converted into monetary value. One solution to this problem is to use utility-cost analysis. The utility-cost analysis assigns a weight to each goal and sub-goal. Then, each alternative is rated based on the utility of each alternative in satisfying each goal and sub-goal. Then, by applying the following formula, the utility can be calculated:

$$\text{Utility} = \Sigma \text{ Weight of goal} * \text{rate of goal}$$

The utility-cost ratio can be determined with the following formula:

U/C = (Utility of alternative i)/(cost of alternative i)

Box 6-4 provides a best practice example for a benefit-cost analysis.

Best Practice: In considering the application of a ramp metering system on freeways in Alabama, researchers in the Department of Civil and Environmental Engineering at the University of Alabama at Birmingham (UAB) conducted a benefit-cost analysis as part of their study. To assist in this analysis, researchers used the FHWA's ITS Deployment Analysis System (IDAS). This software package helps planners calculate the benefits and costs of potential ITS system implementations.

The Cost Module Report was the first part of the analysis. The initial, operations and maintenance costs of the ramp metering system were calculated. Using these values, the average annual system cost was determined for the installation and maintenance for the first 25 years of the system life cycle. The second part of the analysis is the Benefit Module Report formulation. Here, weights and monetary values for various relevant categories are calculated and given as an average annual benefit over the first 25 years. Figure 6-8 shows these categories and the results of the benefit-cost analysis.

BENEFITS/COST SUMMARY		
Project: Birmingham Ramp Metering		
ANNUAL BENEFITS	**Weight**	**Ramp Meter (2005 US $)**
Change in User Mobility	1.00	-
Change in User Travel Time	1.00	11,000
Travel Time Reliability	1.00	1,150,000
Fuel Costs	1.00	700,000
Accident Costs (Internal)	1.00	500,000
Accident Costs (External)	1.00	275,000
Emissions	1.00	
HR/ROG	1.00	9,000
Nox	1.00	35,000
CO	1.00	225,000
PM10	0.00	-
CO2	1.00	150,000
SO2	1.00	10,000
Global Warming	0.00	-
Noise	0.00	-
Other Mileage-Based External Costs	0.00	-
Other Trip-Based External Costs	0.00	-
Change in Public Agencies Costs	0.00	-
Other Calculated Benefits	0.00	-
User Defined Additional Benefits	0.00	-
Total Annual Benefits		**3,065,000**
ANNUAL COSTS		
Average Annual Private Sector Costs		-
Average Annual Public Sector Costs		208,000
Total Annual Costs		208,000
BENEFIT/COST COMPARISON		
Net Benefit (Annual Benefit-Annual Cost)		**2,857,000**
B/C Ratio (Annual Benefit/Annual Cost)		**14.7:1**

Box 6-4: Benefit-cost analysis best practice (Sisiopiku 2005)

6.3 Reporting Practices

Reporting allows for communicating valuable information about the TMS with the stakeholders, decision makers and the public. These stakeholders can include (but are not limited to) government officials, agency management, and agency staff (Transportation Research Board 2003). This communication link is achieved by analyzing and interpreting the meaning and significance of the information into terms that are understandable by the audience. Good performance reporting focuses on a few critical aspects of the performance of the system and explains why these attributes of the performance were chosen to report (GASB 2003).

Two important aspects within reporting are: (i) the audience, i.e., the stakeholders for whom the report is meant and (ii) the content and frequency of reporting. These two aspects are explained in the next two subsections.

6.3.1 Audience

Reporting needs for various stakeholder groups are often different, so they should be linked to previously established goals and objectives. Stating goals and performance expectations show the relation of the results through either visual or written information (Governmental Accounting Standards Board 2003).

For those stakeholders in management or government positions, the report should communicate the current program status, future plans, and ways for the program to proceed. The public, however, is more interested in areas such as the acquisition and use of resources, service efforts, and accomplishments (GASB 2003). One way to illustrate these accomplishments is to relate the results to the capacity to meet or exceed the current performance expectations. The public is also interested in any risks that it may be susceptible to as a user of the system. Thus, it is good practice to explain what the key risks are, the level of the risks and how they influenced any choices made in relation to policy, goals and performance expectations.

One way to communicate transportation information to the public is through the media. Releasing results of traffic and other related studies to the press has proven an effective way to increase public awareness. For example, the National Transportation Operations Coalition (NTOC) released its first National Traffic Signal Report Card in April 2005. This study used the results of a traffic signal system survey to give national grades from A to F in six distinct categories related to traffic signals. To raise awareness about the results—traffic signals are not being used to their full potential—the NTOC released the study findings through various media channels and held a national press conference in Washington, DC (ITE Journal 2005). By disseminating information through the media, officials can thus reach many more people with important new developments in transportation.

In addition to disseminating information to the public, reporting is also important to several activities within a TMS agency. These activities include planning, designing, operations and enforcement. The report related to any of these specific activities provides crucial information that could help improve the quality of the activities themselves.

The people responsible for reporting usually spend a considerable amount of time on structuring, formatting and publishing performance measurement results in the form of written and electronic reports (MTG Management Consultants 2004). A major resource in planning a system is the information gained from long-term travel trends and infrastructure projects. They utilize some of the aforementioned analysis techniques, such as benefit-cost evaluation, to determine the appropriate applications that should be implemented in the system (CDOT 2005).

One primary purpose of performance reporting is to help manage operations. Most performance measures capture information related to everyday operations (MTG 2004). This information usually includes information on traffic data, such as traffic congestion (Kwon 2004). Reporting on everyday information provides the audience with feedback on what it is doing and how well.

Law enforcement is an integral part of any transportation system. The enforcement agencies often are considered stakeholders for a system. They help promote safety within the transportation system. Thus, numerous performance measures relate to the operations of these enforcement agencies (such as response time). By reporting the results from these performance measures, these agencies can determine what areas under their purview need improvement.

6.3.2 Content and Frequency of Reporting

There are two types of reports that TMSs use to communicate information: internal reports and external reports. Internal reports stay within the agency and communicate information to different staff members. External reports, on the other hand, convey to audiences outside the agency how successful the agency is at accomplishing its mission, goals and objectives in the context of "potential significant decision making or accountability implications" (GASB 2004).

There are several trends among agencies on how to report information. One trend is to post the report on their intranet sites. These types of reports are reported on a more frequent basis, such as weekly, monthly or continually. To make some information accessible to a broader public, many agencies also choose to post data via the Internet. One example is the Washington DOT's Gray Notebook. These types of reports tend to be generated either monthly or quarterly. Agencies also tend to generate more formal reports biannually or annually for their government and business stakeholders. These formal reports are those most commonly used among agencies. These types of reports include annual reports, business plans and other bounded reports. To keep managers and CEOs knowledgeable about the system, many agencies produce executive and mid-management reports. These reports can be produced in printed or electronic form. They do not need to be created with any particular frequency, but rather, depend on how often the executive members would like them. They vary from weekly to annually. "Notebooks" are another trend in reporting. The purpose of a notebook is to ensure that key decision makers are up-to-date on the goals of the program and its progress. Notebooks tend to be updated every month or quarter (MTG Management Consultants 2004).

Best Practice (WSDOT 2005): Washington Department of Transportation is one of the leading agencies in terms of public communication. Their quarterly performance report is called *Measures, Markers and Mileposts,* also known as the "Gray Notebook." This Gray Notebook explains the agency's planning process and the rationale behind different actions. It also assesses the effectiveness of the statewide system. It tracks a variety of performance and accountability measures for routine review by the Transportation Commission. The Gray Notebook also is continually evolving and has become an important source of information about department performance for the CEO, state legislators and other agency stakeholders. These reports engage the reader and make data more readily accessible to the audience. There are several criteria that this report abides by, which are:

- Avoid colors; make the chart work in black and white.

- Use plain English and avoid jargon.
- Show only relevant data and remove “chart junk” (outline boxes, lines, colors).
- Cite data sources.
- Eliminate legend boxes and use pointers to label data.
- Drop extra grid lines and numbers and lighten line values.
- Avoid 3Ds; Don’t do multidimensional graphs.
- Use clear chart title and subtitles to explain the X-axis and Y-axis, content and purpose.

The Gray Notebook contains an array of information about the agency. The report is divided into two sections: the *Beige Pages* and the *White Pages*. The *Beige Pages* is a project delivery performance report that summarizes the project and the associated financial information. The *White Pages* gives three types of updates: annual performance topics, quarterly performance topics and special topics. Annual performance topics include pavement conditions, congestion and bridge conditions. The specific topics relevant to TMSs include:

- Traffic Fatalities
  - Comparing Fatal and Disabling Crashes and Vehicle Miles Traveled (VMT)
  - Fatality Rate per Capita
  - Fatality Rates Compared to National Average
  - Seatbelt Use
- Pavement Assessment
  - Pavement Condition Rating
  - Washington Pavement Roughness vs. Other States
- Highway Maintenance
- Incident Response
  - Total Number of Responses by Month
  - Number of Responses to All Incidents by Time of Day
  - Clearance Time by Response Mode
  - Training Incident Responders

Quarterly performance topics include highway construction, worker safety, incident response, Washington State ferries and Amtrak cascades. Specifically, they cover:

- Washington State Ferries

- Total Number of Complaints per 100,000 customers
- Common Complaints Rate per 100,000 customers
- Trip Reliability
- On-time Performance
- Ridership and Revenue
- Fare Box Recovery
- Terminal and Vessel Preservation Performance
- Capital Expenditure Performance

