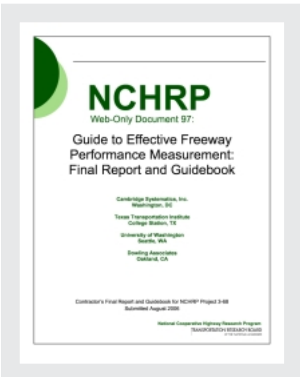
NCHRP
Web-Only Document 97:
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Guide to Effective Freeway Performance Measurement: Final Report and Guidebook

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Contractor's Final Report and Guidebook for NCHRP Project 3-68
Submitted August 2006

National Cooperative Highway Research Program
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Guide to Effective Freeway Performance Measurement

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ABSTRACT

This report documents the research performed on the project. Detailed recommendations and guidance are provided in the *Guidebook*, which is structured for providing transportation engineers and planners assistance in developing and maintaining a comprehensive freeway performance monitoring program. In the research, multiple aspects of freeway performance were considered, but congestion and mobility performance was emphasized because of the lack of guidance and experience in this area. Other aspects included safety, operational efficiency, ride quality, environmental, and customer satisfaction. A review of current practice was conducted, including a review of the private sector as well as 11 benchmarking interviews with state and local transportation agencies. Based on these results, the *Guidebook* was structured to answer four primary questions about freeway performance: 1) what measures should be used; 2) how can the measures be developed with data and models; 3) how should freeway performance be communicated; and 4) how can freeway performance measures be used in decision-making. The draft *Guidebook* was developed as a series of nearly 400 annotated slides which were reviewed in five additional interviews with state and local agencies. The final *Guidebook* presents step-by-step procedures addressing the four primary issues associated with freeway performance monitoring. Ongoing freeway performance monitoring of recent trends is emphasized although the use of performance measures across project evaluations and analysis also is covered.

SUMMARY OF FINDINGS

BACKGROUND

The use of freeway performance measures has been growing in recent years, and ranges from site-specific operations analysis, corridor-level alternative investments analysis, and area-wide planning and public information studies. In the past few years, the issue of performance monitoring has been elevated by transportation agencies to be responsive to the demands of the public and state legislatures and the Transportation Equity Act for the 21st Century's (TEA-21). The Safe, Accountable, Flexible, Efficient Transportation Equity Act for the 21st Century – A Legacy for Users (SAFETEA-LU), the most recent Federal transportation authorization legislation, continued this emphasis on performance monitoring, particularly with regard to system operations and management. Simultaneously, the deployment of intelligent transportation systems (ITS) technologies has the potential to make a vast amount of data available for analysis.

However, many challenges lie ahead before freeway performance measurement becomes "standard practice" and is imbedded in the transportation decision-making process. These challenges include the following:

- The transportation profession is only beginning to define and measure congestion/mobility performance in objective terms.
- More detailed measures than *HCM*-based levels of service are required to capture the effect of operational strategies, which are often more subtle than capacity expansion projects.
- Based on what data are available, congestion is growing in areas of every size.
- Freeway performance must be viewed from several perspectives.
- The concept of "reliability" is growing in importance.
- While advances in freeway performance concepts have been made, data limitations hamper their implementation.
- In the short term, some combination of surveillance data, planning data, and modeling must be used to support freeway performance measurement.
- Communication of freeway performance monitoring results also is crucial.
- How freeway performance measures are to be used in the transportation decision-making process is still evolving.

BENCHMARKING INTERVIEWS

A major part of this research effort was to ascertain what the more progressive agencies are doing in the area of freeway performance measures. A series of benchmarking interviews with state and local transportation agencies was conducted, resulting in the following findings.

Motivations for Undertaking Freeway Performance Measurement

Four motivations exist for agencies to undertake freeway performance measurement:

1. **Legislative Mandates**. State legislatures may require transportation (as well as other state) agencies to engage in a formal performance measurement and reporting process. Freeway performance measures are undertaken initially primarily to feed a mandated reporting process, but managers learn that there is intrinsic value in conducting freeway performance measurement for their own purposes (see reasons 3 and 4 below).

2. **Agencywide Performance Measurement Initiatives.** Even in the absence of legislative intervention, DOTs and MPOs often initiate department-wide performance measurement programs for a variety of reasons. Usually these are ostensibly linked to the notion of "customer focus" and improved public relations and involvement. Like legislative mandates, these efforts result in Annual Performance Reports. Freeway performance is usually couched in terms of congestion/mobility in these reports and is usually summarized at the State or major metropolitan area level.

3. **Formal Business Plan Linkage, Particularly for Operations.** Several agencies have taken a formal business plan approach to the actions. The undertaking of Business Plan can be dictated by DOT upper management or self-initiated by a champion.

4. **Quantification of Benefits for Freeway Programs, Particularly for Operations.** Operations personnel are discovering that when it comes to competing for internal resources and visibility, they are at a disadvantage compared to other functional areas. Infrastructure programs have a long history of documenting the effects their program have users, as embodied in pavement, bridge, and maintenance management systems. "Not having the numbers" makes it hard to argue in favor of programs when others do have the numbers.

In two of the interview cities freeway performance measurement has not yet been undertaken, though there were signs that this may change (i.e., they may just be "late adopters"). None of the four motivations currently are present in these cities and local managers are not convinced of the cost-effectiveness of implementing performance measurement. In this sense, they are no different from the other cities – without strategic, legislative, or top management mandates/initiatives, it is doubtful that the other areas would have undertaken performance measurement.

Types of Performance Measures Used by Agencies

Both outcome and output measures are used by agencies. In the literature of performance measurement, a distinction is made between output and outcome types of measures:

- **Output** measures relate to the physical quantities of items; levels of effort expended, scale or scope of activities; and the efficiency in converting resources into some kind of product. Output measures are sometimes called "efficiency" measures.
- **Outcome** measures relate to how well the firm or agency is meeting its mission and stated goals. In the private sector, outcome measures relate to the "bottom-line" – the financial viability of the firm (e.g., profit and revenue). For transportation agencies, outcomes are more related to the nature and extent of the services provided to transportation users.

The research team and the project panel thought that, although the output/outcome dichotomy is well-established, it is confusing to new users. Therefore, an alternative naming convention was adopted:

- **"Quality of Service"** is a more intuitive term for the **outcome** category of measures, and
- **"Activity-Based"** is more apt for the **output** category of measures.

It is clear that agencies who have undertaken freeway performance measurement have accessed the literature on performance measurement because they use the outcome/output terminology.

For outcome measures, derivatives of speed and delay are commonly used by both operating and planning agencies. The Travel Time Index is a popular metric. Level of service as a metric is still in use in both planning and operations agencies, though it is not as widespread as it might have been 10 years ago. Reliability metrics have not yet found their way into widespread use. These metrics are usually formulated for short segments or at key locations. An exception is Seattle where a series of defined "freeway trips" have been defined – these can involve travel over multiple freeway routes for extended lengths. Output measures are used primarily by operating agencies, and then primarily for incident management activities and the operation of field equipment (e.g., sensors, cameras).

Many areas are beginning to define more sophisticated measures for measuring congestion/mobility performance but have not yet implemented them. Overall, there appears to be a trend away from the general categories of performance (LOS) and toward continuous measures that are based on delay and travel time. Further, consideration of travel time reliability is growing in acceptance, though its implementation is still problematic, primarily due to data requirements.

Customer satisfaction measures, where collected, are not used specifically for freeway performance measurement. Rather, they are instituted to gauge overall opinions about how well an agency is dealing with congestion.

Use of Performance Measures

Development of performance reports appears to be the major use right now for outcome-related freeway performance measures. The frequency of publication varies from weekly to annually, but annual reports are the most common. The linking of performance measures (more specifically, changes in them over time or their level relative to preset targets) and investment decisions is not well established. The best examples of actions taken based on performance measures is the tracking of detailed output measures for incident management programs – there is evidence that agencies act on these to modify activities such as service patrol routing and schedules. However, a linkage between major freeway investments and outcome measures (e.g., freeway delay) was not found. This may be due to the lack of experience with developing and applying the measures rather than with an unwillingness to use them to support investment decisions. It is true, however, that having better information on the scope and causes of congestion tends to lead towards more open thinking about what to fund to improve the situation. What it does not solve is the fact that the state and MPO planning processes choose large investments that are based on long-range needs rather than on short-term changes in performance measures (or the failure to meet current performance targets).

State DOTs and MPOs have not yet directly collaborated in joint efforts in developing freeway performance measurement programs. There seems to be a split of responsibility along traditional lines: DOTs tend to handle construction and operations while MPOs handle planning activities. Some MPOs and DOTs use common measures, but also develop measures unique to their applications.

Data Collection and Analysis

Metrics are developed through a variety of methods: operations agencies (whose focus is primarily freeways) rely heavily on archived roadway surveillance data; the development of formal data archive management systems is on the rise. Planning agencies (whose purview includes all roadways in an area) use a mix of methods, including travel demand forecasting and other models; sample-based travel time runs from floating cars; and overlapping aerial photography. Planning agencies are just now starting to tap ITS data archives as a source of data for performance measures; this occurrence is not very widespread.

Universities within a state are commonly used to set up (at least initially) performance measurement programs and data archives. Sometimes these functions are passed on to the DOT, sometimes the universities retain control.

Integration of the various data sources available (ITS roadway surveillance, events {incidents, weather, work zones}, and sample-based data) is not well very well advanced. However, there is recognition that this must occur, especially in areas that consider delay by congestion source (e.g., incidents) as an important measure.

Collection and use of incident data are becoming more common among freeway management systems. However, every area defines data elements and collects data differently. Work zones are occasionally collected as part of incident data. Collection of weather data is uncommon.

Data Quality

The quality of data from ITS roadway sensors is a major concern of agencies and has even caused trepidation in using the data for freeway performance measurement. Data quality problems can be traced primarily to two sources: 1) improper installation (including initial calibration and acceptance testing of equipment) and 2) inadequate detector maintenance due to funding shortfalls. This is a serious problem for freeway performance measurement, especially since ITS roadway sensors provide continuous data at the small time and geographic increments necessary to support sophisticated measures (reliability, congestion by source). The most extreme case is Houston which basically relies on probe readers for travel time estimates – they do not rely on the roadway sensors originally installed. As a result, since volumes are not available, not all the performance measures that are possible can be constructed.

When formal archived data management systems are implemented, data quality control checks are instituted. However, these are *post hoc* in nature – they can test for inconsistencies based on valid ranges, checks against theory, and checks against history, but subtle errors in accuracy still occur and are unknown. (The only way to determine accuracy is to validate field measurements independently.)

GUIDEBOOK DEVELOPMENT

The *Guidebook* was structured to deal with the technical and institutional issues identified in the bench-marking interviews. The *Guidebook* addresses each stage in the freeway performance measurement process with step-by-step procedures for transportations to follow. The scope of the *Guidebook* covers:

- Urban and rural freeways: a comprehensive approach to freeway performance measurement;
- A focus on throughput/congestion/mobility of freeways, because of the lack of experience in these areas;
- Discussion of additional aspects of freeway performance:
  - Freeway safety;
  - Operational efficiency;
  - Ride quality – Affects quality of traffic flow (link to asset management information systems);
  - Environmental – Emissions and fuel use; and
  - Customer satisfaction.

A chapter of the *Guidebook* is devoted to each stage of the freeway performance measurement process:

- **Rationale for Freeway Performance Measurement: "Why are we doing this?"**
- **Context for Freeway Performance Measurement: "How does it fit in?"**
- **Performance Measures (Metrics): "What measures should be used?"**
- **Supporting Data and Methods: "How are the measures developed?"**
- **Presentation and Communication: "How are the measures best presented?"**
- **Use of Freeway Performance Measures in Decision-Making: "How are the measures used to support decisions?"**

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

1.1 BACKGROUND

The use of freeway performance measures has been growing in recent years, and ranges from site-specific operations analysis to corridor-level alternative investments analysis and to areawide planning and public information studies. In the past few years, the issue of performance monitoring has been elevated by transportation agencies to be responsive to the demands of the public and state legislatures and the Transportation Equity Act for the 21st Century's (TEA-21). The Safe, Accountable, Flexible, Efficient Transportation Equity Act for the 21st Century – A Legacy for Users (SAFETEA-LU), the most recent Federal transportation authorization legislation, continued this emphasis on performance monitoring, particularly with regard to system operations and management. Simultaneously, the deployment of intelligent transportation systems (ITS) technologies has the potential to make a vast amount of data available for analysis.

However, many challenges lie ahead before freeway performance measurement becomes "standard practice" and is imbedded in the transportation decision-making process. These challenges include the following below.

The transportation profession is only beginning to define and measure congestion/mobility performance in objective terms. For more than 35 years, the *Highway Capacity Manual* (*HCM*)[1] has served as the focal point for defining quality of traffic flow. Prior to the 2000 edition of the *Manual*, performance was defined by broad ranges of "levels of service" (LOS). Even with the publication of the 2000 edition, freeway performance is still largely tied to the level of service concept. The 2000 edition of the *Manual is* beginning to address the "saturated flow regime" (i.e., congestion) in a comprehensive fashion and to recognize that a single LOS category, ("F") does not capture the nature and extent of congestion. At the local level, measuring and reporting congestion have often been done anecdotally without the advantage of the limited application of the *HCM*. Future versions of the *HCM* will delve into this problem more deeply.

More detailed measures than *HCM*-based levels of service are required to capture the effect of operational strategies, which are often more subtle than capacity expansion projects. Implementing operational strategies usually never eliminate congestion but rather improve it slightly. These effects are not captured with the broad LOS ranges recommended by the *HCM*.

Based on what data are available, congestion is growing in areas of every size. The Texas Transportation Institute's (TTI) *2004 Annual Urban Mobility Report*[2] shows more severe congestion that lasts for a longer period of time, and affects more of the transportation network in 1999 than in 1982 in all urban population categories. The average annual delay per person climbed from 11 hours in 1982 to 36 hours in 1999. And delay over the same period quintupled in areas with less than one million people. The time to complete a trip during the congested period also continues to get longer. Further, congestion is consuming a greater part of the day in many metropolitan areas. The concept of a "peak hour" (rush hour) has been rendered irrelevant by travel patterns that have led to "peak periods" – multiple successive hours characterized by congestion.

Freeway performance must be viewed from several perspectives. A debate within the profession has arisen over the proper perspective for measuring performance. With regard to mobility performance, some have suggested that the view of the **user** (traveler) is the most appropriate, while others argue that the view from the **facility** is the correct perspective. We have found this to be a specious argument: both perspectives are needed. The user perspective is important, because that is how transportation customers experience the system; this relates to characteristics of users' trips. The facility perspective is important, because transportation professionals mainly manage facilities; trips also are managed by such strategies as traveler information and demand management, but to a lesser degree than facilities. Further, the two perspectives are closely related in computation, data requirements, and the measures that can be applied. With regard to freeway performance, "trips" can be defined over extended segments. Finally, **homeland security** issues are becoming increasingly important for transportation professionals. Freeway performance measures can be useful in both planning (identifying evacuation routes) and operations (real-time management of evacuations.)

The concept of "reliability" is growing in importance. There is growing recognition in the profession that not only does congestion occur on "typical" or "average" days, but it is the variability that occurs day to day that is important. Therefore, freeway performance must include the notion of reliability to be useful to both operators and planners.

While advances in freeway performance concepts have been made, data limitations hamper their implementation. As performance concepts become more sophisticated, the data requirements of supporting them become more onerous. In particular, reliability requires that data be collected nearly continuously. Even without considering reliability, more detailed data resolution is required to monitor changes due to operational strategies;

and traditional monitoring data, which are scattered and sampled, may be adequate for determining major capacity expansions, but lack the resolution to capture the effects of more modest operational improvements. As our own work has demonstrated, freeway surveillance data generated from ITS technologies can be used effectively for these purposes. But these data bring with them a variety of new issues, among them:

- In the short term, some combination of surveillance data, planning data, and modeling must be used to support freeway performance measurement. Since surveillance coverage is not complete and data problems will cause gaps in existing coverage, other means must be used to fill in the freeway performance picture. However, the system performance data derived from surveillance data may be significantly different from other estimates or modeling efforts. Combining freeway surveillance data with other data sources should be conducted only where the differences in each type of data are well understood, and where the need for a combination of data is unavoidable.
- **Communication of freeway performance monitoring results also is crucial.** This involves not only selecting measures that are easily understood by a broad audience, but also conveying the results in formats that can be easily interpreted. Communication to both technical and lay audiences is a major part of our current efforts in this area, and we will build on this experience.
- **How freeway performance measures are to be used in the transportation decision-making process is still evolving.** Most of the work to date on freeway performance monitoring has been in defining the concepts, measures, and data to support them. However, it is clear that the profession must move beyond the simple reporting of freeway performance trends – performance measures must be used to develop better investment decisions.

1.2 SCOPE OF THE RESEARCH

The objective of the research is to produce a practical *Guidebook* that provides guidance: "… on the effective use of freeway performance measures in operating the system and in meeting the information needs of a large spectrum of potential local, regional, and national users." The *Guidebook* presents a comprehensive approach to measuring the performance of urban and rural freeways. Freeways are defined as access-controlled highways characterized by uninterrupted traffic flow. The aspects of freeway performance covered by this *Guidebook* are as follows.

The focus of the work is on congestion/mobility performance of freeways. This can be further defined as "quality of traffic flow or traffic conditions as experienced by users of the freeway." This category includes measures related to typical congestion levels, travel time reliability, and throughput. It also includes supporting measures on the nature of roadway "events" that impede traffic flow: incidents, weather, and work zones. Most of the research conducted in preparing the *Guidebook* shows how these measures are developed from data and other analytic methods. Mobility is defined differently for urban versus rural freeways, as discussed later in this *Guidebook*. The rationale for focusing on congestion/mobility performance is that, of the major performance categories, it has the least amount of history with practitioners and is the least well formed. New concepts such as travel time reliability and the deployment of transportation operations strategies in recent years underscore the emerging nature of this area.

Despite the focus on congestion/mobility, other aspects of freeway performance also are covered, but not at the same level of detail. These areas (with the exception of customer satisfaction) have a much longer history of performance measurement in the profession. So, rather than "reinvent the wheel," the *Guidebook* uses references for much of its material. As a result, data and methods for other aspects of freeway performance are not covered in detail. Rather, the measures for each category are identified and methods for integrating them into a comprehensive freeway performance measurement program are presented, including their use in applications and decision-making. In some cases, these other performance aspects have or are developing their own performance measures, usually applied on an areawide basis. These additional aspects of freeway performance are:

- Freeway Safety – Especially safety aspects that are under the direct control of transportation agencies. Safety performance measures are now being considered as part of the recent emphasis on comprehensive highway safety plans.
- Operational Efficiency – Measures that relate to the activities and equipment used in freeway management.
- Ride Quality – Especially as it relates to the quality of traffic flow. Asset management information systems have long history of ride quality performance measures.
- Environmental – Emissions and fuel use are the areas covered in this *Guidebook*, although many other additional environmental aspects could be covered.

- Customer Satisfaction – As transportation agencies adopt a stronger focus on their customers (i.e., users of the system), customer perceptions of performance are becoming important feedback on the effectiveness of transportation programs.

1.3 RESEARCH APPROACH

The research undertaken for this project was in several parts.

- The research team compiled a list of potential performance measures and their uses by reviewing the literature and compiling their own experiences with Federal, state, and local agencies.
- Benchmarking interviews were conducted to ascertain the state of the practice. Agencies from 10 areas were interviewed (Table 1). Six of the interviews included multiple agencies, usually state operations personnel, state, and local planners. Four interviews were conducted with operations personnel only.
- An interim report and detailed annotated outline were produced based on the above activities. It included establishing basic principles for freeway performance measures that were used to guide the rest of the project.
- The annotated outline was used to construct approximately 400 annotated slides which form the basis for the *Guidebook*. The slides were distributed to agencies from five areas and these areas were interviewed by the research team to validate the approach and information:
  - Oregon DOT/Portland Metro;
  - Arizona DOT/Maricopa Association of Governments;
  - Minnesota DOT/Twin Cities Metropolitan Council;
  - Georgia DOT/Atlanta Regional Commission; and
  - New York State DOT/Capital District Transportation Committee.
- Based on the validation interviews, the annotated outline was revised and the draft *Guidebook* was prepared. This preparation included developing analysis procedures using data from ITS sources.

Table 1. Initial Benchmarking Interview Locations

Metro Area	Agencies Interviewed
Multiple Agency Interviews	
1. Minneapolis-St. Paul, Minnesota	Metro District Operations, Mn/DOT Center for Transportation Studies, University of Minnesota Metro Council
2. Seattle, Washington	WSDOT HQ Traffic Office WSDOT NW Region WSDOT HQ Strategic Planning and Programming Puget Sound Regional Council
3. Hampton Roads, Virginia	Hampton Roads STC, VDOT Hampton Roads Planning District Commission
4. Milwaukee, Wisconsin	WisDOT District 2 Operations WisDOT Central Office University of Wisconsin-Madison WisDOT District 2 Planning
5. Phoenix, Arizona	ADOT/Intermodal Transportation Division ADOT/Transportation Planning Division Maricopa Association of Governments
6. Los Angeles, California	Caltrans, Freeway Operations, District 7 Southern California Association of Governments Caltrans, Planning
Operations Interviews Only	
7. Portland, Oregon	See Note[1]
8. Houston, Texas	Houston TRANSTAR
9. San Antonio, Texas	See Note[2]
10. Washington, D.C.	CHART (Maryland) VDOT Northern Virginia District
11. Atlanta, Georgia	GDOT, Office of Traffic Operations

[1] No formal interviews were conducted as part of NCHRP 3-68. Rather, the team relied on other work conducted by TTI on performance measures. As part of this effort ODOT assembled a Technical Advisory Committee (TAC) made up of individuals from ODOT sections of traffic management, transportation planning and analysis, transportation data, traffic operations, and internal audit/performance measures. The TAC also included individuals from the metropolitan planning organization (MPO) in Portland (Metro) and the Eugene/Springfield area (Lane Council of Governments), academia, and the local Federal Highway Administration (FHWA) office.

[2] Initial conversations with TransGuide indicated that they are not currently using performance measures nor are they planning on developing them in the near future. TransGuide does have an extensive sensor system (485 lane-miles) and a formal incident management program from which detailed performance measures could be developed, however.

1.4 RELATIONSHIP TO CURRENT RESEARCH EFFORTS

There currently is much activity in the area of performance measurement, particularly for congestion/mobility performance. Table 2 summarizes these efforts and indicates their relationship/value to the current project. Many of these projects have been drawn on in later sections to provide examples of freeway performance measurement. Note that only projects that are active have been included; these are the ones that may influence – and be influenced by – the current project. In addition, the Strategic Highway Research Program II (SHRP II) also may include projects related to freeway performance measurement.

Of the projects listed in Table 2, NCHRP Project 7-15 is the closest in nature to the research in this report. HRP 3-68 has coordinated with the Project 7-15 team to ensure synergy and avoid duplication. The thrust of Project 7-15 is the use of travel time, delay, and reliability measures in a wide variety of applications undertaken by planners. Note that it is meant to cover all highway types, not just freeways. Much detail on development of performance measures is given there, and in some ways the Project 7-15 report can be viewed as a companion document to this one.

Specifically, NCHRP 7-15 is geared to estimating travel time, delay, and reliability for the following planning applications:

- **Application #1. Evaluate Trends In Travel Time, Delay, And Reliability.** The objective of this application is to identify and track overall trends in travel time, delay, and reliability for the purposes of preparing a report to the public on agency performance.
- **Application #2. Identify Existing Deficiencies.** The objective of this application is to identify and diagnose existing deficiencies in travel time, delay, and reliability for the purposes of determining appropriate agency actions.
- **Application #3. Evaluation of Effectiveness of Improvements**. The objective of this application is to determine if the implemented improvement actually resulting in the desired travel time, delay and reliability savings for the purposes of the cost-effectiveness of agency of specific actions.

- **Application #4. Prediction of Future Conditions.** The objective of this application is to identify and diagnose future deficiencies in travel time, delay, and reliability for the purposes of determining appropriate agency actions.
- **Application #5. Alternatives Analysis**. The objective of this application is to develop a set of actions to improve facility or system performance.

Of these applications, Application #1 has the most overlap with this report; the *Guidebook* is focused on developing ongoing performance monitoring programs. The *Guidebook* provides exhaustive detail on this application. The other applications are discussed in the *Guidebook,* but NCHRP 7-15 covers these in detail. On the other hand, the congestion/mobility performance measures (including reliability) identified in the *Guidebook* are the basis for the NCHRP 7-15 effort.

1.5 *GUIDEBOOK* Development

The *Guidebook* was structured to deal with the technical and institutional issues identified in the bench-marking interviews. The *Guidebook* addresses each stage in the freeway performance measurement process with step-by-step procedures for transportations to follow. In developing this *Guidebook*, a set of primary questions was developed surrounding freeway performance measurement. Answering these questions from the practitioner's point of view is the thrust of the *Guidebook* and serves as the basis for its structure:

- **Rationale for Freeway Performance Measurement: "Why are we doing this?"** Why is freeway performance important and why should its measurement be undertaken? What applications and uses can use freeway performance measures? What is the current state of the practice in freeway performance measurement? (Section 3.0)
- **Context for Freeway Performance Measurement: "How does it fit in?"** How does one establish and maintain a freeway performance measurement program? How does it mesh with other local, regional, state, and national activities in planning, operations, maintenance, and design? How should it evolve over time? (Section 4.0)
- **Performance Measures (Metrics): "What measures should be used?"** What aspects of freeway performance should be measured? What principles should be followed in establishing freeway

performance measurement programs? What specific and quantifiable measures (metrics) should be used for each of these aspects? (Sections 5.0 and 6.0)

- **Supporting Data and Methods: "How are the measures developed?"** What data are required to support the development of freeway performance measures? What data collection mechanisms are available now or should be instituted? (Section 7.0) How should the data be processed and combined with analytic methods to create freeway performance measures? (Section 8.0)
- **Presentation and Communication: "How are the measures best presented?"** What are the options for presenting freeway performance measures to other professionals, decision-makers, and the public? How should freeway performance be explained and what is the significance of trends? (Section 9.0)
- **Use of Freeway Performance Measures in Decision-Making: "How are the measures used to support decisions?"** What should stakeholders' involvement be in using freeway performance measures? What are some examples of how freeway performance measures can be used in the decision-making process for setting policies and guiding investments? (Section 10.0)

Table 2. Relationship of NCHRP 3-68 to Other Current Performance Measurement Projects

Project	Description	Relationship to NCHRP 3-68
NCHRP 7-15, *Cost-Effective Measures and Planning Procedures for Travel Time, Delay, and Reliability*[a]	Developing analytic methods to compute travel time reliability measures, including when continuously collected data is not available. Delay by source of congestion also being considered.	Reliability measures will be compatible; analytic methods will be of value in computing freeway performance, especially for planning applications.
FHWA, *Urban Congestion Report (UCR)*[b]	Monthly reports on areawide freeway congestion developed from web-based speed maps and data.	Provides example of how to track trends at the metropolitan area level and develop performance measures from available data.
FHWA, *Mobility Monitoring Program*[c]	Annual reports (soon to be monthly) on corridor and areawide freeway congestion developed from archived and QC-passed surveillance data.	Similar to UCR for tracking trends, although corridors are the basic unit of analysis (more valuable to locals); special studies include “Lessons Learned” and analysis method to decompose congestion by source.
TTI, *Urban Mobility Study*[d]	Freeway and arterial areawide congestion trends for top 78 metro areas.	Long-standing history of congestion trends, widely accepted; pioneered new measures of congestion and develops them from planning-level data.
FHWA, *Work Zone Performance Measures*	Highly detailed performance measures and supporting data collection for monitoring work zone performance at the national and state levels.	Includes both outcome and output measures for 13 categories of work zone performance.
NCHRP 3-81, *Strategies for Integrated Operation of Freeway and Arterial Corridors*[e]	Project is to develop a manual of recommended strategies for integrating the operation of a freeway and arterial corridor, including their benefits and methods of implementing them.	Performance measures used to evaluate effectiveness of various strategies and serve as a basis for implementing them.
NCHRP 8-36/Task 47, *Effective Organization of Performance Measurement*	Studying: 1) how transportation organizations structure the performance measurement function; 2) how they organize and deliver performance information; 3) how performance measures are used to guide decisions at levels from top management down to operations; and 4) how measures are used in asset management.	Addressing the key issue of how performance measures are used in decision-making.
NCHRP 3-85, *Guidance for the Use of Simulation and Other Models in Highway Capacity Analyses*	This project will enhance the guidance in the *Highway Capacity Manual* for selection and use of simulation and other models.	Measures of effectiveness from model outputs are essentially performance measures (see Sections 4.4 and 5.0).