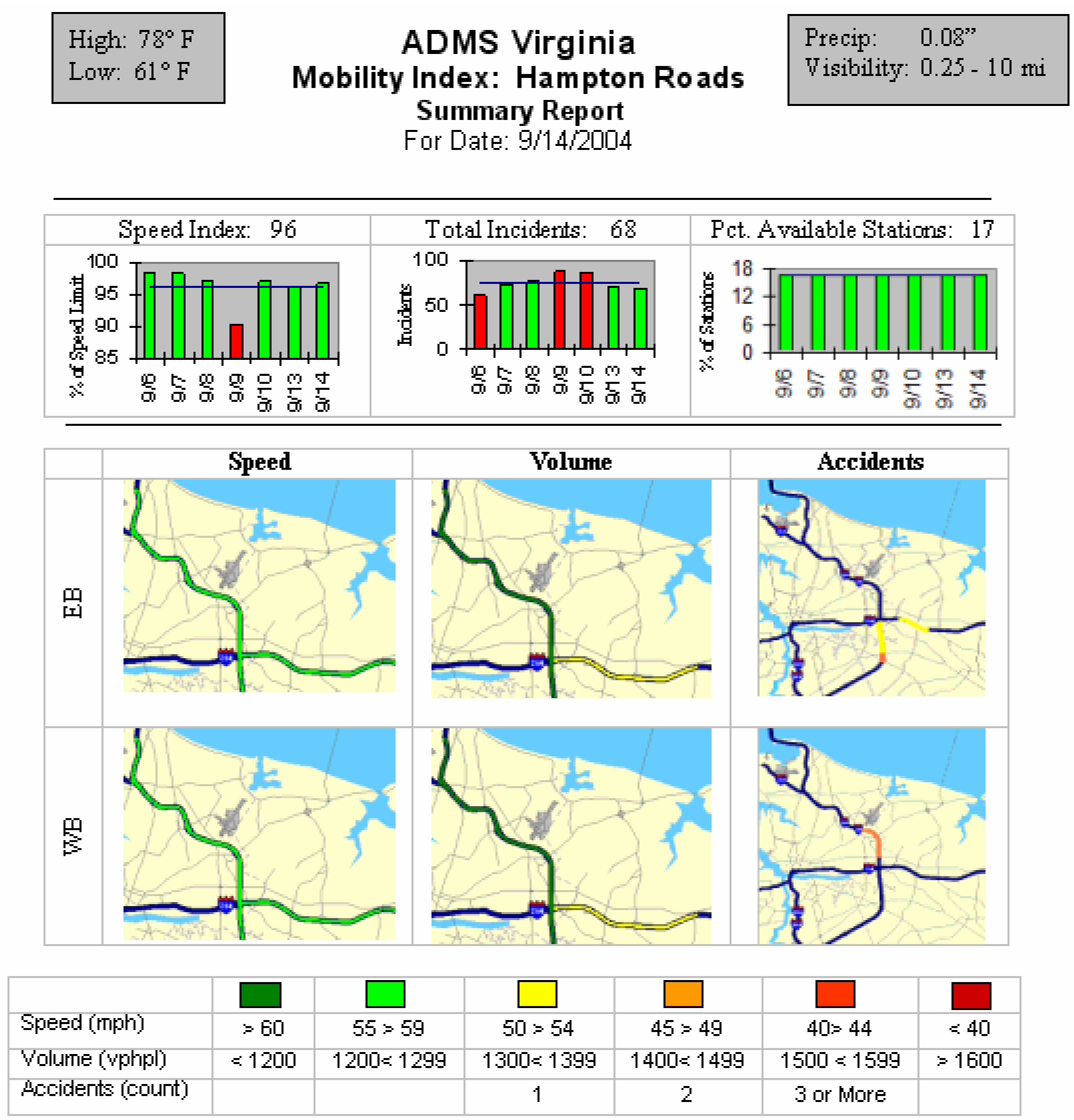
- State-supported Amtrak *Cascade*
    - Monthly and Annual Ridership
    - On-time Performance
    - Fare box Recovery
    - Grain Train Carload

Special topics include special events and innovations. Specific topics found in their 2004 report included:

- Oversize and Overweight Permits
    - Nonelectric Permits Turn Around Time
    - Motor Vehicle Permit Revenue
    - Pre-audit of Projects
        - Highway and Ferry Programs
        - Capital Management Projects
        - Environmental Programs

Due to the popularity of the Internet, most reports are available online. Reports also are commonly published electronically on a CD-ROM. A key factor for reporting these results is that the information must be presented in a manner for the audience to understand and interpret. NCHRP Report 311 states that reports combine written text (9%), tables (37%), charts (24%) and maps (24%). As charts and maps are very effective visualization tools for reporting, the next section presents some useful hints and practices on these elements.

Best Practice: As a part of an upcoming build of the Archived Data Management System (ADMS) Web site, a daily report will provide transportation officials with a summary of the previous day's freeway traffic conditions in a metropolitan region. For instance, the report gives updates on freeway mobility, number of incidents and traffic sensor availability from the previous day using graphs and maps. Below is an example of the first page of the report.



Box 6-5: Virginia ADMS daily report best practice

6.3.3 Charts Used in Reporting

Charts can include graphs such as histograms, line graphs and contour maps. The remainder of this section will discuss good examples of these charts.

Histogram

A histogram involves two discrete variables that are represented on a two dimensional graph. Figure 6-8 is an example histogram, which compares roadway incidents by location and year. Although the histogram is appropriate for this comparison because two discrete variables (location and frequency) are involved, a few problems exist in this example. First, it is difficult to distinguish which year some of the values apply to (such as 60 & 61). This problem is caused by the fact that a large range of frequencies exists with this specific chart. One solution would be to separate the data such that the frequencies for each chart have a smaller range of values. Another problem is that some of the locations only have values for one year. Thus, there is no point in a comparison for this location. These locations could then be omitted from the chart. Nonessential values of frequency also create a crowded feel to the chart and are difficult to read. In this case, because so many locations are represented, including the value may confuse the reader.

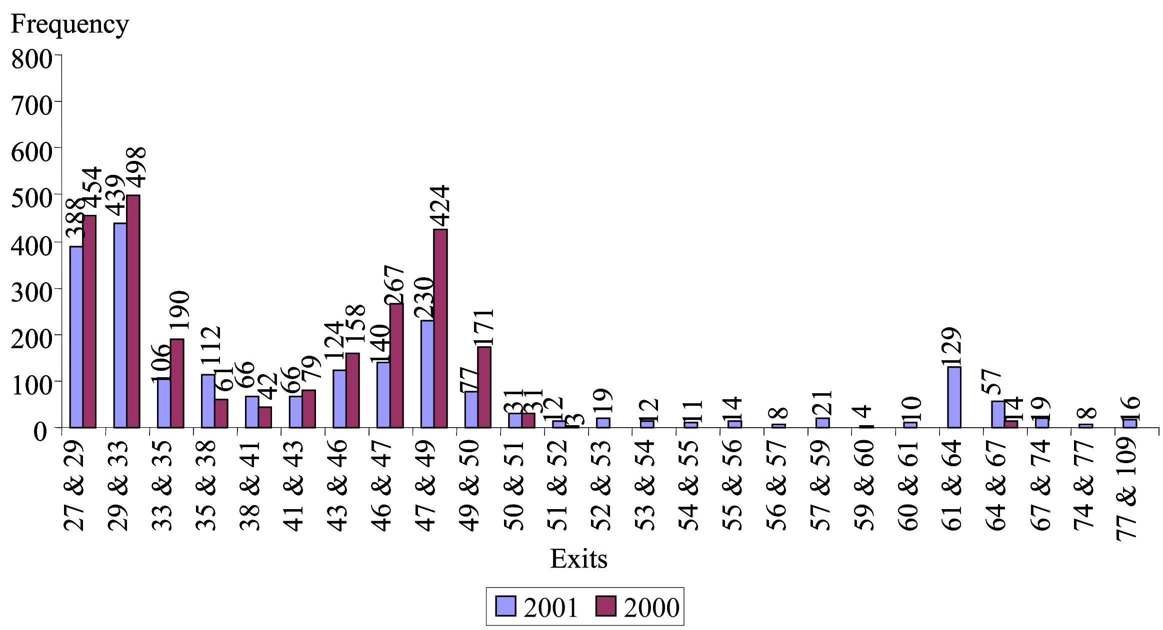


Figure 6-8: Comparison of incidents/disabled vehicles distribution by location

Figure 6-9 is another example of a histogram comparing two years. It provides data quality information for the years 2000 and 2001. The three-dimensional element improves the look of the graph. The specific percent is displayed in a horizontal manner, making it easier to read. The chart is streamlined and imparts essential information easily.