[a]http://www4.trb.org/trb/crp.nsf/e7bcd526f5af4a2c8525672f006245fa/62bad24780b7ac4b85256d0b005e07fb?OpenDocument.

[b]trb.org/Conferences/NATMEC/35-Wunderlich.pdf.

[c]http://mobility.tamu.edu/mmp/.

[d]http:/mobility.tamu.edu/ums/.

[e]http://www4.trb.org/trb/crp.nsf/e7bcd526f5af4a2c8525672f006245fa/e1818912cb5a8ade85256efd005b6770?OpenDocument.

CHAPTER 2

FINDINGS

2.1 BENCHMARKING INTERVIEWS

A major part of this research effort was to ascertain what the more progressive agencies are doing in the area of freeway performance measures. From these interviews it was then possible to borrow selected best practices and weave them into the *Guidebook*. It also was possible to get an understanding of what will and won't be palatable to agencies in terms of the *Guidebook* procedures. Details of the interviews appear in the Appendix and are summarized below.

Motivations for Undertaking Freeway Performance Measurement

Four motivations exist for agencies to undertake freeway performance measurement:

1. **Legislative Mandates**. State legislatures may require transportation (as well as other state) agencies to engage in a formal performance measurement and reporting process. Freeway performance measures are undertaken initially primarily to feed the mandated reporting process, managers learn that there is intrinsic value in conducting freeway performance measurement for their own purposes (see reasons 3 and 4 below).
2. **Agencywide Performance Measurement Initiatives.** Even in the absence of legislative intervention, DOTs and MPOs often initiate department-wide performance measurement programs for a variety of reasons. Usually these are ostensibly linked to the notion of "customer focus" and improved public relations and involvement. Like legislative mandates, these efforts result in Annual Performance Reports. Freeway performance is usually couched in terms of congestion/mobility in these reports and are usually summarized at the State or major metropolitan area level.
3. **Formal Business Plan Linkage, Particularly for Operations.** Several agencies have taken a formal business plan approach to the actions. Most of these are found in the private sector scan of performance measurement, i.e., the Vision-Goals-Objectives-Performance Measures-Targets-Actions sequence. The undertaking of Business Plan can be dictated by DOT upper management or self-initiated by a champion.
4. **Quantification of Benefits for Freeway Programs, Particularly for Operations.** Operations personnel are discovering that when it comes to competing for internal resources and visibility, they are at a disadvantage compared to other functional areas. Infrastructure programs have a long history of documenting

the effects their program have users, as embodied in pavement, bridge, and maintenance management systems. "Not having the numbers" makes it hard to argue in favor of programs when others do have the numbers. Maryland State Highway Administration (SHA) and Wisconsin DOT are two examples of this.

In two of the interview cities – San Antonio and Houston – freeway performance measurement has not yet been undertaken, though there are signs that this may change (i.e., they may just be "late adopters"). None of the four motivations currently are present in these cities and local managers are not convinced of the cost-effectiveness of implementing performance measurement. In this sense, they are no different from the other cities – without strategic, legislative, or top management mandates/initiatives, it is doubtful that the other areas would have undertaken performance measurement.

In applying performance measurement concepts, it appears that public agencies mirror those in the private sector. Implementation of the concepts are the difficult part for public agencies. Once the institutional hurdle of establishing a performance measurement program is passed, many technical difficulties still lie ahead, as discussed below.

Types of Performance Measures Used by Agencies

Both outcome and output measures are used by agencies. It is clear that agencies who have undertaken freeway performance measurement have accessed the literature on performance measurement because they use the outcome/output terminology.

For outcome measures, derivatives of speed and delay are commonly used by both operating and planning agencies. The Travel Time Index is a popular metric. Level of service as a metric is still in use in both planning and operations agencies, though it is not as widespread as it might have been 10 years ago. Reliability metrics have not yet found their way into widespread use. (Seattle and Minneapolis are exceptions.) These metrics are usually formulated for short segments or at key locations. An exception is Seattle where a series of defined "freeway trips" have been defined – these can involve travel over multiple freeway routes for extended lengths.

Some of the more interesting metrics used by agencies include:

- The number of very slow trips (half of free flow speed) that occurs each year by time of day and major trip (Seattle);
- Percentage of reduction in incident congestion delay; and
- Percent of freeway lane-miles below congested volumes (based on volume per lane).

Output measures are used primarily by operating agencies, and then primarily for incident management activities and the operation of field equipment (e.g., sensors, cameras).

Many areas are beginning to define more sophisticated measures for measuring congestion/mobility performance but have not yet implemented them. Overall, there appears to be a trend away from the general categories of performance (LOS) and toward continuous measures that are based on delay and travel time. Further, consideration of travel time reliability is growing in acceptance, though its implementation is still problematic, primarily due to data requirements.

Customer satisfaction measures, where collected, are not used specifically for freeway performance measurement. Rather, they are instituted to gauge overall opinions about how well an agency is dealing with congestion.

Use of Performance Measures

Development of performance reports appears to be the major use right now for outcome-related freeway performance measures. The frequency of publication varies from weekly to annually, but annual reports are the most common. The existence of dashboards was not found in any of the areas, though the Minnesota Department of Transportation (Mn/DOT) is in the development phase.

The linking of performance measures (more specifically, changes in them over time or their level relative to preset targets) and investment decisions is not well established. The best examples of actions taken based on performance measures is the tracking of detailed output measures for incident management programs – there is evidence that agencies act on these to modify activities such as service patrol routing and schedules. However, a linkage between major freeway investments and outcome measures (e.g., freeway delay) was not found. Washington State seems to be farthest along on this matter, but even there the correlation is not direct. This may be due to the lack of experience with developing and applying the measures rather than with an unwillingness to use them to support investment decisions. It is true, however, that having better information on the scope and causes of congestion tends to lead towards more open thinking about what to fund to improve the situation (at least in the case of Washington State). What it does not solve is the fact that the State and MPO planning processes choose large investments that are based on long-range needs rather than on short-term changes in performance measures (or the failure to meet current performance targets).

State DOTs and MPOs have not yet directly collaborate in joint efforts in developing freeway performance measurement programs. There seems to be a split of responsibility along traditional lines: DOTs tend to handle construction and operations while MPOs handle planning activities. Some MPOs and DOTs use common measures, but also develop measures unique to their applications.

Data Collection and Analysis

Metrics are developed through a variety of methods: operations agencies (whose focus is primarily freeways) rely heavily on archived roadway surveillance data; the development of formal data archive management systems is on the rise. Planning agencies (whose purview includes all roadways in an area) use a mix of methods, including travel demand forecasting and other models; sample-based travel time runs from floating cars; and overlapping aerial photography. Planning agencies are just now starting to tap ITS data archives as a source of data for performance measures; this occurrence is not very widespread.

Universities within a state are commonly used to at least initially set up performance measurement programs and data archives. Sometimes these functions are passed on to the DOT, sometimes the universities retain control.

Integration of the various data sources available (ITS roadway surveillance, events {incidents, weather, work zones}, and sample-based data) is not well very well advanced. However, there is recognition that this must occur, especially in areas that consider delay by congestion source (e.g., incidents) as an important measure.

Collection and use of incident data is becoming more common among freeway management systems. However, every area defines data elements and collects data differently. Work zones are occasionally collected as part of incident data. Collection of weather data is uncommon.

Data Quality

The quality of data from ITS roadway sensors is a major concern of agencies and has even caused trepidation in using the data for freeway performance measurement (e.g., Atlanta). Data quality problems can be traced primarily to two sources: 1) improper installation (including initial calibration and acceptance testing of equipment) and 2) inadequate detector maintenance due to funding shortfalls. This is a serious problem for freeway performance measurement, especially since ITS roadway sensors provide continuous data at the small time and geographic increments necessary to support sophisticated measures (reliability, congestion by source). The most extreme case is Houston which basically relies on probe readers for travel time estimates – they do not rely on the roadway sensors originally installed. As a result, since volumes are not available, not all the performance measures that are possible can be constructed.

Several agencies have done formal studies of data quality. One strategy to deal with data quality (identified by the Georgia Department of Transportation; GDOT) is to concentrate calibration and maintenance on "key" detectors, with the idea that these can be used to detect major problems (e.g., at known bottlenecks). The key detectors can then be used to adjust measurements from the remaining detectors. However, it is unclear how the adjustments will be done and how well this procedures will work to improve data quality. Father, developing performance measurements from a few isolated detector locations also is highly problematic – since most of the detailed performance measures are based on converting detector measurements to travel times in a corridor, the efficacy of this approach is in doubt.

When formal archived data management systems are implemented, data quality control checks are instituted. However, these are *post hoc* in nature – they can test for inconsistencies based on valid ranges, checks against theory, and checks against history, but subtle errors in accuracy still occur and are unknown. (The only way to determine accuracy is to independently validate field measurements.)

2.2 Basic Principles for Freeway Performance Measurement

In order to develop the suite of freeway performance measures, the research team developed a set of basic principles for guidance. Table 3 summarizes the principles. Consistent with the scope of the project, ***the focus is on measuring the performance of freeways in terms of congestion/mobility and the activities related to improving traffic flow.*** Detailed discussion of each principle appears in the *Guidebook*.

Table 3. Basic Principles for Freeway Performance Monitoring

Principle 1	Mobility performance measures must be based on the measurement or estimation of travel time.
Principle 2	Measure where you can – model everything else
Principle 3	Multiple metrics should be used to report freeway performance, especially for mobility.
Principle 4	Traditional HCM-based performance measures for mobility (V/C[3] ratio and level of service) should not be ignored but should serve as supplementary, not primary measures of performance in most cases.
Principle 5	Both vehicle- and person-based performance measures of throughput are useful and should be developed, depending on the application.
Principle 6	Both quality of service (outcome) and activity-based (output) performance measures are required for freeway performance monitoring.
Principle 7	Activity-based measures should be chosen so that improvements in them can be linked to improvements in quality of service measures.
Principle 8	Customer satisfaction measures should be included with quality of service measures for monitoring freeway performance.
Principle 9	The measurement of travel time reliability is a key aspect of freeway performance measurement and reliability measures should be developed and applied.
Principle 10	Three dimensions of freeway mobility/congestion should be tracked with mobility performance measures: source of congestion, temporal aspects, and spatial detail.
Principle 11	Communication of freeway performance measurement should be done with graphics that resonate with a variety of technical and nontechnical audiences.
Principle 12	Continuity should be maintained in performance measures across applications and time horizons; the same performance measures should be used for trend monitoring, project design, forecasting, and evaluations.

2.3 Recommended Freeway Performance Measures

The recommended performance measures fall into two categories: Core (Table 4) and Supplemental (Table 5). The Core measures represent those that should be developed by all agencies involved with freeway performance that have sufficient data available to them to undertake their development. In cases where data currently do not exist, agencies should strongly consider developing the data necessary to compute the Core measures.

[3] Volume-to-capacity

Table 4. Recommended Core Freeway Performance Measures

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average (Typical) Congestion Conditions (Quality of Service)					
Travel Time	The average time consumed by vehicles traversing a fixed distance of freeway	Minutes	Specific points on a section or a representative trip only; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	Direct correspondence to NTOC measure, but distinction between "link" and "trip" travel time is not used
Travel Time Index	The ratio of the actual travel rate to the ideal travel rate[a]	None; minimum value = 1.000	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by BTOC
Total Delay, Vehicles	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions[b]	Vehicle-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC distinguishes between recurring and nonrecurring delay; delay by source recommended by *Guidebook* as supplements
Total Delay, Persons	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions[c]	Person-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC distinguishes between recurring and nonrecurring delay; delay by source recommended by *Guidebook* as supplements
Delay per Vehicle	Total freeway delay divided by the number of vehicles using the freeway	Hours (vehicle-hours per vehicle)	Section and areawide	Peak hour, a.m./p.m. peak periods; daily	Not recommended by NTOC
Spatial Extent of Congestion No. 1	Percent of Freeway VMT with Average Section Speeds <50 mph[d]	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Spatial Extent of Congestion No. 2	Percent of Freeway VMT with Average Section Speeds <30 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods	
Temporal Extent of Congestion No. 1	Percent of Day with Average Freeway Section Speeds <50 mph	Percent	Section and areawide	Daily	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Temporal Extent of Congestion No. 2	Percent of Day with Average Freeway Section Speeds <30 mph	Percent	Section and areawide	Daily	
Density	Number of vehicles occupying a length of freeway	Vehicles per lane-mile	Section	Peak hour/periods for weekday/weekend	Not recommended by NTOC
Reliability (Quality of Service)					
Buffer Index	The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC recommends a "buffer time" which is the difference between the 95th percentile travel time and the average; conceptually the same as the *Guidebook*
Planning Time Index	The 95th Percentile Travel Time Index	None; minimum value = 1.000	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	

a. Travel rate is the inverse of speed, measured in minutes per mile. The "ideal travel rate" is the rate that occurs at the free flow speed of a facility, or a fixed value set for all facilities that is meant to indicate ideal conditions or "unconstrained" (see text for discussion of the ideal/unconstrained/free flow speed).

b. See text above for definition of "ideal."

c. See text above for definition of "ideal."

d. A freeway "section" is length of freeway that represents a relatively homogenous trip by users. Logical breakpoints are major interchanges (especially freeway-to-freeway) and destinations (e.g., Central Business District). The term "section" is sometimes used to describe this, but it usually implies additional parallel freeways and/or transit routes.

Table 4. Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Capacity Bottlenecks (Activity-Based)					
Geometric Deficiencies Related to Traffic Flow (Potential Bottlenecks)	Count of potential bottleneck locations by type[e]	Number	Section and areawide	N/A	Not recommended by NTOC
Major Traffic-Influencing Bottlenecks	Count of locations that are the primary cause of traffic flow breakdown on a highway section, by type	Number	Section and areawide	N/A	Not recommended by NTOC
Throughput (Quality of Service)					
Throughput – Vehicle	Number of vehicles traversing a freeway in vehicles	Vehicles per unit time	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Direct correspondence to NTOC measure
Throughout – Persons	Number of persons traversing a freeway	Persons per unit time	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Direct correspondence to NTOC measure
Vehicle-Miles of Travel	The product of the number of vehicles traveling over a length of freeway, times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Truck Vehicle-Miles of Travel	The product of the number of trucks traveling over a length of freeway,[f] times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Lost Highway Productivity	Lost capacity due to flow breakdown – the difference between measured volumes on a freeway segment under congested flow versus the maximum capacity for that segment	Vehicles per hour	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Customer Satisfaction (Quality of Service)					
Worst Aspect of Freeway Congestion	(Defined by question)	1) happens every work day; 2) incidents that are not cleared in time; and 3) encountering work zones	Areawide or statewide	Annually; tied to survey frequency	Not recommended by NTOC
Satisfaction with Time to Make Long-Distance Trips Using Freeways	(Defined by question)	1) very satisfied; 2) somewhat satisfied; 3) neutral; 4) somewhat dissatisfied; 5) very dissatisfied; and 6) do not know	Areawide or statewide	Annually; tied to survey frequency	Direct correspondence to NTOC measure

[e.] Bottleneck types are: Types A-C weaving areas (see HCM and Section 7.0); left exits; freeway-to-freeway merge areas; surface street on-ramp merge areas; acceleration lanes at merge areas <300 feet; lane drops; lane width drops >= 1 foot; directional miles with left shoulders <6 feet; directional miles with right shoulders <6 feet; steep grades; substandard horizontal curves. The shoulder categories are included because of the ability of more than 6-foot shoulders to shelter vehicles during traffic incidents.

[f.] Trucks are defined as vehicles with at least six tires, i.e., FHWA Classes 5-13 plus any larger vehicles as defined by a state.

Table 4. Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Safety (Quality of Service)					
Total Crashes	Freeway crashes as defined by the State, i.e., those for which a police accident report form is generated	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	Not recommended by NTOC
Fatal Crashes	Freeway crashes as defined by the State, i.e., those for which a police accident report form is generated, where at least one fatality occurred	Number			Not recommended by NTOC
Overall Crash Rate	Total freeway crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles			Not recommended by NTOC
Fatality Crash Rate	Total freeway fatal crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles			Not recommended by NTOC
Secondary Crashes	A police-reported crash that occurs in the presence of an earlier crash[g]	Number			Not recommended by NTOC
Ride Quality (Quality of Service)					
Present Serviceability Rating (PSR)	The general indicator of ride quality on pavement surfaces[h]	(Internal scale)	Section and areawide	Annually	Not recommended by NTOC
International Roughness Index (IRI)	Cumulative deviation from a smooth surface	Inches per mile	Section and areawide	Annually	Not recommended by NTOC
Environment (Quality of Service)					
Nitrous Oxides (NO_x) Emission Rate	Modeled NO_x attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Volatile Organic Compound (VOC) Emission Rate	Modeled VOC attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Carbon Monoxide (CO) Emission Rate	Modeled CO attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Fuel Consumption per VMT	Modeled gallons of fuel consumed on a freeway divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC

g. See text for discussion.
h. See: http://www.fhwa.dot.gov/policy/1999cpr/ch_03/cpg03_2.htm.

Table 4. Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Incident Characteristics (Activity-Based)					
No. of Incidents by Type and Extent of Blockage	Self-explanatory	Type: 1) crash; 2) vehicle breakdown; 3) spill; and 4) other. Blockage: Actual number of lanes blocked; separate code for shoulder blockage	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Incident Duration[i]	The time elapsed from the notification of an incident to when the last responder has left the incident scene	Minutes (median)	Section and areawide	a.m./p.m. peak periods, daily	Direct correspondence to NTOC measure
Blockage Duration	The time elapsed from the notification of an incident to when all evidence of the incident (including responders' vehicles) has been removed from the travel lanes	Minutes (median)	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Lane-Hours Loss Due to Incidents	The number of whole or partial freeway lanes blocked by the incident and its responders, multiplied by the number of hours the lanes are blocked	Lane-hours	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Work Zones (Activity-Based)					
No. of Work Zones by Type of Activity	The underlying reason why the work zone was initiated: 1) resurfacing only; 2) RRR; 3) lane addition w/o interchanges; 4) lane additions w/interchanges; 5) minor cross-section; 6) grade flattening; 7) curve flattening; 8) bridge deck; 9) bridge superstructure; 10) bridge replacement; and 11) sign-related	Number	Section and areawide	Daily	Not recommended by NTOC
Lane-Hours Lost Due to Work Zones	The number of whole or partial freeway lanes blocked by the work zone, multiplied by the number of hours the lanes are blocked	Lane-hours	Section and areawide	a.m./p.m. peak periods; midday; night; daily	Not recommended by NTOC
Average Work Zone Duration by Type of Activity	The elapsed time that work zone activities are in effect	Hours	Section and areawide	Daily	Not recommended by NTOC
Lane-Miles Lost Due to Work Zones	The number of whole or partial freeway lanes blocked by the work zone, multiplied by the length of the work zone	Lane-miles	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC

i. Since in many cases the actual time the incident occurred is unknown, the notification time is used to indicate the official "start" of the incident. On most urban freeways, through the use of cell phones by the public, the time between when the incident occurs and when it is first reported is very small.

Table 4. Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Weather (Activity-Based)					
Extent of highways affected by snow or ice	Highway centerline mileage under the influence of uncleared snow or ice multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Extent of highways affected by rain	Highway centerline mileage under the influence of rain multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Extent of highways affected by fog	Highway centerline mileage under the influence of fog multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Operational Efficiency (Activity-Based)					
Percent Freeway Directional Miles with (traffic sensors, surveillance cameras, DMS, service patrol coverage)	One measure for each type of equipment deployed in an area	Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Percent of Equipment (DMS, surveillance cameras, traffic sensors, ramp meters, RWIS) in “Good” or Better Condition		Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Percent of total device-days out-of-service (by type of device)		Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Service patrol assists	Self-explanatory	Number	Section and areawide	Annually	Not recommended by NTOC

Table 5. Supplemental Freeway Performance Measures

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average Congestion Conditions (Quality of Service)					
Bottleneck ("Recurring") Delay	Delay that is attributable to bottlenecks[j]	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC defines two categories: recurring and nonrecurring; see text for discussion
Incident Delay	Delay that is attributable to traffic incidents	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	
Work Zone Delay	Delay that is attributable to work zones	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	
Weather Delay	Delay that is attributable to inclement weather	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	
Ramp delay (where ramp metering exists)	Delay that occurs at ramp meters	Vehicle-hours	Individual ramps and section as a minimum	Peak hour, a.m./p.m. peak periods	
Abnormal Volume-Related Delay	Delay caused by abnormal high volumes[k]	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	
Volume-to-capacity ratio	The ratio of the demand volume attempting to use a short segment of freeway divided by the freeway's capacity, as defined by the *HCM*	None	Bottleneck locations only (freeway interchanges, lane-drops, bridges)	Peak-hour volume/peak-hour capacity Peak-period volume/peak-period capacity	Not recommended by NTOC
Traffic Demand Indicator	Ratio of actual traffic demand (volume) to average traffic demand[l]	None	Section and areawide	Peak+Shoulder Periods	Not recommended by NTOC
Delay per Capita	Total freeway delay divided by the population of the area being studied	Vehicle-hours per person	Areawide and statewide	Peak hour, a.m./p.m. peak periods; daily	Not recommended by NTOC
Average speeds by hour of the day (used primarily as an indicator of air quality)	The miles traveled by vehicles over a distance divided by the time it took to travel that distance (space mean speed)[m]	Miles per hour	Section and areawide	Peak hour, a.m./p.m. peak periods; daily	NTOC defines "speed" as the time mean speed
Reliability (Quality of Service)					
Reliability: Failure Measure No. 1	Percent of trips (section or O/D) with space mean speeds <= 50 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Reliability: Failure Measure No. 2	Percent of trips (section or O/D) with space mean speeds <= 30 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Planning Time Index	95th percentile travel time divided by the free flow travel time	N/A	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Throughput (Quality of Service)					
VMT per capita	Freeway VMT divided by the population of the study area	N/A	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC

j. Delay is the excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions; see text for a discussion of "ideal" conditions.
k. May be due to either special events or normal variation due to daily/seasonal fluctuations in demand.
l. See text for a more complete explanation.
m. Although the *Guidebook* calls this space mean speed, depending on how the measurements are taken, it may be a "synthesized" space mean speed. That is, if the basic measurements are from point detectors, theoretically speaking, it is closer to being a time mean speed. See Section 9.0 for more discussion.

Table 5. Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[n]		All customer satisfaction measures apply areawide or statewide		All customer satisfaction measures developed every 1-3 years	
Biggest concern about transportation[o]	Defined by survey question	Percent			Not recommended by NTOC
Most important thing the Department could do to improve congestion[p]	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to broadcast video images	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to traveler information about 1) congestion and 2) work zones	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to DMS messages	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to service patrols	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response to work zone management	Defined by survey question				Not recommended by NTOC
Percent of favorable response to freeway planning process	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with completed projects	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with air quality	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with long-distance travel	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with pavement condition	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with highway safety (how safe it is to travel?)	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with amount of salt used on main rural highways	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with environmental aspects of road construction	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with environmental aspects of road planning and design	Defined by survey question	Percent			Not recommended by NTOC

n. Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.
o. 1) Congestion, 2) poor road and bridge condition, 3) highway crashes, 4) transit not available.
p. 1) Build more roads, 2) clear incidents faster, 3) reduce time that work zones are needed, 4) more effective snow removal, 5) better inform travelers about congestion they will encounter on their trips.

Table 5. Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[q]		All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1-3 years			
Safety (Quality of Service)	All safety data defined by state police accident report (PAR)		All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Number of fatal, injury, and PDO crashes – total and by: 1) type of collision; 2) time of day; 3) relation to ramps; and 4) "first harmful event" (fixed object, rollover, etc.)		Number; distribution percents within each category			
High-crash locations[r]			Specific locations or short segments of freeway		
Alcohol-involved crashes (fatal, injury, total)		Number			
Commercial vehicle crashes (total and hazmat involved)		Number			
Commercial vehicle crash rate	Total number of commercial vehicle crashes divided by commercial vehicle VMT	Rate			
Crashes where speed was a contributing factor		Number			
Total Work Zone Crashes, Injuries, and Fatalities		Number			
Total Weather-Related Crashes, Injuries, and Fatalities		Number			
Incident Management (Activity-Based)					
First Responder Response Time	Time difference between when the incident was first detected by an agency and the on-scene arrival of the first responder	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Notification Time	Time difference between when the incident was first detected to when the last agency needed to respond to the incident was notified	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Total Response Time	Time difference between when the incident was first detected by an agency and the on-scene arrival of the last responder	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Clearance time	Time difference between when the first responder arrived on the scene and blockage of a travel lane is removed	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
On-Scene Time	Time difference between when the first responder arrives and the last responder leaves an incident scene; also may be computed for individual responders	Minutes	Section and areawide		Not recommended by NTOC

q. Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.
r. Most states have procedures for identifying high-crash locations. Additional guidance may be available through software packages such as FHWA's *SafetyAnalyst*.

Table 5. Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[s]		All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1-3 years			
Linger Time	Time difference between when the blockage of a travel lane is removed and the last responder leaves the incident scene	Minutes	Section and areawide		Not recommended by NTOC
Traffic Influence Time	Time between when an incident was first detected and the last responder leaves the incident scene	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Detection Method (citizens, police, other agencies) per month	The method which incidents are detected or reported	Locally defined	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Service patrol assists (total and by incident type)			Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Work Zones (Activity-Based)					
Traffic volume passing through work zones	Self-explanatory; AADT estimates may be used in place of actual counts	Vehicles	Section and areawide	Daily	No work measures recommended by NTOC
Average Time Between Rehabilitation Activities by Type of Activity	Type of activity: 1) resurfacing only; 2) RRR; 3) lane addition w/o interchanges; 4) lane additions w/interchanges; 5) minor cross-section; 6) grade flattening; 7) curve flattening; 8) bridge deck; 9) bridge superstructure; 10) bridge replacement; and 11) sign-related	Months	Areawide	N/A	
Average Number of Days Projects Completed Late	"Late" is any time after the scheduled completion	Days	Areawide	N/A	
Ratio of Inactive Days to Active Days	"Active" is when some work zone activity was performed during a day	N/A	Areawide	Annually	
Crashes per lane-mile lost	Work zone crashes divided by the number of lanes lost	N/A	Section, areawide, and statewide	Annually	
Average Work Zone Duration by Work Zone Type by Lanes Lost	Time length of work zone activities by their severity in terms of traffic impact; Lanes lost = 0, 1, 2, 3, 4+	Hours	Areawide	Annually	
Average Number of Days That a Contract Work Zone is Active	"Active" is when some work zone activity was performed during a day	Days	Areawide	Annually	
Weather (Activity-Based)					
Number of incident responses during weather-related events	Self-explanatory	Number	Areawide	Monthly and annually	
Lane-miles and freeway miles officially closed due to weather or flooding	Self-explanatory	Lane-miles	Areawide	Monthly and annually	
Number of freeways with reduced speed limits by MP3 reductions	Self-explanatory	Number	Areawide	Monthly and annually	
Number of freeway ramps closed due to weather by weather event	Self-explanatory	Number	Areawide		

[s.] Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.