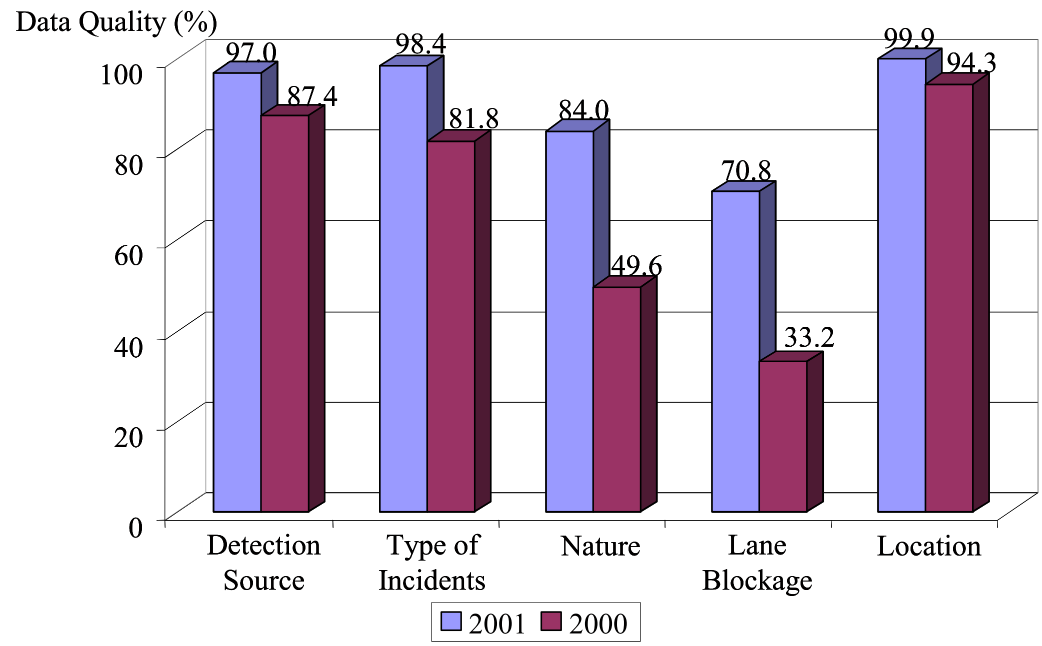


Figure 6-9: Summary of data quality based on all available reports (CHART)

Line Graph

A line graph involves one discrete variable and one continuous variable. Figure 6-10 is a line graph illustrating a trend among incidents occurring on secondary roadways. Although this graph is not busy and the values are easy to read, because there is no key, the reader would be unable to determine what the different lines represent.

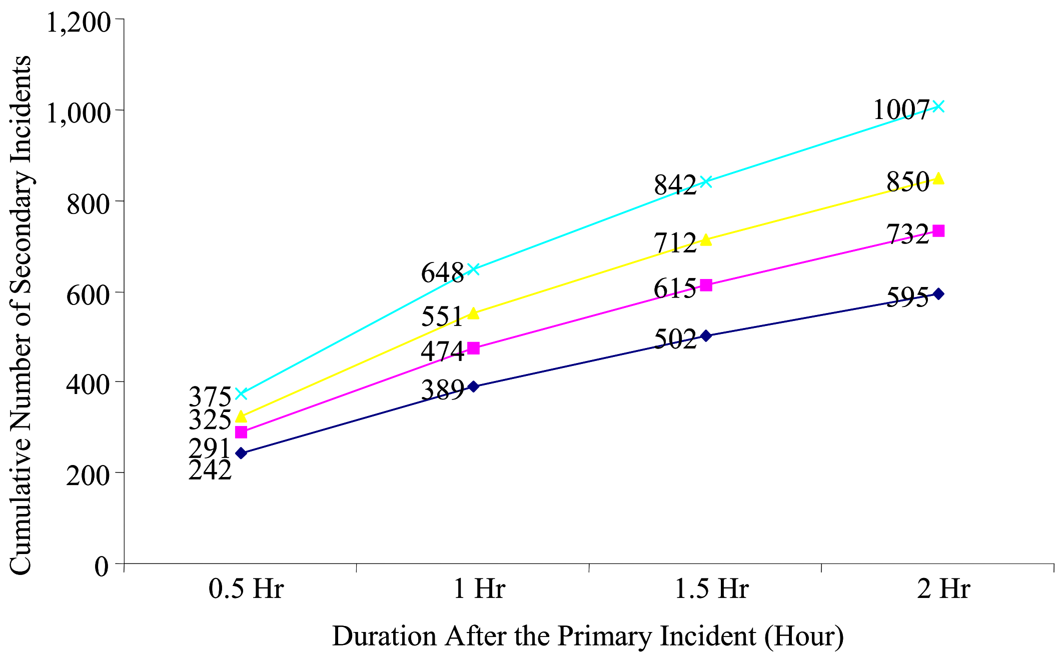


Figure 6-10: Distribution of reported secondary incidents

Figure 6-11, on the other hand, is an excellent line graph. Importantly, it includes a key, making it easier to understand. Also, since the values on the y-axis have a small range, determining where individual values fall on the line is clear and simple. Both the x- and y-axes are labeled with the values they represent and the unit of measure (e.g., mph). Additionally, this graph is an appropriate choice because the agency can show the trends associated with speed for different years.

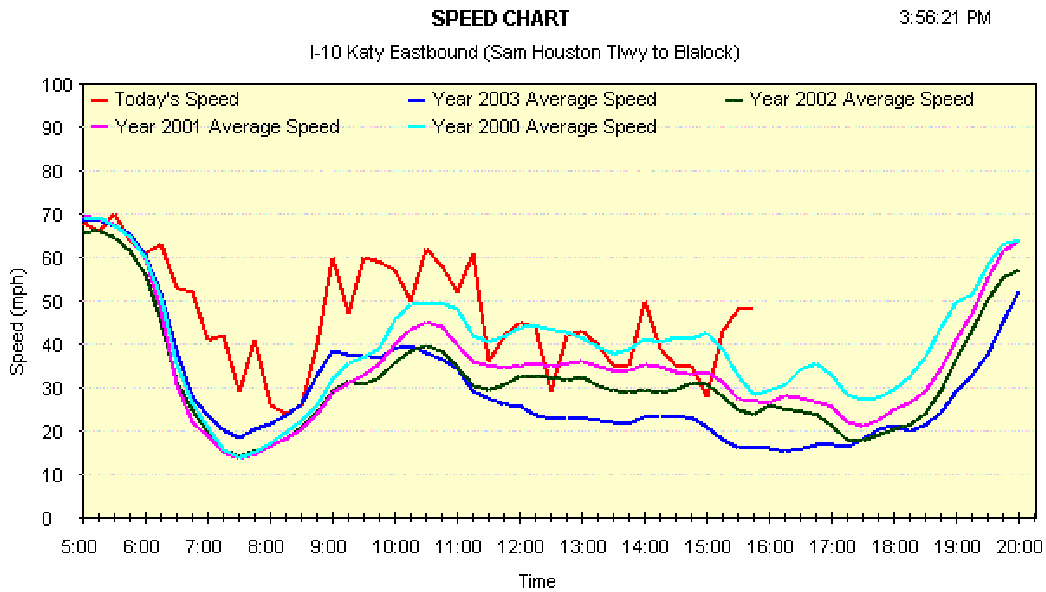


Figure 6-11: Travel speeds in the I-10 Katy eastbound corridor

Pie Charts

Pie charts illustrate how specific components comprise an entire system. For example, as seen in Figure 6-12, the pie chart shows the types of calls and the frequency of each type. This graph is a good example because, along with the visual of the pie chart, the precise percentage is listed. There are not too many types, so the graph is not too cluttered either.

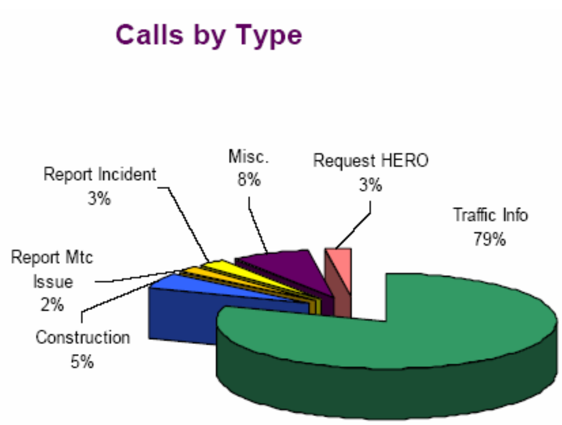
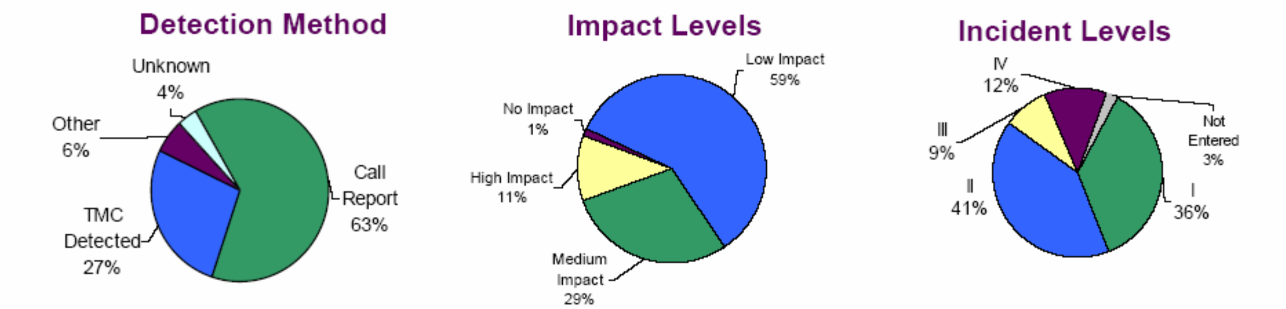


Figure 6-12: Pie chart of calls by type

Figure 6-13 has similar features as Figure 6-17, except this example also includes a table denoting the precise number of each type. The table data make clear the size of the sample.



Detection Type	# Recorded	% of Total
Call Report	294	63%
TMC Detected	126	27%
Other	27	6%
Unknown	17	4%

Incident Impact	# Recorded	% of Total
No Impact	8	1%
Low Impact	320	59%
Medium Impact	158	29%
High Impact	60	11%

Incident Level	# Recorded	% of Total
Not Entered	11	2.4%
I	167	36.0%
II	191	41.2%
III	40	8.6%
IV	55	11.9%

Figure 6-13: Pie charts with tables

Other Chart Types

A combination of a line graph and histogram can present a clear picture of congestion trends. Specifically, it can show when congestion usually occurs and its effects on vehicle speed and output. Figure 6-14 is a combination of a line graph and histogram. Here, the histogram provides the frequency of congestion, defined as LOS F, at the specified times. The line graph gives the roadway volumes and is color-coded according to vehicle speed. As a result of using these multiple display functions, this single graph provides a great amount of congestion information.

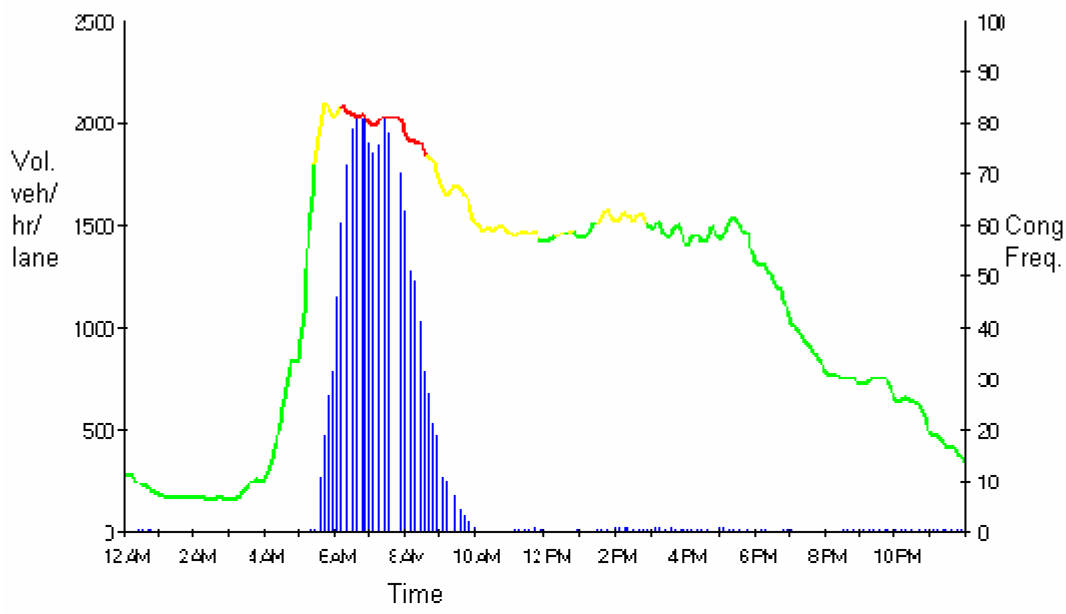


Figure 6-14: Estimated speeds, volumes, and frequency of congestion on I-5 near S. 184th St. in Washington in 2000 (Hallenbeck 2003)

Another effective way to illustrate congestion trends is to use a "temperature" diagram. These diagrams can be applied to specific corridors to show variations in congestion based on direction, time of day, and severity. Figure 6-15 provides an example of a "temperature" traffic profile.

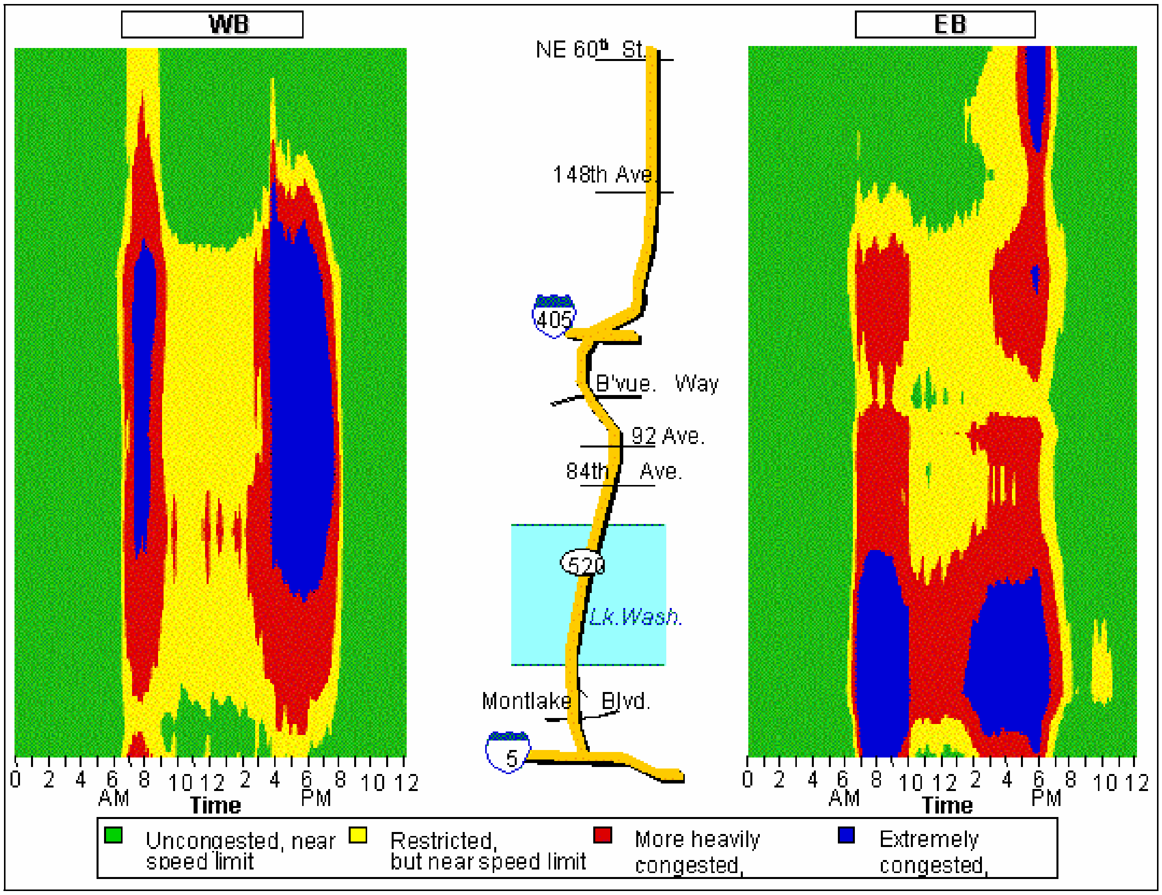


Figure 6-15: Traffic profile of general purpose lanes along Rt. 520 in Washington (HCM 2000)

6.4 Summary

This chapter presented and explained various methodologies that have been used (or can be used) in the TMS performance monitoring, evaluation and reporting. In addition, best practices in the applications of performance monitoring, evaluation and reporting methodologies were presented to help understanding the use of these in practice. The next chapter provides a self assessment tool that will help TMS/TMC managers assess and improve their TMS/TMS performance monitoring, evaluation and reporting.

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Chapter 7. Self-Assessment Tool and Case Studies

Introduction

This chapter presents the self-assessment toolkit, and then results from the national survey demonstrating the state-of-the-practice in TMS performance measurement practices. The third section explains several case studies performed by the project team, using the self-assessment tool. These results can be used by other TMSs to compare their practices with the national statistics, and focus further to improve their weak areas. The case studies also highlight particular aspects of performance measurement that have proven to be useful. The results presented are also helpful as models and guides for other regions considering performance monitoring, evaluation and reporting practices.

7.1 Self-Assessment Tool

This Self-Assessment Tool is designed for Transportation Management Centers (TMC) that monitor the performance of Transportation Management Systems (TMS). TMS includes software systems, computer hardware and communications and surveillance technologies that service freeway and arterial systems. The integrated system also includes the TMC, which is the building or room monitoring command and control of the automated system. The purpose of this tool is to provide TMCs with a means of assessing their current practices and recognizing areas of their performance measurement plans that could be improved. The tool addresses program and institutional issues, operational issues, and communications and technology issues. The word 'Agency' is used through out the tool instead of 'TMC,' as the TMCs are called by different names at different places, and perform a very diverse range of functions.

7.1.1 Description

The Self-Assessment Tool is the large, multicolored table that follows. The table is divided into subject areas, which are identified in the handbook, including:

- Agency Goals and Performance Measures
- Data Requirements, Collection and Archiving
- Performance Monitoring, Evaluation and Reporting

The table will help you assess your current performance practices for each of the subject areas. Within the subject areas, each row in the table contains a specific action statement associated with the subject area as well as room to assess the level of implementation for that action statement using a five-point rating scale. The meaning of each level of the scale is defined in the next section.

7.1.1.1 Instructions

- To use the Self-Assessment Tool, the following actions should be taken:
- Read the details of "TMS Performance Monitoring, Evaluation, and Reporting Handbook" to better understand the elements involved in a performance measurement plan.
- Review the five-point rating scale in the "Key to Assessment Scale" section on the next page to familiarize yourself with the meaning of each rating.
- Review the first subject area and review the action statements associated with that subject area. Then, decide which column on the five-point scale best expresses the level of your agreement or

disagreement with how well the statement describes your agency's progress in implementing the action. Mark the box in the appropriate column next to the statement.

- Continue to the next action statement and repeat the process until you have reached the end of the Assessment Tool.
- When finished, review the ratings and note those items where the ratings are low, especially those with a rating of 1 or 2.
- Refer to subsequent actions following the Self-Assessment Tool.

7.1.1.2 Key to Assessment Scale

1 – Strongly Disagree: The agency has no program planned or in place to address the action statement.

2 – Disagree: The agency has some minimal action planned or underway, but is not aggressively addressing the action statement.

3 – Neutral: The action statement may not directly apply to the agency.

4 – Agree: The agency has a program underway to address the action statement, but the effectiveness of the program has not been evaluated.

5 – Strongly Agree: The agency has a comprehensive program to address the action statement, evaluates effectiveness of the program and takes actions to improve performance.