Table 5. Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[t]		All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1-3 years			
Weather (Activity-Based)					
Time between 2 inches of snow accumulation and plowing (clearance)	Self-explanatory	Minutes	Areawide (lane-mile weighted)	Annually	
Lane-miles pretreated with chemical snow/ ice control	Self-explanatory	Lane-miles	Areawide	Annually	
Lane-miles pretreated with chemical snow/ ice control that experienced snow or ice conditions	Self-explanatory	Lane-miles	Areawide	Annually	
Weather event VMT ratio	VMT during event: VMT for recent same DOW	N/A	Areawide	Annually	
Weather event delay ratio	Delay during event: Delay for recent same DOW	N/A	Areawide	Annually	
Delay per lane-mile affected by major weather events	Self-explanatory	Rate	Areawide	Annually	
Crashes per lane-mile affected by major weather events	Self-explanatory	Rate	Areawide	Annually	
Operational Efficiency (Activity-Based)[u]					
Service patrol vehicles in operation per shift	Self-explanatory	Number	Section and areawide	User-specified	
Percent freeway miles with (electronic data collection, surveillance cameras, DMS, service patrol coverage)	Self-explanatory	Percent	Areawide	User-specified	
Number of messages placed on DMSs	Self-explanatory	Number	Section and areawide	User-specified	
Individuals receiving traveler information by source (511, other direct means)	Self-explanatory	Number	Section and areawide	User-specified	
Percent of equipment (DMS, surveillance cameras, sensors, ramp meters, RWIS) in "good" or better condition	Self-explanatory	Percent	Section and areawide	User-specified	
Percent of total device-days out-of-service (by type of device)	Self-explanatory	Percent	Section and areawide	User-specified	
Incident detection method	Self-explanatory	Number	Areawide	User-specified	
No. devices exceeding design life	Self-explanatory	Number	Section and areawide	User-specified	
MTBF for field equipment (by type of device)	Self-explanatory	Days	Section and areawide	User-specified	
Number of freeway miles instrumented with traffic data collection devices	Self-explanatory; directional miles	Miles	Areawide	User-specified	
Freeway construction projects completed within 30 days of scheduled completion	Self-explanatory	Number	Areawide	User-specified	

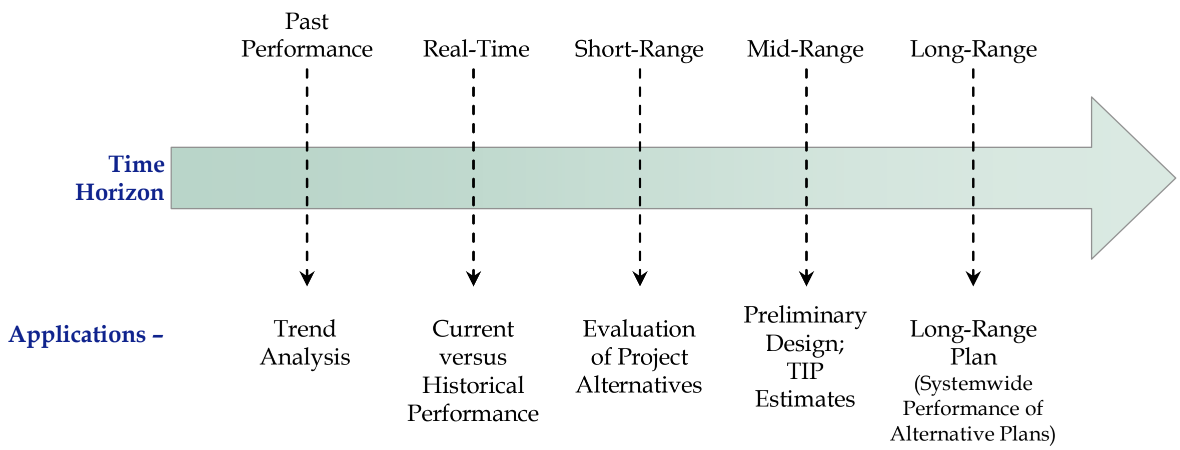
[t] Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.
[u] A multitude of other operational efficiency measures resides in asset management information and performance measurement systems.

CHAPTER 3

INTERPRETATION, APPRAISAL, AND APPLICATIONS

The *Guidebook* takes a comprehensive view of freeway performance measurement and monitoring. Its guidance can be applied across the spectrum of applications, as shown in Figure 1, to the extent that the same performance measures should be used across all applications. By maintaining this consistency, linkage to the goals and objectives of the agency is achieved.

Figure 1. The Same Performance Measures Should be Carried Across Applications Spanning the Entire Time Horizon



The *Guidebook* touches on all aspects of the project time horizon shown in Figure 1, but the emphasis is clearly on trend analysis. The reason for this is twofold:

1. During the benchmarking interviews, this was revealed to be the area that agencies were struggling with the most. Many agencies had received directives from legislatures or top DOT management to institute performance measurement programs, yet there were little or no precedents to follow. Further, agencies were use to applying performance measures for conducting analyses and evaluations, although they were usually called "measures of effectiveness."
2. NCHRP Project 7-15, which was still in development at the time of this report, was focusing on how to develop and apply congestion/mobility performance measures for short-, mid-, and long-range applications. The research teams coordinated their work so as to avoid duplication and concentrate resources where they would do the most good.

Using the same performance measures across the time horizon is not as difficult as it sounds. Most models used in transportation analyses produce as output some variant of travel time for measuring congestion/mobility performance. These outputs can be easily transformed to the recommended performance measures recommended here, although it may require post-processing of model outputs.

In terms of the categories of performance that should be measured, congestion/mobility is the category that receives the most attention in the *Guidebook*. As mentioned previously, the other areas of performance are generally well-covered elsewhere but there has been little consensus in the transportation profession about how to measure and report congestion. The *Guidebook* goes into great detail (which will not be repeated here) on how to measure congestion, what data and analytic methods should be used to develop them, how they should be reported and communicated, and how they may be used in the decision-making process.

CHAPTER 4

CONCLUSIONS AND SUGGESTED RESEARCH

4.1 Conclusions

The research conducted for this study came in two parts: 1) an assessment of current practice and the determining the unmet needs and 2) development of data processing, analytic techniques, presentation methods, and guidelines for applying freeway performance measures to decision-making. From this work, several broad-ranging conclusions can be reached.

- **Performance measurement of all kinds (not just that related to freeways) is growing in importance and is becoming institutionalized within transportation agencies.** Transportation agencies are increasingly adopting a customer focus in their activities, i.e., a more "business-like" approach to doing business. While the motivations of private firms and public agencies are different, many of the tools and principles have equal merit in both worlds. Performance measurement, which has been used in the private sector for some time, is one of these tools. Additionally, practitioners are recognizing that using performance measures allows them to improve their functions in several ways:
    - Deficiencies are identified with better precision and improvement strategies can be better tailored to the deficiencies.
    - Public relations is enhanced; just by the fact that statistics are reported, it provides a view to the public that professionals understand the nature of the problems.
    - In the congestion/mobility realm, having information on the outcomes of investments provides high-level input to transportation programming decisions.
- **Collection of quality data is required to build the foundation of a freeway performance measurement program.** There's no getting around the fact that a comprehensive freeway performance measurement program needs a large amount of detailed and accurate data to be effective. Much of these data already are being collected by ITS deployments in some form. However, data quality has proven to be a major issue, and some of the required data will need new data collection programs.
- **Congestion and mobility performance measurement on freeways has been the largest gap in knowledge.** Based on the benchmarking interviews and the research team's experiences on other

projects, the biggest need for support is in the area of congestion and mobility. This support is likely to be required into the future as agencies engage more actively in freeway performance measurement. Customer satisfaction is a relatively immature area as well, but in general its implications are not necessarily focused on freeways.

- **Travel time reliability is being recognized as characteristic of congestion that is on equal footing with average congestion levels.** With regard to congestion/mobility performance measurement, substantial emphasis is placed on the concept of travel time reliability, which is emerging as a key issue for operators and planners. Travel time reliability is becoming a major theme for operators because it relates directly to the events that cause travel conditions to vary from day to day. As planners take on a larger role in operations ("planning for operations"), they too are recognizing that just dealing with physical capacity-related congestion is only part of the congestion puzzle. The *Guidebook* notes there are two closely related views of what constitutes travel time reliability, namely, variability in travel times and number of "failures" to meet established travel time thresholds. Both can be related to the underlying distribution (or history) of travel conditions experienced by users, leading to a general definition of travel time reliability:

    Travel time reliability is defined as the level of consistency in travel conditions over time, and is measured by describing the distribution of travel times that occur over a substantial period of time.

  Traditionally, mobility/congestion has been defined in terms of "average" or "typical" conditions (e.g., *HCM* applications). One way to look at the measurement philosophy proposed in this report is that "mobility" is analogous to average or typical travel time, while "reliability" is analogous to variability or inconsistency in travel times.

- **Measuring average congestion and overall travel time reliability is only the start of understanding congestion and crafting strategies to deal with it.** Quality of service (outcome) measures are extremely important for agencies because they represent the "bottom-line" for their customers (travelers). However, measuring total delay and travel time reliability is really just the starting point for freeway performance measurement – deciphering what causes travel times to be unreliable is the next step. The transportation profession has traditionally used the terms recurring and nonrecurring congestion to get at this issue, and the *Guidebook* acknowledges this, but these terms only supply a limited amount of additional information. Instead, the *Guidebook* prefers to decompose congestion into "seven sources": physical bottlenecks, traffic incidents, inclement weather, work zones, traffic control devices, special events, and variable demand.[3] These sources interact in complex ways to produce total congestion. Quantifying how much congestion is due to these sources is still problematic, although the *Guidebook* provides interim advice on how to do it.

- **Quality of service (outcome) and activity-based (output) performance measures must be linked together and tied into the mission of the transportation agency.** Development and reporting trends in performance measures at one level of detail usually begs the question, "why did this happen?" Practitioners need to be willing to dig deeper into this question by constructing lower levels of performance measures (activity-based) that are linked to the upper levels (quality of service). Continuing the example of congestion by source, each source has its own characteristics and treatments that should be tracked. For example, traffic incident-related delay is determined by the nature of traffic incidents and the effectiveness of incident management strategies. Tracking these characteristics and activities indicates what aspects of incident management need to be improved, and provides answers to outside requests to explain the situation.
- **Some experimentation and deviation from the *Guidebook* on the part of practitioners is warranted.** Because local issues are all slightly different, the *Guidebook* is ultimately a reference rather than a prescriptive document. Further, because the state of the art in reporting performance measures is still not mature, practitioners should be free to try new forms of graphics and presentation techniques.

4.2 Suggested Research

Benchmarks and Levels of Service for Reliability and Event Performance Measures

Use of performance measures is usually associated with setting of performance targets for the measures. However, what is considered to be "good," "acceptable," or "poor" for individual performance measures currently is highly subjective. Also, should performance targets be set so as to be achievable, or should they aspire to be lofty "stretch" goals (e.g., zero fatalities)? There is a need to provide guidance to practitioners as to what the performance targets should be, or at least a process for setting them should be defined. For key quality of service (outcome) measures of interest such as congestion level and reliability as well as key activity-based (output) measures such as incident duration (and other incident component times), work zone duration, etc., benchmarks should be established. These can be set in a manner similar to the "level of service" concept used in the HCM.

Consistent and Comprehensive Event Data Collection and Use

The collection of data on events (incidents, weather, work zones, special events), especially at traffic management centers (TMC) is very scattered. The data that does get saved is a function of the features that were built into the TMC operating software, and these features do not follow any standard practice. Sometimes the information doesn't even exist in true database format – it's just archived text messages. This research would:

- Identify the data that needs to be collected at TMCs to capture event characteristics. Coordinate with current FHWA efforts on traffic incident management, the National Transportation Operations Coalition (NTOC), and existing ITS data dictionaries. Develop a "TMC Event Data Dictionary" that can be implemented by TMC software.
- Identify the policies that need to be in place to ensure that TMC personnel capture data on all events under their purview.
- Develop a prototype system for use by a TMC. This will have to be done in conjunction with a TMC software upgrade – the data capture system needs to be integrated with the existing software.

Compatibility of Travel Estimation Techniques

Travel times are the basis for the congestion/mobility performance metrics recommended in the current research, especially reliability metrics. Travel times can be estimated directly by measuring the passage on individual vehicles over time, synthesized from point detection of spot speeds, or computed with models. Because there is no universal coverage of a single method in urban areas, it is likely that multiple methods will be used in the foreseeable future. The question is: do these methods produce compatible results so that corridor performance can be compared and areawide statistics can be developed by combining them. The issue will become more significant as cell phone and vehicle-based monitoring become more pervasive.

This research would collect travel time data at a detailed level using closely spaced floating cars traveling in a heavily instrumented freeway corridor, and then compare the travel time estimates to statistics developed from the roadway-based detectors and models (e.g., HCM).

Application of Recommendations in the Field: Use of Performance Measures to Guide Operations and Planning Investment Decisions

Many agencies are developing performance measures and producing reports on trends in performance (e.g., dashboards, quarterly reports like WSDOT'S Gray Book.). The issues now become:

- How can changes in performance measures (trends) or deviations from goal-based benchmarks lead to changes in investments and policies?
- Can changes in performance measures be keyed to specific actions (e.g., a shift in the percentage of congestion due to a nonrecurring event type, such as incidents)?
- How detailed do performance need to be to allow this linking to types of actions (e.g., do we need to measure the activities of personnel at a very detailed level)?
- How are reliability metrics used? Are areawide or corridor levels useful in reporting performance?
- How does tracking recent performance trends modify:
  - Short- and long-range transportation plans?
  - Daily operating policies?
  - Annual capital budgeting for operations?
- How are congestion/mobility performance measures used in conjunction with asset management and safety measures to prioritize projects? Do they help operations compete on a "level playing field"?

Estimating Reliability and Congestion Source Performance Measures

There is a need for operators and planners to make estimates of reliability where continuous data do not exist. A current FHWA effort is considering how existing models can be used to estimate reliability, but there is still lacking an empirical basis for these applications, especially when trying to develop current year estimates of reliability. This study would use continuous ITS data on freeways to relate reliability levels to easily obtainable data that are known to influence the characteristics of events, the cause of unreliable travel. These include:

- Incident/crash rates;
- Shoulder presence;
- Number of lanes;
- Base congestion level (AADT/C, V/C);

- Bottleneck presence/severity; and
- Average weather conditions over a year.

Additionally, improved methods for calculating delay by source of congestion are needed. The *Guidebook* promotes the use of delay by source and documents some existing methods that may be considered “interim,” yet definitive methods for calculating the delay due to the seven sources of congestion from empirical data do not exist.

Traffic Data Quality for Real-Time and Performance Monitoring Applications

If ITS-derived traffic data are to be used to detect the often subtle changes in traffic conditions due to implementing operations strategies, it is crucial that the error bounds on the data are small enough to allow accurate comparisons. High-quality data also is essential for advanced operations strategies such as providing travel time estimates to highway users. Also, if the private sector becomes a major supplier of data in the future (via cell phones, in-vehicle tracking, or roadway-based sensors), what performance targets for data quality should be imposed? A related issue is if travel time data is provided via the private sector, is there still a need for agencies to maintain sensors as a check on data quality, backup in case of outages or private firms disappearing from the market, and to provide volume data for integrated corridor management, evacuation management, and performance measures?