7.1.1.3 Self-Assessment Tool

The Self-Assessment Tool begins on the following page.

TMS Performance Measurement Plan	Assessment Scale				
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	1	2	3	4	5
Agency Goals and Performance Measures					
Our agency has adopted a performance measurement plan including agency objectives, goals, and performance measures. (i.e., there is a program in place for regular measurement of transportation system and TMS performance.)					
Our agency has implemented decision-making (e.g., resource allocation, procedural refinements, and/or future project selections) based on TMS performance measures.					
Our agency's planning process reflects measurements of actual system performance, like travel time, reliability, and incidence of non-recurring congestion.					
Our agency has a performance measure-based index to gauge the system as a whole.					
Our agency has conducted executive-level TMS performance measurement briefings for policy and decision makers.					
Our agency promotes multi-disciplinary teams to improve coordination, cooperation, and communication of TMS performance measurements.					
Our agency promotes communication between data collectors and users to improve understanding of data issues and uses.					
Our agency has established multi-agency agreements on what measures will be tracked and used to measure TMS performance					
Our agency has conducted, adopted or collaborated with other agencies research on best practices for improving TMS performance measurement initiatives.					
Our agency has documented a guide of best practices for improved collection, management and use of performance measures and information.					

TMS Performance Measurement Plan	Assessment Scale				
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	1	2	3	4	5
Our agency conducts periodic reviews of whether or not progress is being made to achieve agency goals (i.e., targets).					
Data Requirements, Collection and Archiving					
Our agency evaluates its field data requirements to insure they support the performance measures being used for our TMS.					
Our agency directly collects field data to support performance measurement, where possible (e.g., direct collection of travel time instead of estimating from speed).					
Our agency maintains the inventory of operational field devices (e.g., traffic sensors, CCTV, VMS, loops, controllers, ramp meters).					
Our agency tests the functional reliability of field devices (e.g., traffic sensors, CCTV, VMS, loops, controllers, ramp meters), on a regular basis.					
Our agency practices its adopted guidelines to maintain good quality and consistency of data collection.					
Our agency conducts periodic independent data record assessments to ensure quality of data.					
Our agency documents data quality and the data quality criteria are passed on to our data users.					
Our agency archives data.					
Our agency shares data with external users.					
Performance Monitoring, Evaluation and Reporting					
Our agency monitors transportation system performance (e.g., system outcomes such as throughput, speed, travel time, spatial distribution & status of incidents, etc) in real-time.					
Our agency monitors and evaluates various TMS components (e.g., sensors, communication systems) used in collecting data for performance measures at regular intervals (weekly, monthly, quarterly, or yearly etc.).					

TMS Performance Measurement Plan	Assessment Scale				
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	1	2	3	4	5
Our agency monitors the performance of our maintenance program (i.e. device maintenance, system up and downtime, mean time between failure of equipment etc.).					
Our agency has a set of quantitative performance measurement goals (e.g., duration for which average speeds are below a certain mph at peak period, incident response time etc.).					
Our agency has a set of qualitative performance measurement goals (e.g., customer satisfaction, coordination with other agencies, etc.).					
Our agency internally measures the performance of human operations (e.g. response time to incidents, efficiency of operators etc.).					
Our agency measures the percentage of signals coordinated across jurisdictions with other cities/counties etc.					
Our agency often uses simulation modeling or estimation based performance measures when direct measures are not available					
Our agency uses data from external sources for performance evaluation.					
Our performances measures are being used in other types of analyses besides performance reporting (e.g., system evaluations or multimodal analyses). [Do not answer this question if the performance measures are not used for any purpose other than performance reporting]					
Our agency reports TMS (e.g., incident management system, etc.) and transportation network performance (e.g., average speed, number of incidents, etc.) at regular intervals (monthly, quarterly, or yearly).					
Our agency's performance measurement report includes trends over time.					
Our agency's performance measurement report is published on our website, or through other media.					

7.1.1.4 Subsequent Actions

After the initial assessment has been completed, the following actions are suggested:

- Meet with managers and staff to review and discuss the results of the assessment. Discuss possible actions that could be taken to fully address elements involved in a performance measurement plan.
- Develop an implementation plan to address the strategies that need additional attention.
- Seek legal advise on the proposed strategies to assess vulnerability to litigation.
- Seek management approval for the plan.
- Seek necessary additional funding.
- Seek and implement additional or revised training for staff to implement the performance measurement plan.
- Implement the plan and monitor results to determine if the actions taken are having the desired effect on transportation management systems and decision-making.
- Continually update the performance measurement plan to improve effectiveness.
- Prepare a summary report for each of the items in your implementation plan, describing the program activities and cost, the results, and recommendations for future actions.
- Publicize and make the summary report available to other agencies that may be able to benefit from your experience.

7.2 National Survey Results

This section explains the results of the national-level (second, main) survey conducted using the self-assessment tool presented in section 7.1 above. The online survey was developed based on the presented format, and distributed as a companion to an earlier preliminary survey instituted by the project team. The preliminary survey was instituted at the beginning of the project, and collected information about the TMS systems, physical assets, budgets and other facts. All that information was used to select case studies and the TMS elements of focus in the handbook. That preliminary survey is presented in Appendix A. Both the surveys were targeted to the agencies participating in the TMC Pooled Fund Studies, and from other sources. The results from the main survey are discussed in detail here. This survey was sent out to a total of 110 people across the nation, during the period 06/29/05 and 09/16/2005. 32 actual responses were received, corresponding to 29% of the entire group. The prominent results are summarized here below:

- For the performance measurement program, most agencies are split down the center on the existence, usefulness and updating of the programs. Based on these results, it appears that the agencies that do have a program in place find it useful, update in on a regular basis, and often have multi-disciplinary teams working on all the related challenges. The following sub-aspects of the program stand out with significant results:
  - Culturally, many TMSs promote the communication channels between the data collection group and the data user group.
  - Most agencies (80%) do not currently have agreements or coordination with external agencies in the region to decide the actual measures to be tracked for the transportation system.
  - Most agencies (80%) do not currently have any documentation or guidelines for improved collection, management and use of performance measures and information. This handbook could fill that gap and provide definite guidance to the agencies.

- 80-90% of TMSs across the nation have an existing, and detailed data collection system. Most of them are well inventoried, and often checked for functionality. Most TMSs also archive the data and share them with external agencies (cities, counties, planning divisions etc.). However, two important aspects of the data programs that show striking results are:
    - More than 60% of the TMSs currently (a) do not validate the data for data quality, and (b) do not document the data quality for later usage by other external agencies.
    - More than 50% of the TMSs currently do not correlate their data needs for performance measurement with their data collection efforts. This is in contrast to the agency culture where such coordinated efforts are encouraged, but little else seems to be actually done.
- Most agencies (more than 70%) of the agencies monitor their transportation operations system in real time, and monitor the functioning of TMS components. However, the overall levels reported in many areas of performance monitoring, evaluation and reporting are quite low.
    - Only about 50% of the agencies seem to have a robust maintenance system, for the various TMS components
    - Less than 40% of the agencies track quantitative performance measures. The number of agencies tracking qualitative performance measures is also similar. Furthermore, less than a quarter of all the agencies reported usage of measures from simulation or other estimations when direct measures are not available.
    - Only 16% of the agencies use any performance measures for purposes other than reporting.
    - Usage of data from other external sources (such as Police CAD etc.) for the TMS performance measurement also shows a very low level (16% of the agencies).
    - Signal system coordination with nearby jurisdictions seem to be measured by more than 25% of the agencies.

On the whole, the survey finds that most agencies are moving towards the establishment of performance measurement programs, and are already tracking a number of transportation system outcome measures. Tracking of output measures, and the impacts of TMS on the transportation system, need to be improved.

7.3 Case Study Results

Along with the national survey, the project team also interviewed selected agencies through teleconferences to obtain more detailed information. A diverse set of agencies was selected to represent variations in geography, TMS size, budgets and current utilization of different performance measurement practices. These case studies have been summarized here for the benefit of other TMSs. Interested agencies could also contact these agencies through the information provided with each case study. A total of 5 case studies were conducted. Each case study first describes the TMCs and other factual information. This section is followed by information on the agency systems operations practices, and performance measurement practices. Finally, a discussion by the project team and contact information are provided.

7.3.1 Milwaukee, Wisconsin

7.3.1.1 TMC Overview

The city of Milwaukee, Wisconsin is part of the Gary-Chicago-Milwaukee (GCM) Intelligent Transportation Systems Priority Corridor, designated in 1993. As such, the city has to coordinate with the visionary directions, operational activities, and performance measurements for both the Wisconsin state DOT and the GCM corridor. Both these crucial views are presented in this case study. Four main transportation agencies have a stake in the GCM undertaking as Priority Cooperative Partners—the state departments of transportation of Illinois, Indiana, and Wisconsin, and the Federal Highway Administration. The corridor includes the sixteen urbanized counties, nearly 2,500 miles of roadway, and more than ten million people located within the tri-city area. The GCM Corridor agencies oversee all expressways, major arterials, ports, transit, and rail systems in the region.

WisDOT's Milwaukee TMC uses approximately 100 closed-circuit television (CCTV) cameras, thirty-six variable message signs (VMSs), 120 ramp meters, and around-the-clock operating TMCs for traffic management across the state. The state of Wisconsin is currently in the process of combining all the TMCs into one statewide TMC.

7.3.1.2 Agency PMER Practices

The GCM Corridor monitors and manages traffic via each state's own TMC. It also coordinates with other agencies in the region, such as computer-aided dispatch centers, the traffic incident management (TIM) program, and emergency/fire/police departments. The agency archives volume, speed, and occupancy data at one-minute intervals and incident data via its data hub in Illinois. All participating agencies push their data into this hub and use information available from other agencies. Apart from all these archives, WisDOT maintains its own maintenance database, which includes all equipment used in Wisconsin.

For performance evaluation, GCM has recently proposed six measures to monitor the focus areas of safety, mobility, emissions, fuel consumption, and driver stress. The philosophy it has adopted is to measure the transportation system outcomes instead of agency outputs. WisDOT, on the other hand, is planning to add maintenance measures in the near future. WisDOT is also currently in the process of collecting baseline data for benchmarking the selected measures. Based on the collected operational performance measures so far, and to improve them, WisDOT undertakes individual studies such as ramp meter retiming, speed studies, focus areas for improving enforcement, etc. Currently collected measures include outputs such as the number of activated ramp meters and VMSs.

The GCM Corridor maintains two Web sites. One site is for internal use and shows current network conditions. Another, for public use (<http://www.gcmtravel.com/gcm/maps_corridor.jsp>), shows travel times, selected CCTV camera images, and incident data for the tri-city area. While the agency does not publish its own reports, it does provide data to the Texas Transportation Institute for its annual Mobility Report. The TMC activities also receive considerable attention from newspapers and other media, which showcase their operations and accrued benefits.

7.3.1.3 Discussion

The performance measurement of the participating agencies as an integral part of the bigger GCM-region goal is an exemplary situation serving as a model for other regions. The GCM corridor does an excellent job at communicating and coordinating among the various involved agencies, with other outside agencies and the public. The WisDOT TMC in Milwaukee holds face-to-face meetings at six-week intervals with police and other cooperating agencies. The TMC has established an active liaison with the local county sheriff's office and shares part-time staff members. The TIM and other outreach programs have also helped communication with the public. However, data sharing is not always as easy as personnel communication. Undoubtedly, the GCM corridor is a very big initiative, and similar projects elsewhere should be careful to not be overwhelmed by the magnitude of the regional extent and tasks.

Contact for further information:

Name: Mr. Doug Dembowski
Phone: 414-227-2149
E-mail: douglas.dembowski@dot.state.wi.us

7.3.2 San Antonio, Texas

7.3.2.1 TMC Overview

The TransGuide Operations Center, located in San Antonio, Texas, manages ninety-three centerline miles of roadway in the San Antonio metropolitan area. It has been in operation for ten years and holds an operating budget of approximately $1.3 million per year. More than 100 people work at the TransGuide Operations Center, which includes employees of the Texas Department of Transportation (TXDOT), police department, transit authority, and city traffic signal operations department.

7.3.2.2 Agency PMER Practices

To manage area traffic, TransGuide uses closed-circuit television (CCTV) cameras, dynamic message signs (DMS), traffic signal coordination, ramp metering, and lane control signals. Using road sensors, it collects travel time data, average speed, and traffic volumes, the latter two of which are archived. TransGuide also archives incident response, DMS, and lane control signal data. A maintenance database, implemented five years ago, tracks system performance and field equipment history, allowing the agency to identify inefficient products to exclude in the future.

San Antonio is classified as an attainment city. As a result, federal transportation funding requests by the city are not tied to performance measures. Thus, a performance measurement program is not a regular focus of TransGuide. The Texas Transportation Institute (TTI), however, has conducted studies for the agency—an initial before-and-after study when TransGuide first became operational and, currently, a ten-year benefits evaluation.

TransGuide uses a variety of methods to report traffic information to the public, which include a web site, dedicated cable television, kiosks, wireless notifications, and low power UHF television. The agency does not, however, currently publish a system performance/status report.

TransGuide is also part of a statewide campaign to increase the communication of travel information to the public. A new 511 traveler information system is currently under investigation by TXDOT. Additionally, a federally sponsored highway advisory radio (HAR) project will install two systems in two of the seven radial freeways in rural areas outside San Antonio's outer freeway loop. These systems will then be tested for effectiveness in routing traffic around the metropolitan area in case of a special event or incident.

7.3.2.3 Discussion

Due to the area's unique road network that includes two loops around San Antonio, TransGuide is able to provide alternate routes to travelers in case of an incident. The agency also coordinates well with police, allowing for better emergency and incident response. TransGuide collaborates with the local media by sharing video data, which helps to foster a high level of trust with the public.

According to TransGuide, performance measures are critical and should be a focus of all TMCs. Agency self-assessment is helpful early in the system life cycle but not as much once the system matures.

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7.3.3 Arizona DOT

7.3.3.1 TOC Overview

The Arizona Department of Transportation (ADOT) currently oversees a transportation operations center (TOC) in the Phoenix metropolitan area. The ADOT TOC has been operational since 1995 and carries an annual budget of approximately $2.5 million. It manages around 100 centerline miles of roadway with thirty-five TOC employees.

7.3.3.2 Agency PMER Practices

The ADOT TOC uses closed-circuit television (CCTV), dynamic message signs (DMS), ramp metering, and high-occupancy vehicle (HOV) lanes to manage Phoenix-area freeways. ADOT uses its DMS system, Web site, Highway Condition Reporting System (HCRS), and 511 to relay travel information to Phoenix and outlying rural areas to help travelers avoid incidents, as well as to provide roadway construction and maintenance conditions. From its roadways, the TOC collects speed, volume, incident delay, emergency response time, and weather data. Both speed and volume data are then archived. The TOC also tracks DMS and AMBER Alert messages, and the number of functioning signal systems in the Phoenix area.

To gauge system performance, the Phoenix TOC uses a combination of output and outcome measures. For instance, it tracks the number of functioning traffic signals (output) and the level of service (LOS) on area freeways (outcome), part of quantifying a TOC stated goal to reduce congestion.

ADOT provides a basic employee evaluation format to all agency divisions, which can then customize it to their own specifications. The individual divisions can use the evaluations to track the efficiency and effectiveness of their operators. ADOT also measures internal TOC performance through an operators' certification program, which consists of an operator certification test. This test consists of twenty-five different categories in which the operator must demonstrate various skills. For instance, in the "DMS" category, the operator must show knowledge of editing the text and display of a given DMS. For each skill, the operator and a supervisor must initial the test with the date to acknowledge proper completion of that skill.

The ADOT TOC compiles and submits an annual formal report for internal DOT and TMC use. Additionally, it produces an informal report for a quarterly meeting with TOC supervisors and managers.

This report includes information on practices from the previous quarterly period and future plans and goals for the agency.

ADOT Strategic Management Division has set (and updates) agency-wide goals. For each agency, several performance measures are identified that gauge the degree to which ADOT is meeting its goals and objectives. For instance, toward the goal "to improve the movement of people and products throughout Arizona" and objective "operate sixty percent of the Phoenix freeways [. . .] at a level 'D' or better during rush hour," ADOT uses the average percentage of Phoenix freeways that reach LOS 'E' or 'F' on the weekdays. The expected and actual values for this and other performance measures for seven fiscal-year cycles (three past years and four future years) are then compared.

In addition to this intra-agency communication, the TOC coordinates with other agencies in the region. It shares CCTV control with the cities of Phoenix and Scottsdale, Maricopa County, and communicates (via telephone) with the state highway patrol about incidents.

Transportation funding for Arizona comes from various sources. Federal monies, which include Congestion Mitigation and Air Quality (CMAQ) Improvement Program funds, support the construction costs. ADOT, however, covers operations and maintenance costs and supports the state's ITS program.

7.3.3.3 Discussion

There are some important notes from this case study useful for other transportation operations agencies across the nation. TOCs in Arizona (operated by the state and other governmental agencies) are highly motivated for measuring their operational performance through the high-level management initiative set at ADOT. Both the outputs and outcomes are measured and tracked over a long period of time for trends.

TMS operators are often forced to work in a multi-tasking environment where the incidents and situations encountered are usually singular in nature. In such new situations, there is as much scope for error as there is for effective tackling. Therefore, it is very important, but very difficult, to track operator performance. The Arizona Department of Transportation's (ADOT) operator certification program is unique and cleverly addresses the challenge of measuring operator performance. ADOT uses this program to gauge internal performance at its Phoenix-area transportation management center (TMC). The program consists of an operator certification test, composed of twenty-five different categories in which the operator must demonstrate various skills. For instance, in the "Variable Message Sign" (VMS) category, the operator must show that he/she can edit the text and display of a given VMS. For each skill, the operator and a supervisor must initial the test with the date to acknowledge proper completion of that skill.

ADOT further expressed the need to make the survey more comprehensive, by including detailed questions.

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7.3.4 Hudson Valley, New York

7.3.4.1 TMC Overview

The Hudson Valley Transportation Management Center is jointly operated by the New York State Department of Transportation (NYSDOT) and the New York State Police. The Center operates on a 24/7 schedule and coordinates incident response and management on hundreds of miles of interstates, parkways, and arterials in seven counties. There are five full-time NYSDOT employees, three full-time state police officials, and a fully contracted operations staff that covers three shifts at the Center. The Center also provides space for the New York State Police 911 Call Center, the New York State Office of Emergency Management, and the Westchester County Office of Emergency Services. Other agencies located in the building include the New York State Thruway Authority, New York State Bridge Authority, and the I-95 Corridor Coalition. The New York State Police also have a troop headquarters in half of the building. The State Police manage the Highway Emergency Local Patrol (HELP) Program from the center, designed to be the first responders to motorists experiencing trouble on the roadways. The Center uses a GIS-based advanced traffic management system (ATMS) to communicate and control over thirty variable message signs (VMSs), twenty closed-circuit television (CCTV) cameras, and two dozen sensors. There is a planned build out underway to install an additional 100 CCTVs, twenty-five variable message signs (VMSs) and 200 sensors on sixty miles of parkways. There currently is a TRANSMIT system under construction on the roadway network to provide origin destination information to the Center. The Operations budget for the Center is about $200,000 a month, and the HELP Program and computer-aided dispatch (CAD) system costs about $225,000 per month to operate. Currently, there is approximately $50,000 in software development and integration carried out at the Center each month.