This research would:

- Compile best agency practices in maintaining quality sensor data **at the field level**, including acceptance, calibration, routine maintenance, and communications. Costs for maintaining data at different levels of quality also will be compiled.
- Recommend testing procedures for certifying that data provided by the private sector meet preset quality targets.

REFERENCES

1 *Highway Capacity Manual*, Transportation Research Board, National Research Council, Washington, D.C., 2000.

2 Schrank, David, and Lomax, Timothy, *The 2004 Urban Mobility Report*, Texas Transportation Institute, September 2004.

3 Cambridge Systematics, Inc. *et al*, "Providing a Highway System with Reliable Travel Times", NCHRP 20-58(3) Contractor's Report, Transportation Research Board, National Research Council, Washington, D.C., September 2003.

APPENDIX A

RESULTS OF BENCHMARKING INTERVIEWS

Table A.1 Agencies Participating in the Benchmarking Interviews

Metro Area	Reasons for Selection	Agencies Interviewed
Multiple Agency Interviews		
1. Minneapolis-St. Paul, Minnesota	Mn/DOT has been collecting and using performance and efficiency data for many years – they were an early leader in performance measures, earning themselves the title of "Land of 10,000 performance measures." Mn/DOT Ops aggressive at using operations data and information for decision-making. Long history of active freeway management and data collection. Location of high-profile public debate on operational policy (ramp metering), and location of significant transit technology test (buses on narrow shoulders)	Metro District Operations, Mn/DOT Center for Transportation Studies, University of Minnesota Metro Council
2. Seattle, Washington	WSDOT very actively pursuing performance measures as a means of selling O&M program. Very active public reporting process, active experimentation in performance measure development., and freeway performance is a key subject in proposed ballot initiatives.	WSDOT HQ Traffic Office WSDOT NW Region WSDOT HQ Strategic Planning and Programming Puget Sound Regional Council
3. Hampton Roads, Virginia	Field Operational Test aimed at developing a comprehensive archive data management system (ADMS) being conducted here. Multiple stakeholder groups actively engaged in use of the archive; performance measurement at different levels a major thrust. CS is leading the evaluation.	Hampton Roads STC, VDOT Hampton Roads Planning District Commission
4. Milwaukee, Wisconsin	WisDOT embarked on aggressive use of information for operations and planning	WisDOT District 2 Operations WisDOT Central Office University of Wisconsin-Madison WisDOT District 2 Planning
5. Phoenix, Arizona	MAG beginning a performance measurement program (planning); Maricopa County DOT also interested in warehousing data and providing performance reports. MAG has recently provided significant funding for improved data collection for performance reporting. Arizona DOT Traffic Operations Center currently monitors 50% of freeways in Phoenix and Tucson metro areas (100 centerline miles). Real-time information is provided to web site and 511. A quarterly report is published internally on freeway congestion in the Phoenix area and how well departmental objectives are being met. ADOT currently spends $2.25 million a year on its Traffic Operations Center plus $1.25 million a year on detector maintenance.	ADOT/Intermodal Transportation Division ADOT/Transportation Planning Division Maricopa Association of Governments
6. Los Angeles, California	Caltrans HQ actively involved in performance measurement for both Operations and planning activities. Caltrans currently is funding development of an arterial monitoring system to supplement the freeway monitoring system. Real-time freeway congestion information currently is posted to the web.	Caltrans, Freeway Operations, District 7 Southern California Association of Governments Caltrans, Planning
Operations Interviews Only		
7. Portland, Oregon	Portland has a very active freeway management effort, an ongoing performance measure development effort with Portland State University, and considerable public pressure to improve roadway performance.	See Note[a]
8. Houston, Texas	TxDOT/TRANSTAR currently prepares an annual performance report.	Houston TRANSTAR
9. San Antonio, Texas	TxDOT Operations has shown interest in better exploiting their data resources.	See Note[b]
10. Washington, D.C.	CHART very active in incident management performance measures; expansion of Hampton Roads ADMS being planned for Northern Virginia	CHART (Maryland) VDOT Northern Virginia District
11. Atlanta, Georgia	NaviGAtor actively using incident management performance measures. Business Plan being developed tied to multiple performance measures	GDOT, Office of Traffic Operations

[a] No formal interviews were conducted as part of NCHRP 3-68. Rather, the team relied on other work conducted by TTI on performance measures. As part of this effort ODOT assembled a Technical Advisory Committee (TAC) made up of individuals from ODOT sections of traffic management, transportation planning and analysis, transportation data, traffic operations, and internal audit/performance measures. The TAC also included individuals from the metropolitan planning organization (MPO) in Portland (Metro) and the Eugene/Springfield area (Lane Council of Governments), academia, and the local Federal Highway Administration (FHWA) office.

[b] Initial conversations with TransGuide indicated that they currently are not using performance measures nor are they planning on developing them in the near future. TransGuide does have an extensive sensor system (485 lane-miles) and a formal incident management program from which detailed performance measures could be developed, however.

Table A.2 Reasons for Undertaking Performance Measurement

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
1. Minneapolis-St. Paul, Minnesota	TMC confirms traffic incidents with nearly 285 Closed-circuit TV (CCTV) cameras posted along 210 miles of metro-area freeway. Information on incident location and resulting traffic back-ups are relayed to travelers via Traffic Radio, Traffic TV, various Internet sites and a telephone service. The RTMC provides traffic information to local radio and television traffic reporters as well. Travelers also are alerted to traffic problems via 70 electronic message signs placed throughout the freeway system. TMC staff also operates 430 ramp meters and 4,000 loop detectors (traffic sensors).	In an annual Departmental Results report, Mn/DOT tracks a number of performance measures statewide. Performance measures have therefore become part of an institutional reporting process.
2. Seattle, Washington	WSDOT has a very active freeway management program, including: freeway ramp meters throughout most of the instrumented freeway system; an active, roving, service patrol program; a coordinated, multiagency incident management program, including designated WSDOT incident management staff; a very active traveler information system, including a 511 call-in line, a heavily used Web site that displays a congestion map and access to both still images and streaming video. WSDOT has adopted "WSDOT's Congestion Measurement Principles" which are as follows: • Use real-time measurements rather than computer models whenever possible; • Measure congestion due to incidents as distinct from congestion due to inadequate capacity; • Show whether reducing congestion from incidents will improve travel time reliability; • Demonstrate both long-term trends and short- to intermediate-term results; • Communicate about possible congestion fixes by using an "apples to apples" comparison with the current situation; and • Use plain English to describe measurements.	Original request from state legislature resulted in the annual performance report known as *Measures, Markers, and Mileposts*, the "Departmental accountability" report published by WSDOT each quarter to inform the legislature and public about how the Department is responding to public direction and spending taxpayer resources. Agencies now using performance measures as part of everyday practice to help make informed decisions.
3. Hampton Roads, Virginia	The Smart Traffic Center (STC) is the Virginia Department of Transportation's (VDOT) high-tech, customer service approach to regional freeway traffic management and communications. The Freeway Traffic Management System installed at STC consists of an extensive computer controlled, fiberoptic-based communications and control network installed along 31 miles of the area freeways (I-64, I-264, I-564, and I-664), 80 closed circuit television cameras plus access to 36 additional cameras in the tunnels and bridges, over 85 dynamic message signs and over 1,050 vehicle detectors strategically positioned across the entire Hampton Roads region, Wide-Area Highway Advisory Radio System (HARS), and Freeway Incident Response Teams (FIRT) patrolling over 70 miles of interstate in the region.	The Smart Travel Lab (STL) at UVA is responsible for gathering and archiving performance data from the region's loop, radar, and acoustic detectors. The STL does not report travel time and speed performance measures on a regular basis, but uses the Hampton Roads Smart Traffic Center loop data for research. From the research, more direct use of performance measures in day-to-day operations is hoped to be achieved. Output measures are more developed and in use than outcome measures.

Table A.2 Reasons for Undertaking Performance Measurement (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
4. Milwaukee, Wisconsin	The TOC archives many different types of operations data. As part of planned enhancements to their data archiving system, they plan to include a performance reporting "module" in their new data warehouse.	A formal performance measurement program, the Freeway System Operational Assessment (FSOA) program, bas been instituted to provide better information to operators, public officials, and travelers. The impetus for FSOA came from the MONITOR traffic operations center, where WisDOT engineers were dealing with operational problems created by a "project" mentality in the planning and project development process. FSOA was created to provide a comprehensive, systemwide assessment of the safety and operational performance of all freeways in the Waukesha District, and to provide a framework in which geometric and/or operational improvement projects could be considered in the current project development process. The impetus for developing an operations performance monitoring process is two-fold: 1) The TOC wants to communicate the benefits of operations to WisDOT managers/administration as well as other nontechnical leaders and elected officials; 2) The TOC already has significant archived data resources that could be used, and there was an opportunity to develop this capability as part of planned enhancements to their data archiving system. Data from the MetaManager system drives many project development decisions. Thus, the operations group would like to develop the traffic analogy to MetaManager, which would essentially be a freeway performance reporting system based upon archived traffic operations data.
5. Phoenix, Arizona	There are approximately 100 miles of High-Occupancy Vehicle (HOV) lanes in the area. The HOV lanes are restricted during peak traffic hours between 6:00 and 9:00 a.m. and 3:00 and 7:00 p.m. During these hours, travel on the HOV lanes is limited to vehicles with two or more occupants. Vehicles travel over 22.5 million miles on Phoenix's freeway system everyday according to the CY2002 Highway Performance Monitoring System (HPMS) Report. This volume translates to approximately 8.22 billion annual VMT on the 189 miles of freeway. As a result, recurring bottlenecks and congested corridors are significant problems in the area. The Maricopa Association of Governments has identified 16 congested segments in the preliminary draft working paper of the *MAG Regional Freeway Bottleneck Study.* A freeway management system (FMS) that uses intelligent transportation technologies to collect freeway data and to monitor freeway conditions to optimize traffic flow covers approximately one-half of the freeway system in the Phoenix metropolitan area. TTG plans to extend the coverage area in the future.	The original impetus was to support ADOT's Strategic Action Plan, which is performance-based. Performance measures are at the core of this effort. Agencies are discovering uses for performance measures beyond fulfilling the requirements of the Strategic Action Plan.

Table A.2 Reasons for Undertaking Performance Measurement (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
6. Los Angeles, California	The Division of Operations of Caltrans 7 is responsible for constructing and maintaining all interstate and state highways in the Greater Los Angeles Area. It has developed an Advanced Traffic Management System (ATMS), which "integrates recurrent/nonrecurrent incident detection, verification, incident response, planned events of freeway management, and field element operational control." ATMS uses electronic devices, such as loop detectors, to collect freeway performance data. The information collected by ATMS is fed to the District's Transportation Management Center (TMC) and forms the basis for many performance measures. Caltrans aims to optimize traffic flow by managing existing traffic operations and anticipating future demands.	Preliminary internal or "agency" performance measures for operations have been drafted. Two implicit policies in developing the measures are: 1) measures need to be monitored as well as forecast; and 2) measures should be modally and jurisdictionally blind whenever possible. In addition, Caltrans follows a system management philosophy. As such, freeway performance is not evaluated independent from the rest of the system. SCAG is required to produce a Regional Transportation Plan (RTP). As part of this effort, SCAG has developed goals and performance measures that aimed to evaluate the performance of the Plan. SCAG also takes a holistic, modally blind approach, where the goals and measures are applied to the entire transportation system. While freeway data are collected in such a way that they may be singled out for evaluation, they are not generally being reviewed apart from the whole system.
7. Portland, Oregon	(Part of statewide study of performance measures).	ODOT had a historical performance measurement process that was in need of updating to capture the effect of operational treatments on congestion/mobility.
8. Houston, Texas	The hub for traffic operations in the greater Houston area is the Houston TranStar [Greater Houston Transportation and Emergency Management Center]. The Houston District of TxDOT is responsible for State maintained roadways within a six county area encompassing 5,948 miles with a population of approximately 4.9 million persons, 3.6 million of which are in Harris County. Houston TranStar generally covers about 235 centerline miles of the freeways located within Harris County only. Operations are typically focused on peak periods. There are 4 operators on duty in the Center during each weekday peak, 2 in the midday and one in the overnight and weekend periods. The Motorist Assistance Patrol and most other operational treatments operate only on weekdays. This is focused on the urban areas with very little interaction with rural areas around Houston.	The performance measures are primarily derived to develop a "deficiency" report and to provide data for the changeable message signs and web site. An Annual Report also is prepared to describe the activities, actions and benefits from TranStar. The "deficiency" report identifies the technologies and their operating status. It is used to guide maintenance activity, especially in the case of dangerous potholes or inoperable signs or signals. There are some emerging programs, principally the Texas Metropolitan Mobility Plan, which may require more extensive performance reporting, but there is no Central Office-type mandate for measures or monitoring data.

Table A.2 Reasons for Undertaking Performance Measurement (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
9. Washington, D.C.	**Maryland** CHART currently has traffic sensors at 1.0- to 1.5-mile spacing along some sections of I-70, I-83, I-95, I-270, I-495, I-695, I-795, and U.S. 50. Many sections do not have any instrumentation. There also are video cameras in the same areas as the sensors. Sensor and camera coverage is shown on the CHART web site located at http://www.chart.state.md.us The traffic sensors provide volume, occupancy and speed. U. of Maryland is starting a process to archive this VOS data. CHART recently awarded a contract to a vendor to design reports for presenting the VOS and incident data. Currently, sensors are only used to update the real-time traffic maps on the web site and in the operations centers. **Virginia** The Northern Virginia (NOVA) District operates over 800 signalized intersections and automatically receives data from over 11,000 loop detectors. NOVA has both presence detectors (6' x 40' located at the stopbar) and system detectors (6' x 6' located 200-300 upstream from the stopbar). All loops are set up to detect volume, occupancy and speed.	**Maryland** SHA and CHART participate in the Maryland DOT "Managing for Results" program. The program was initiated in 1999. It is linked to a Business Plan: goals, objectives, and performance measures, and strategies to achieve goals are linked. **Virginia** VDOT beginning a department-wide performance measurement program.
10. Atlanta, Georgia	The NaviGAtor Program is the Georgia Department of Transportation's (GDOT) high-tech, customer service approach to regional freeway traffic management and communications. The NaviGAtor system consists of an extensive computer controlled, fiberoptic-based communications and control network installed along 222 miles of the area freeways (I-20, I-75, I-85 and I-285 and GA 400), 319 closed circuit television cameras on the freeways plus 211 additional cameras on the arterial system managed by local jurisdictions, over 100 dynamic message signs and over 1,100 vehicle detectors strategically positioned across the Atlanta region, and Highway Emergency Response Operators (HERO) patrolling over 250 miles of interstate in 55 vehicles in the region.	Development of an Operations Business Plan, which follows the "vision-goals-objectives-performance measures-targets-actions" sequence is driving the implementation of performance measures at NaviGAtor.