7.3.4.2 Agency PMER Practices

To manage traffic, the HVTMC uses variable message signs (VMS), closed-circuit television (CCTV) cameras, and road sensors. It coordinates with state police for the Highway Emergency Local Patrol (HELP) program, which dispatches emergency vehicles to incidents. The HVTMC collects incident data through their ATMS and CAD systems, specifically the type of incident, response time, number of lanes blocked, and clearance time. Other collected data include volume, occupancy, and speed data from the road sensors, as well as VMS data during and following an incident.

The HVTMC obtains its funds from non-Congestion Mitigation and Air Quality (CMAQ) sources. Thus, no performance measures tied to CMAQ funding have been required of the agency. Since the HVTMC does not receive Congestion Mitigation and Air Quality (CMAQ) funds, a performance measurement plan is not required of the agency. One notable study that the HVTMC conducted was regarding the HELP program. The study, performed by a private consultant, showed that incident response times dropped dramatically after implementing HELP.

The operations contractor reports on statistics for incidents to the HVTMC staff on a regular basis. System conditions, including equipment status, are reported regularly. The agency plans to report HELP statistics routinely, but due to high staff turnover, cannot currently do so.

The HVTMC has three separate incident databases into which operators enter incident data—the agency's ATMS system, CARS, and TRANSCOM. CARS is the statewide incident database, and TRANSCOM links data between New York, New Jersey, and Connecticut. The ATMS has also been integrated with the CAD system; the goal is to further integrate the ATMS with CARS and TRANSCOM to provide a single entry data point for operations staff.

With regards to the future, the HVTMC has plans to increase its road sensor coverage significantly. Over the next five years, 200-300 new sensors, 100 additional CCTV cameras, and several dozen VMSs will be installed on area roadways.

7.3.4.3 Discussion

A longer trial for ITS implementation throughout the region is necessary before it is possible to report performance. Putting measures into place now to gather baseline data is underway. Restricted staff resources and the additional requirements of entering data into multiple databases are seen as major contributors to the current lack of performance measurement and reporting. Some resolution to these issues will be realized with the additional monitoring equipment (sensors, CCTV cameras, VMS) currently planned for installation. The INFORM system on Long Island has been helpful in sharing experiences with operations (e.g., Highway Performance Monitoring System (HPMS)) and has assisted the HVTMC in improving their program.

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7.3.5 El Paso, Texas

7.3.5.1 TMC Overview

TransVista, the TMC for the El Paso, Texas metropolitan region, has been fully operational since November 2000. Overseen by the Texas Department of Transportation, TransVista manages seventy-five centerline miles of roadway with less than twenty-five TMC employees. It carries annual salary and maintenance budgets of $250,000 and $1,000,000, respectively.

7.3.5.2 Agency PMER Practices

TransVista monitors and controls freeway operations in the El Paso area, which includes the use of closed-circuit television (CCTV) cameras, dynamic message signs (DMS), lane control signals, and vehicle data collection. The TMC also provides network connection to the City of El Paso for traffic signal interconnection. In the near future, TransVista will be implementing a highway advisory radio system, the latter of which will be the largest of its kind in the nation. It also has plans to replace its inducted loop detectors with side-fired microwave detectors on area freeways.

From its freeway traffic monitoring, TransVista collects speed, volume, and recurring delay data. The agency also shares CCTV video and control with other TMCs, emergency personnel (fire, police, etc.), and local media outlets. The speed and volume data are archived, in addition to DMS messages and field maintenance/equipment data.

As part of its self-evaluation process, TransVista's highway emergency response operators (HEROs), the area roadside courtesy patrol, gives customers surveys to return regarding their service. Other forms of evaluation include the use of the DYNASMART traffic simulation tool to determine the effects of adding a lane to a local freeway, I-10.

The Texas Transportation Institute (TTI) compiles an annual internal report, which is provided to TransVista and shared with the FHWA, TXDOT, emergency personnel, and other TMCs. It also provides certain traffic data, such as number of incidents and incident clearing time, to the TTI as part of its pollution study.

Most monetary funding for TransVista comes from the federal Congestion Mitigation and Air Quality (CMAQ) Improvement Program. TXDOT, however, provides monies that cover ITS maintenance costs for El Paso area state highways.

7.3.5.3 Discussion

TransVista maintains a strong relationship with its partners, meeting once per month to develop and discuss its incident management plan and the rerouting of traffic around an incident. The agency also can communicate with the local emergency operations center, 911, the city traffic management center and the city signal systems. TransVista also shares a fiber-optic network with the city of El Paso. A previous shortcoming of the agency was the lack of communication with law enforcement. Currently, there is cooperation between TransVista and the police department in sharing computer-aided dispatch information.

TransVista's operations and performance evaluation activities are similar to many other TMCs across the nation. Performance measurement, reporting, and decision-making do not seem to be a major focus of the higher management at this time. The agency is, however, interested in finding out more about best practices in this field and the particular actions taken/considered by other TMCs.

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7.4 Summary

This chapter presented the self-evaluation tool that interested agencies could take to assess their current practices related to performance measurement. Results from a national survey based on this tool are presented next. The last section demonstrates the case studies of particular TMSs, conducted by the project team. These provide several details and discussion of potential interest to many readers.

Chapter References

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Preliminary Online Survey, TMC Performance Measures Survey, www.zoomerang.com, deployed August 11-September 28, 2004

Self-Assessment Toolkit Model, http://safety.transportation.org/doc/SelfAssessmentTool.pdf

Telephone Interviews for the case studies: Mr. Brian Fariello, San Antonio, Texas; Mr. Doug Dembowski, WisDOT, Milwaukee; Ms. Maggie Cusack, HVTMC, New York; Mr. Manny Agah, ADOT; and Mr. Victor De La Garza, El Paso, Texas. Interviews conducted by Dr. Park, Mr. Venkatanarayana and Mr. Best.

The GCM Corridor Performance Measures Subcommittee, A Proposal for Developing GCM Performance Measures, December 2004

WisDOT Southeast Region, MONITOR Traffic Operations Center, Monthly Performance Report, draft, September 2005

Appendix A. Preliminary Survey

The following is a summary of results from a survey conducted entitled "TMC Performance Measures." It was launched via the online survey service Zoomerang (http://www.zoomerang.com) on August 11, 2004. It consisted of 24 questions. A total of 53 TMC personnel were invited to take the survey, of which 28 responded. Some of the information collected through this survey divulged personal information about the person taking it; such responses have not been included in this report to keep this information confidential. The results have been summarized as much detail as possible.

Question 1 – Name and Contact Information. Information collected included Name, Position, Name of TMC, Address, Phone Number, and Email Address.

Individual responses kept private in this report.

Question 2 -- At what stage of development is your TMC? Is your TMC operational in that ITS functions are being carried out routinely, or is your TMC working to develop an ITS program?

Fully operational – 86%

Partially operational – 14%

Question 3 -- What is your annual operational budget?

Less than $500,000 – 22%

$500,000 to $999,999 – 7%

$1,000,000 to $1,999,999 – 19%

$2,000,000 to $2,999,999 – 15%

$3,000,000 to $3,999,999 – 7%

$4,000,000 to $4,999,999 – 7%

More than $5,000,000 – 15%

Don't Know – 7%

Question 4 -- How many centerline miles with real-time traffic data collection technologies do you manage?

0 to 49 miles – 32%

50 to 99 miles – 2%

100 to 149 miles – 18%

150 to 199 miles – 14%

200 or more miles – 11%

Question 5 -- How many total employees are on staff at your TMC?

Less than 25 – 68%

25-49 – 21%

50-99 – 7%

100 or more – 4%

Question 6 -- What percentage of your employees are privately-contracted employees?

0% -- 46%

1% to 25% -- 29%

25% to 49% -- 4%

50% to 74% -- 4%

75% to 100% -- 18%

Don't know – 0%

Question 7 -- If your TMC hires contracted work, what jobs are given to contractors? Check all that apply.

Software Development/IT – 65%

Dispatcher Positions – 27%

Management – 15%

Secretaries – 4%

Performance Evaluations – 12%

Planners – 4%

Incident Response Team Drivers – 19%

None of the Above – 19%

Other, Please Specify -- Responses Included: Towing operations on the roadway, system and equipment maintenance, operations staff, field work, and ATMS operators.

Question 8 -- What ITS functions does your TMC currently use? Check all that apply.

Closed-circuit television monitoring – 100%

Variable Message Signs – 100%

Variable Speed Limit Signs – 14%

Automated Collision Notification Systems – 7%

Traffic Signal Coordination – 36%

Ramp Metering – 32%

Lane Control Signals – 21%

HOV System – 29%

Electronic Fare Payment – 0%

Electronic Toll Collection – 4%

None of the Above – 0%

Other, Please Specify – Responses Included: HAR, speed sensors, weather stations, vehicle detection, speed detection, website, and travel time estimation.

Question 9 -- Which ATIS methods does your TMC use to distribute information to the public? Check all that apply.

Web Site – 100%

Dedicated Cable Television – 25%

Kiosks – 14%

Automated Telephone System – 39%

In-Vehicle Navigation Systems – 0%

Notifications by Email, Pager, or Cell Phone – 54%

None of the Above – 0%

Other, Please Specify – Responses Included: VMS, fax, media notification, television news media, HAR, and highway condition reporting system.