Table A.3 Congestion/Mobility Performance Measures Under Consideration in Selected DOTs

State	Performance Measures
Florida	• Person-miles traveled; • Truck-miles traveled; • Vehicle-miles traveled; • Average speed; • Average delay per vehicle; • Average door-to-door trip time; • Variance of average travel time or speed(“Reliability”; not yet defined); • Vehicles per hour per lane during peak hour (“Maneuverability”); • Percent highway miles at LOS E or F; • Percent VMT at LOS E or F; • Vehicles per lane-mile (“Density”); and • Lane-mile-hours at LOS E or F (“Duration of Congestion”).
Oregon	• Roadway miles at V/C >0.70 during peak period; • Hours of delay from nonrecurring congestion; • Delay per incident; and • Hours of delay per system user (multimodal).

Table A.4 Types of Performance Measures Used by Agencies

Metro Area	Operation Agencies	Planning Agencies
1. Minneapolis-St. Paul, Minnesota	• Average incident duration; • Percent of highway miles w/peak-period speeds <45 mph; • Travel Time Index; and • Travel times on selected segments, including mean, median, and 95^{th} percentile.	• HOV usage; • Roadway congestion index; • Percent of daily travel in congestion; • Percent of congested lane-miles in the peak period; • Percent of congested person-miles of travel; • Annual hours of delay; • Change in citizen's time spent in delay; • Congestion impact on travel time; and • Travel Time Index.
2. Seattle, Washington	**Real-Time Operations** TSMC staff use displays of three primary sets of information to determine the performance of the freeway system. These three displays include: • A "congestion map" based on vehicle-lane occupancy; • A set of computed travel times for 30 representative "trips" on the freeway system; and • A bank of television monitors displaying various CCTV images. **Operations Planning/Output Measures** Many output measures tracked; a sample includes: • The number of loop detectors deployed; • The number of loops functioning currently; • The percentage of loops functioning during a year; • The number of service patrol vehicles currently deployed; • The number of hours of service patrol efforts supplied by WSDOT; • The number of motorist assists provided by those service patrols by type of assistance provided; and • The number, duration, and severity of incidents by location (roadway segment) and type of incident. **Operations Planning/Outcome Measures** • The average vehicle volume by location and time of day and by type of facility (HOV/GP lane); • The average person volume by location and time of day and by type of facility; • The frequency of severe congestion (LOS f) by location; • The average travel time by corridor and major trip (O/D pairs); • The 95^{th} percentile travel time by corridor and major trip (also reported as Buffer Time); • The number of very slow trips (half of FFS) that occur each year by time of day and major trip; • The amount of lost efficiency (speeds <45 mph) by location; and • The number of times that HOV lanes fail to meet adopted travel time performance standards. • The percentage of HOV lane violators observed by monitoring location	The planning process incorporates all of the performance measures discussed above. In addition, the planning process uses the additional summary measures of: • Person-hours of travel; • Vehicle-hours of travel; • Person-hours of delay; • Vehicle-hours of delay; • Vehicle-miles of travel; and • Person-miles of travel.

Table A.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
3. Hampton Roads, Virginia	**Outcome** • Speed; • Volume; and • Occupancy. **Output** • Numbers of total incidents by type; • Number of vehicles involved; • Number of lanes blocked; • FIRT vehicle mileage; • TOC staff availability; • Numbers of variable message signs; • Average times for incident duration; • Average times for response; • Miles of STC coverage; • Numbers of messages placed on the signs; • Availability of STC field equipment; • Percent of surveillance devices responding; • Turnover rate; • Number of hours worked – Operators; • Number of hours worked – FIRT drivers; and • Number of miles driven – FIRT drivers by route.	HCM LOS ranges, developed with a combination of models and roadway surveillance data; specifically: • Lane-miles operating at LOS F.
4. Milwaukee, Wisconsin	Still under development, but several concepts are being applied: • Average congestion level (exact definition still being discussed); • Congestion duration (to quantify peak spreading); • Travel reliability (exact definition still being discussed); • Road safety index (exact definition still being discussed); • Measures for freeway service patrol (such as decrease in related incident congestion and secondary crashes); and • Impacts of work zones.	• *Benefit/Cost Ratio* – Quantitative monetized benefits include: 1) travel time savings versus a no-build scenario; 2) value of improved traveler information; and 3) crash reduction. All benefits and costs are projected using 3 scenarios: best case, midrange, and worst case. • *Environment* – Qualitative assessment of changes. • *Interconnection* – Qualitative assessment of benefits for multimodal transportation and nondrives. • *Partnerships* – Qualitative assessment of likely sources of public support and/or opposition. **Consideration of Other Performance Measures** WisDOT has considered the use of travel time reliability in their models and may implement a monetized benefit value for reliability in the future. At this point, however, the Project Appraisal Report does not directly address travel time reliability. Freight-specific measures are not included, but freight is considered under the "Interconnection" qualitative assessment.

Table A.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
5. Phoenix, Arizona	**Outcome Measures** • Speed; • Average percent of freeways reaching LOS E or F on weekdays; • Traffic volumes/counts; and • Vehicle occupancy. **Output Measures** • Numbers of total incidents; • Numbers of Level 1 incidents; • TOC staff availability; • Numbers of variable message signs; • Average times for acknowledgment; • Average times for response; • Average times of closure; • Miles of FMS; • Number of traffic interchange signals connected to central system; • Number of hits to TTG's traveler information web site; • Number of calls to TTG's traveler information phone system; • Number of entries into HCRS; • Number of sites with HCRS; • Numbers of messages placed on the signs; • Availabilities of FMS; • Availability of HCRS; • Percent of surveillance devices responding; • Percent of time 511 available; • PC system availability; • Dollar of mandatory employee training; • Percent of mandatory supervisor training; • Percent of employee with >32 hours of training; • Years of ADOT experience; • Turnover rate; • Number of injuries; • People attending TOC tours; • Number of 511 comments; and • Percent of responses within 10 days to constituents.	• Congestion Index (percent of posted speed); • Travel time; • Segment delay (seconds/mile); • Stop delay (<3mph) (seconds/mile); • Average speed (percent of posted speed); • Average speed (mph); • Average HOV lane speed (mph); • Running speed ((length/travel time)-stop delay); • Total volume; • HOV lane volume; • General purpose lane volume; • Percent peak-period truck volume; • Percent peak-period volume; • Lane-mile operating at LOS F; and • Hours operating at LOS F.

Table A.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
6. Los Angeles, California	With the exception of HOV facilities, Caltrans District 7 currently does not use a formal system to measure performance. Therefore, the type of performance measures it collects and the uses of such data are limited. However, with the introduction of the Transportation System Performance Measures (TSPM) Program, performance measures will likely become more important in the near future. The proposed TSPM includes a number of travel time- and throughput-based measurements as well as other nonmobility measurements. It is proposed that interregional travel time in key travel corridors be monitored with actual origins and destinations. This shall include both people- and goods-movements. Total person hours of delay also shall be measured. A standard delay definition that can be applied to all modes has yet to be developed. TSPM also includes a reliability metrics to highlight the variability in travel time between origin and destinations. **HOV Facilities** *Output Measures* • Total length of HOV facilities; and • Net change in lane-miles. *Outcome Measures* • Level of Service (LOS) during peak periods; and • Travel time savings per mile. Daily and hourly volume on HOV facilities both in terms of the number of vehicles and of people.	**Caltrans** A Highway Congestion Monitoring Program (HICOMP) is mandated by the State of California to help achieve Caltrans' stated objectives of increasing efficiency and reducing delays on the State's freeway system. Each Caltrans district monitors freeway congestion level based on the following basic travel time parameters: • Magnitude (vehicle-hours of delay per day (vhdpd)); • Extent (congested directional miles (cdm)); and • Duration (hours). HICOMP defines recurrent congestion as a condition lasting for 15 minutes or longer and vehicular speeds are 35 miles per hour or less during peak commute periods on a typical incident-free weekday regardless of the posted speed limit. The total delay per segment is calculated by multiplying hourly vehicle volume by the duration of congestion in hours by the travel time exceeding that when traveling the same distance at 35 miles per hour. **SCAG** • Total delay (vehicle-hours and person-hours); • Total VHT; • Total VMT; • Average System Speed, "Q" (=VMT/VHT); • Percent variation in travel time; • Percent p.m. peak work trips within 45 minutes of home (Accessibility); and • Percent capacity utilized during peak conditions.
7. Portland, Oregon	N/A	• Travel Time Index (TTI); • Travel Delay; • Buffer Index (BI); • Volume-to-capacity Ratio (V/C); • Travel Time; and • Speed.

Table A.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
8. Houston, Texas	• Speed; • Delay; • Incident response time for large truck incidents; and • Web site usage and comments.	N/A
9. Washington, D.C.	**Maryland** (CHART) *Goal:* IMPROVE MOBILITY FOR OUR CUSTOMERS. *Objective:* Reduce congestion delay and associated costs caused by incidents by 1 percent annually. **Performance Measures:** *Output*: • Average incident duration; and • Number of incident responses and complete reports. *Outcome*: • Percentage of reduction in incident congestion delay; • Reduction in user costs ($ million) associated with incidents; and • Reduction in truck user costs ($ million) associated with incidents. **Maryland (Statewide)** • Percent of freeway lane-miles below congested volumes per lane.	N/A

Table A.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
10. Atlanta, Georgia	**Outcome** • Hampered by data quality concerns. Currently experimenting with a two categories of congestion: Moderate (speeds between 30-45 mph) and sever (<30 mph). Considering additional performance measures, including reliability. **Output** • Traveler Information Calls: – Total calls; – Calls per day; – Calls per route; – Calls by type of call; – Average call length; and – Average answer time. • Incidents managed: – By category; – Detection method; and – Impact levels (general categories). • Number of construction closures; • Device Functioning; • Percent time devices are available; • Number of media communications by outlet; • Web site visits by type of information requested; • Service patrol assists: – By shift; – By type; – By detection type; and – By route. • Service patrol service times (auto versus truck): – Response time; – Clear time; and – Notification to clear time.	N/A

Table A.5 Uses of Performance Measures

Metro Area	Operation Agencies	Planning Agencies
1. Minneapolis-St. Paul, Minnesota	The operations outcome measures of travel speed and its derivatives of travel time and reliability are just now being developed for use by the RTMC staff. The primary reason for the previous nonusage is data quality as described in the Data Quality section and the recent move to the new RTMC Building. The RTMC staff uses the output measures for incident and staff efficiency to provide benefits information to Mn/DOT management and to the public. The incident data is published monthly by RTMC staff and distributed to Mn/DOT management staff. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The FIRST incident data is used to adjust individual patrol routes for the FIRST drivers and to define the FIRST divers need per shift.	Performance data also serve as a basis for Metro Council plans and reports such as the Regional Transportation Plan, the Transportation Improvement Plan, the annual update of the Transportation Systems Audit and various operations studies. Although performance measures generally are not linked directly to specific investments, the findings and recommendations of the plans ultimately play a part in influencing investment decisions.
2. Seattle, Washington	WSDOT uses performance measures to help allocate resources, determine the effectiveness of a variety of programs, and help plan and prioritize system improvements, primarily from an operations perspective. A variety of measures are computed. Not all of these measures are routinely reported outside of the Department, but key statistics that describe either the current state-of-the-system, trends that are occurring, or the effectiveness of major policies are reported quarterly as part of the Department's efforts to clarify why it is taking specific actions and to improve its accountability to the public and public decision-makers.	Statistics allow comparisons of the relative performance of various corridors or roadway sections under study. These aggregated statistics also can be converted to unit values (e.g., person hours of delay per mile) to further improve the ability to compare and prioritize the relative condition of corridors or roadway segments.
3. Hampton Roads, Virginia	The operations outcome measures of travel speed and its derivatives of travel time and reliability currently are not used in real time by the STC or the HRPDC staff. The primary reason for the non-usage is that the data quality is often inadequate as a basis for making operations decisions. The STC staff uses the output measures for incident and staff efficiency to provide benefits information to VDOT management and to the public. The incident data is published monthly by the STC contractor and distributed to VDOT management staff. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The FIRST incident data is used to adjust individual patrol routes for the FIRT drivers and to define the FIRT divers need per shift. Operations managers in the STC also use the data for diagnostic purposes in evaluating the effectiveness of implemented strategies under varying conditions. This activity also may be tied to training of STC operations personnel. The field equipment maintenance data is collected and saved, but it is not yet used for management purposes. The current system is stored by use of Automated Maintenance Management software and all equipment is tracked by cabinet location.	HRPDC provides regional planning and policy decisions in areas of transportation, air quality, and regional development. The performance measures allow member agencies to make informed decisions on matters concerning not only the local jurisdictions but the Hampton Roads region as a whole. Historical performance measures reporting also is an important use of the metrics. The cyclical studies enable trend analysis for the travel demand model development and special reports for congestion and air quality; therefore, care is taken when metrics are developed or enhanced to ensure compatibility with historic data. Trend analysis is useful to pinpoint problem areas in both the long and short term. Performance data also serve as a basis for HRPDC plans and reports such as the Regional Transportation Plan, the Transportation Improvement Plan, and various bridge and tunnel operations studies. Although performance measures generally are not linked directly to specific investments, the findings and recommendations of the plans ultimately play a part in influencing investment decisions.