Question 10 -- If your TMC has its own web site, what information is presented on it? Check all that apply.

Construction Delay Information – 57%

Incident Statistics – 7%

Incident Delay Information – 48%

Travel Time – 11%

Weather-Related Delay Information – 30%

CCTV Images – 85%

Current Variable Message Sign Displays – 22%

None, No Web Site – 7%

Other, Please Specify – Responses Included: Travel conditions, closures, current travel speeds, counties in snow emergency, HAR messages, general information about program, reversible lane status, maintenance activities, and current incidents.

Question 11 – What data do you collect from your traffic monitoring procedures? Check all that apply.

Average Motorist Speed – 71%

Recurring Delay – 14%

Travel Time – 21%

Traffic Volume – 75%

Incident Delay – 29%

Emergency Management Response Times – 25%

Weather Information – 25%

None of the Above – 7%

Other, Please Specify – Responses Included: Corridor travel speed, incident response data.

Question 12 -- With whom do you share these traffic data? Check all that apply.

State DOT – 63%

Other TMCs – 63%

Emergency Personnel (Fire, Rescue, Police, Etc.) – 48%

Local Media – 48%

Transit Agencies – 15%

Bridge/Tunnel Authorities –11%

None of the Above – 19%

Other, Please Specify – Responses Included: The public, FHWA, local universities, MPOs, the city.

Question 13 -- Does your center archive data?

Yes – 89%

No – 11%

If so, what type of data is archived?

Responses Included: Number and type of motorists assists, number of CMS and HAR activations, stops by each Incident Management Assistance Patrol drivers, speed, incidents, metering rates, volume, VMS usage and logs, limited traffic volume, vehicle occupancy, incident reports, HAR logs, service patrol activities, lane control signals, daily road conditions and weather, sign changes, loop detector data, VSO data, maintenance field work, field equipment, and courtesy patrol call card data.

Question 14 -- Has your TMC published any information regarding ITS performance measures?

Yes – 14%

No – 64%

Not Yet, But Will in the Future – 21%

Question 15 -- If your TMC has published any sort of performance report, please use the space below to tell us how we may access it.

Individual responses kept private in this report.

Question 16 -- If your TMC has not yet published a performance evaluation report but plans to, at what date should this report be completed?

2004 – 4%

2005 – 18%

Question 17 -- Which of the following performance measures does your TMC analyze in these reports? (If no report has yet been published, which of the following performance measures would likely be used in a performance evaluation?) Check all that apply.

Benefit-Cost Analysis – 57%

Incident Delay Analysis – 62%

Travel Time – 29%

Crash and Fatality Reduction – 38%

Emissions and Fuel Consumption – 24%

Dispatcher Evaluations – 19%

Comment Cards – 19%

Motorist Phone Calls – 14%

Website Surveys – 24%

Website Hits – 38%

None of the Above – 5%

Other, Please Specify – Responses Included: Year to year incident, delay, P.D. response time, number of devices implemented, and number of messages posted

Question 18 -- Does your TMC publish performance evaluations reports periodically? (If no, then skip to question 21)

Yes – 21%

No – 79%

If so, how often are they published?

5 Responses Included:

Annually – 3

Quarterly – 1

Monthly -- 1

Question 19 -- In what format are the reports published?

Newsletter – 0%

Formal Report – 63%

Website Presentation – 0%

None, No Reports Published – 25%

Question 20 -- With whom are performance evaluation reports shared? Check all that apply.

FHWA – 29%

State DOT Administration – 100%

The Public – 14%

Contractors – 0%

Internal Personnel – 57%

Emergency Personnel (Fire, Rescue, Police, Etc.) – 57%

Other TMCs – 29%

Other, Please Specify – 1 Response: Published on the web

Question 21 – Do you have any consistent benchmarks that you use for performance measures?

Yes – 17%

No – 83%

Question 22 -- If certain benchmarks are used, please describe them.

Responses Included: Accidents, speed, volume, occupancy, response time, lane clearance time, urban and rural response times

Question 23 -- Does your TMC design performance measures suited specifically to the TMC, or are performance measures designed according to a system-wide performance monitoring process?

Performance measures designed specifically for TMC – 36%

Performance measures designed for system-wide performance monitoring process – 64%

Question 24 -- If there is anything else you would like to tell us about the performance of your TMC that was not specifically addressed in this survey, please use the space below.

5 Responses Included:

1	We are in the infancy stage of development. It is anticipated that the next two years will lead to dramatic changes in the way we do business.
2	Colorado has three major TMC offices, Denver, Colorado Springs and Glenwood Springs.
3	Performance measurements are being developed through State Central ITS office and local efforts. Final draft is being developed.
4	Our TMC also develops ITS projects for statewide implementation
5	initial steps focus on measuring performance (e.g. number of incidents over time) vs. impact (e.g. delay or reduction in delay at these incidents)

Appendix B. Survey Results on the Execution of the Self Assessment Toolkit

The following is a summary of online survey that executed the self assessment toolkit presented in Chapter 7 of this handbook. Again, the survey was distributed to the agencies participating in the TMC Pooled Fund Studies, and from other sources. The results were discussed in Chapter 7 in great detail. This survey was sent out to a total of 110 people across the nation, during the period 06/29/05 and 09/16/2005 and 32 actual responses were received, corresponding to 29% of the entire group.

TMS Performance Measurement Plans	Percent Responses					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
Our agency has adopted a performance measurement plan including agency objectives, goals, and performance measures (i.e., there is a program in place for regular measurement of transportation system and TMS performance).	20	43	20	10	7	0
Our agency has implemented decision-making (e.g., resource allocation and/or future project selection) based on TMS performance measures.	17	17	33	20	7	7
Our agency's planning process reflects measurements of actual system performance, like travel time, reliability, and incidence of non-recurring congestion.	17	37	10	27	7	3
Our agency has a performance measure-based index to gauge the system as a whole.	13	13	23	37	10	3

TMS Performance Measurement Plans	Percent Responses					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
Our agency has conducted executive-level TMS performance measurement briefings for policy and decision makers.	10	20	23	30	17	0
Our agency promotes multi-disciplinary teams to improve coordination, cooperation, and communication of TMS performance measurements.	23	43	13	10	10	0
Our agency promotes communication between data collectors and users to improve understanding of data issues and uses.	17	45	21	14	3	0
Our agency has established multi-agency agreements on what measures will be tracked and used to measure TMS performance	7	7	30	33	20	3
Our agency has conducted/adopted or collaborated with other agencies research on best practices for improving TMS performance measurement initiatives.	13	40	13	13	13	7
Our agency has documented a guide of best practices for improved collection, management and use of performance measures and information.	13	33	20	20	13	0
Our agency conducts periodic reviews of whether or not progress is being made to achieve agency goals (i.e., targets).	17	27	20	23	10	3

TMS Performance Measurement Plans	Percent Responses					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
Our agency evaluates its field data requirements to insure they support the performance measures being used for our TMS.	13	33	30	10	13	0
Our agency collects field data towards gathering performance measures directly, where possible (e.g., direct collection of travel time instead of estimating from speed).	63	33	3	0	0	0
Our agency maintains the inventory of operational field devices (e.g., traffic sensors, CCTV, VMS, loops, controllers, ramp meters).	43	37	10	10	0	0
Our agency tests the functional reliability of field devices (e.g., traffic sensors, CCTV, VMS, loops, controllers, ramp meters), on a regular basis.	13	47	20	13	7	0
Our agency has adopted guidelines to maintain good quality and consistency of data collection.	0	37	17	33	10	3
Our agency conducts periodic independent data record assessments to ensure quality of data.	3	10	33	17	37	0
Our agency documents data quality and it is passed ontousers and other agencies.	3	10	30	23	23	10
Our agency archives data.	0	0	10	17	43	30

TMS Performance Measurement Plans	Percent Responses					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
Our agency shares data with external users.	0	0	10	7	50	33
Our agency monitors transportation system performance (e.g., system outcomes such as throughput, speed, travel time, number of incidents, etc) in real-time.	0	3	10	13	43	30
Our agency monitors various TMS components (e.g., sensors, communication systems) used in collecting data for performance measures at regular intervals (monthly, quarterly, or yearly).	0	7	13	7	50	23
Our agency monitors the performance of our maintenance program (i.e. device maintenance, system up and downtime, mean time between failure of equipment etc.).	3	3	30	13	40	10
Our agency has a set of quantitative performance measurement goals (e.g., duration for which average speeds are below a certain mph at peak period, incident response time).	3	10	30	23	27	7
Our agency has a set of qualitative performance measurement goals (e.g., customer satisfaction, coordination with other agencies, etc.).	0	10	20	33	27	10
Our agency internally measures the performance of human operations (e.g. response time to incidents, efficiency of operators etc.).	3	13	17	20	33	13

TMS Performance Measurement Plans	Percent Responses					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
Our agency measures the percentage of signals coordinated across jurisdictions with other cities/counties etc.	17	10	31	14	24	3
Our agency often uses simulation modeling or estimation based performance measures when direct measures are not available.	7	13	30	23	23	3
Our agency uses data from external agencies towards performance evaluation.	10	20	30	23	13	3
Our performances measures are being used in other types of analyses besides performance reporting (e.g., system evaluations or multimodal analyses).	7	13	23	40	13	3
Our agency reports TMS (e.g., incident management system, etc.) and transportation network performance (e.g., average speed, number of incidents, etc.) at regular intervals (monthly, quarterly, or yearly).	3	7	27	27	20	17
Our agency's performance measurement report includes trend over time.	3	13	30	30	17	7
Our agency's performance measurement report is published on our website.	10	33	27	20	3	7

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A Technical Handbook

Federal Highway Administration

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