Table A.5 Uses of Performance Measures (continued)

Metro Area	Operation Agencies	Planning Agencies
4. Milwaukee, Wisconsin	WisDOT plans to use performance measures for the following applications: 1. Communicating the benefits of and marketing operations to WisDOT managers/administration; 2. Benchmarking performance for and providing feedback to control room operators; and 3. Use for operations management and planning (e.g., fine-tuning ramp meter timing, scheduling lane and ramp closures, etc.).	The FSOA program has developed a "Project Appraisal Report" (see pages 3 to 5 for an example) that could be used to: 1) compare various alternatives in a particular project or 2) prioritize or rank various projects for programming and funding. The Project Appraisal Report includes 1 quantitative measure and 3 qualitative ("intangible") measures.
5. Phoenix, Arizona	Performance measures are used by TTG for operations, emergency response and traveler information applications. Each measure is employed to achieve the objectives set forth in the ADOT/ITD Strategic Action Plan. The monitoring of speed and volume using FMS data allows TTG to measure the average percentage of Phoenix freeways reaching level of service "E" or "F" on weekdays to determine if the Group's objective of operating 60 percent of the freeways at a level "D" or better during rush hour is met. The speed and volume data also are used for ramp metering. Although TOC staffing level is measured, it is unclear that the information is being used to adjust work schedules. There also is no indication that the data are disseminated to field operations so that steps can be taken to rectify measures that do not meet stated objectives, i.e., clearance time. For freeway construction, performance measures are used in three ways. First, the measures help bolster priorities for freeways versus other transportation projects. They also provide justification of the one-half cent sales tax for construction of controlled-access highways. Lastly, they are used by ITD to prioritize implementation.	The performance measures allow member agencies to make informed decisions on matters concerning not only the local jurisdictions but the region as a whole. One of the key purposes of the Travel Speed Study was to validate MAG's planning model as required by EPA. Therefore, the measures were developed specifically to meet this need. Historical performance measures reporting also is an important use of the metrics. The cyclical studies enable trend analysis; therefore, care is taken when metrics are developed or enhanced to ensure compatibility with historic data. Trend analysis is useful to pinpoint problem areas in both the long and short term. The bottleneck study was commissioned to address the problem areas identified in the Traffic Quality report. Performance data also serve as a basis for MAG plans and reports.
6. Los Angeles, California	The primary use of performance measure is performance reporting. Performance is documented in two reports: the state mandated HICOMP report and the HOV report. The information is then used for planning and program purposes on the State and local levels. Performance measures are generally not linked to investment decisions. However, they are sometimes used to justify specific programs. When fully adopted, PeMS has the potential to dramatically change the way congestion is monitored and performance is measured. PeMS retrieves information from real-time and historic database and presents the information in various forms. Its value lies in allowing planning and operations staff to base their decisions on real system performance data without spending an undue amount of resources on data collection.	SCAG performance measures are developed during the RTP process to evaluate alternatives and select the best ones for inclusion in the Plan. The performance measures are tied directly to at least one of six established RTP goals. The goals and performance measures do not emphasize the freeway system but include it as an integral part of a comprehensive transportation system that includes all modes.
7. Portland, Oregon	N/A	The implementation of the measures and methodology will allow ODOT decision-makers to compare operations program benefits with other programs (e.g., safety, bridge, maintenance). The project provides the operations program with a process for estimating benefits, and this will help the program to identify places for additional study and investment. Finally, these methods will help define the return on operational investments.

Table A.5 Uses of Performance Measures (continued)

Metro Area	Operation Agencies	Planning Agencies
8. Houston, Texas	Very few performance goals. Some operations equipment reliability and timely repair standards are used. These goals are measured. Most use of performance measures are for real-time management of the system.	N/A
9. Washington, D.C.	**Maryland** Used for annual reporting and the development of specific strategies to meet mobility targets	N/A
10. Atlanta, Georgia	The NaviGAtor staff uses the output measures for incident and staff efficiency to provide benefits information to GDOT management and to the public in a weekly newsletter format. The incident and traveler information data is published monthly and distributed to GDOT management staff and others. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The HERO (service patrol) incident data is used to adjust individual patrol routes for the HERO drivers and to define the HERO divers need per shift.	N/A

Table A.6 Data Collection, Analysis, and Quality Procedures

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
1. Minneapolis-St. Paul, Minnesota	Operations performance data are being collected by the RTMC using in-pavement loop detectors. The data is collected and stored in 30 second intervals. Incident detection and verification are done by CCTV monitoring by RTMC operators, radio calls from FIRST drivers and by calls from Minnesota State Patrol, who receive 911 cell phone calls from travelers. RTMC also shares video with the Minnesota State Patrol, Mn/DOT Metro District Maintenance, Metro Transit, cities, counties, and all local television stations. UMN conducts an annual ramp metering evaluation for Mn/DOT. The evaluation is through simulation and it is related to freeway performance. UMN is considering using some cost-based measures, such as a mainline wait time versus a ramp wait time cost comparison for the next ramp meter evaluation.	UMN-Duluth maintains the speed data archive, they receive raw data flat files daily from Mn/DOT. The data is collected and stored in 30 second intervals. Mn/DOT and UMN worked together to develop the data quality process for Mn/DOT. The data quality checks detect outlying and missing data. The data collection algorithm notes loss of communications, flags data that is outlying from expected values or data that is nonchanging over a specified time period, notes missing or off-line detectors and assign a substitute (fake) loop. This process is done only for historical data, not real-time data.
2. Seattle, Washington	The Seattle performance measures effort is driven primarily by the existence of a significant archive of inductance loop data, which are collected by WSDOT's freeway ramp metering algorithm. This system consists of 620 loop stations comprising over 4,080 individual loops, of which 1,020 are paired into dual loop stations and the rest are either single loops located in the freeway mainlines or on-ramps. An archive of the 20-second data is maintained at the University of Washington. In addition to the inductance loop data, WSDOT undertakes four additional, significant data collection efforts: • Vehicle occupancy data collection; • Transit ridership data collection; • Incident occurrence and response reporting; and • Public opinion surveys.	Each of WSDOT's data collection programs has a variety of quality control steps designed to increase the quality of the data collected, as well as to identify and remove from further analyses those data that do not accurately describe actual roadway conditions. The software that operate in the Type 170 traffic controllers used by WSDOT produces an eight-bit error status code with each 20-second data packet transmitted from the field to the TSMC. All vehicle occupancy data used by WSDOT are collected manually by student work crews. Data from the field are entered into personal data assistants (PDA) carried by the data collection staff as each observed vehicle passes the count location. Each field entry is time stamped as it is entered into the PDA. To ensure the quality of these data, a series of software programs has been written to determine whether staff are actually entering real observations. The two basic checks compare the speed at which timestamps are entered (too many too quickly mean that the data collector is "inventing" vehicles) and compare records against continuously repeated numbers (which is usually an indication that a data entry key is stuck in the "on" position). Once the data pass through the initial set of checks, the summary vehicle occupancy rates are checked against previous data collected at this same location.

Table A.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
3. Hampton Roads, Virginia	Surveillance data are compiled with incident data, and traffic data from selected arterial loop detectors in the Hampton Roads Archived Data Management System (ADMS). This recently developed system provides access to real-time and historical traffic volume, speed, and incident data for selected regional corridors. The ADMS server will be moved to the VDOT Central Office in Richmond in the near future. The data are managed using SQL Queries. They are available currently to registered users, including STC and HRPDC staff as well as any user requesting access for research purposes. Data analysis currently is conducted by Smart Travel Lab staff. The data quality of STC-generated information has been hampered by loop detector failures. At any given time, only about one-half of the sensors are operational and the STC does not conduct a systematic sensor calibration process to validate the accuracy of the individual sensors. Further, their maintenance priority is the lowest among field equipment – both CCTV and VMS are a much higher maintenance priority. The operations staff does not use the speed data because of the low quality and travel speeds are reported on the traveler information web site. Realizing this problem impairs the effectiveness of the entire STC, VDOT is holding the Phase 2 contractor to much higher standards of installation quality than in Phase 1 and requiring detector calibration as part of the system delivery. The STC has developed a budget to repair, replace and calibrate defective loop detector installed in Phase 1, however that effort has not yet been funded. The Smart Travel Lab, as part of the ADMS project management task, conducts data quality checks on the detector data. The checks can determine if a detector is on-line and is reporting data continuously.	Traffic count data is collected by VDOT through a statewide count program. The current system uses traffic count machines at specified locations for two days of counting per year. Future plans may include use of STC data in areas where instrumentation is available. HRPDC obtains the traffic count data from VDOT for the Hampton Roads area. HRPDC conducts a CMS analysis in the region once each three years. The travel speed collection is through floating cars. HRPDC plans to incorporate GPS technology in the next update of the CMS. STC data will be used in future updates when the ITS data quality is maintained. Since HRPDC obtains its data from VDOT, they do not conduct independent validation of data. The agency, however, does perform internal checks and cleaning of the data based on historical data and knowledge of local conditions.
4. Milwaukee, Wisconsin	WisDOT is enhancing and upgrading their current ITS data archiving system to support a number of initiatives, one of which is the freeway performance reporting. This upgrade is referred to as the “Data Extractor” project, and the data warehouse. The Data Extractor project is expected to make the TOC’s data resources much more accessible, and will include scheduled (e.g., monthly) and ad hoc reporting functions. The core data types that will be included in the Data Extractor upgrade include: • Traffic detector data; • History of traffic detector failures; • History of traffic detector configurations; and • Lane and ramp closures. **Complementary University Activities** The Traffic Operations and Safety Lab (Traffic Lab, or TOPS) at the University of Wisconsin-Madison is developing the TransPortal system, a data warehouse in which they hope to integrate numerous types of disparate data, such as: • Road-weather information; • Public safety/incident management; • Traffic data; and • Static information (e.g., historical crash records). The vision is that a system like this, once implemented, could be used to support operational decisions and possible state-to-state data exchanges (such as in GCM).	**Loop Detectors** As with most traffic operations centers, loop detector maintenance is an issue for WisDOT. The majority of their loops are double-loops for speed measurement, and they are typically installed in conduit. This installation practice helps somewhat.

Table A.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
5. Phoenix, Arizona	Operations performance data are being collected by FMS using in-pavement loop detectors and passive-acoustic detectors. Incident detection and verification are done by close-circuit television (CCTV) and by 911 cell phone calls from travelers. The system is linked to ADOT's Highway Condition Reporting System (HCRS) is the main conduit for reporting highway conditions to the public. The powerful computer system has the capability to automatically retrieve weather forecast and advisory from the National Weather Service. It also collects special events, road closures and detour information and communicates with TOC's central computer system to obtain incidents and roadway conditions information. Communications take place via the Internet, wide-area network, and dial-up. Data analysis is usually conducted by ADOT staff. Whenever possible, traffic counts are based on data collected by FMS. When loop detectors are not available, either because the system is down or because the survey area is outside the FMS coverage area, radars are used. The annual short-term traffic counts are done over a 48-hour period at 15-minute intervals. MAG uses two different data collection methods for the Traffic Quality report and the Traffic Speed Study: 1) overlapping aerial photography and 2) floating cars.	The data quality of FMS-generated information has been hampered by loop detector failures. At any given time, only about 65 to 85 percent of the sensors are operational. Further, their maintenance priority is the lowest among field equipment. To account for poor detector data, an ITD staff does manual screenings. Techniques published by the Texas Transportation Institute have been helpful for this purpose. The data quality is documented and is available to those using the data.
6. Los Angeles, California	**Caltrans** Caltrans has spearheaded a data archival, processing and analysis system known as Freeway Performance Measurement System (PeMS) to facilitate performance measures calculations and analysis. PeMS includes data from roadway sensors and incident data from the California Highway Patrol and the Caltrans Traffic Accident Surveillance and Analysis System (TASAS). However, the application of incident data is not fully developed. The performance measures collected by ATMS and processed by PeMS are being fed into a newly developed Regional Integrated Intelligent Transportation System (RIITS). RIITS is a collaborate effort by Caltrans, the Los Angeles County Metropolitan Transportation Authority, and the City of Los Angeles. Its goal is to integrate traffic information from a variety of sources into one central system so to facilitate information sharing. It is accessible through the Internet (www.riits.net). The data also are being used by SCAG as basis for its transportation system analysis. **SCAG** SCAG has launched a Regional Transportation Monitoring Information System (RTMIS). RTMIS is a planning tool designed to "assist staff in monitoring and assessing the performance of the current transportation system against regional goals." RTMIS consists of four modules: highway, real-time traffic, and mapping. Four other modules are planned for future implementation. They include transit, aviation, nonmotorized and maritime. SCAG relies heavily on Caltrans as its source of performance data. RTMIS has two input components: 1) HPMS and 2) PeMS. Base year data are established for each mobility-related performance measure. Travel demand model is then used to project future speed and delay and calculate the travel time savings that would result if recommended improvements are made.	The data quality of ATMS-generated information has been hampered by loop detector failures. At any given time, only about 70 percent of the sensors are operational. While there is a Detector Fitness Program in place, it receives no dedicated budget. Freeway maintenance activities are prioritized according to 1) safety, 2) roadway preservation, and 3) others. Loop maintenance is in the lowest priority category. Some detectors are not fixed for weeks or months. For this reason, it will remain a challenge to collecting quality data. Data go through a normalization process. Both sets of data, raw and normalized, are archived. Through PeMS, users can obtain information on data quality and detector health. An application has been developed in PeMS to account for poor detector data.

Table A.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
7. Portland, Oregon	The Oregon statewide procedure is based on using the HERS-ST model and an augmented HPMS data set.	No special data quality procedures undertaken beyond what normally occurs for HPMS.
8. Houston, Texas	The data for the real-time traffic map are collected using vehicle equipped with AVI tags that are generally used for electronic toll collections on the network of the Harris County Toll Road Authority. Archived raw data has been kept since the system came on-line in 1993. The incident portion of the database is very extensive and provides details of each incident such as which lanes were closed, incident duration, and the actions taken to resolve the incident to name a few. Weather is not archived in the TranStar system. Work zone information has been archived since May 2002. Special events, work zone and emergency road closure information are posted on the web site for each day, and for a few days in advance when known. These are text files, not numeric or database files.	On most days 100% of the AVI reader stations are operational at a given time. Some sensors may need to be temporarily removed because of freeway construction activities, but changes can easily be made in the structure of the look-up table of locations for matched pairs to estimate travel times such that continued data collection is not interrupted. TxDOT has a contractor provide maintenance services for the infrastructure needed to collect the AVI data; measures are in place to assure that any nonoperational sites are repaired within certain time limits. The equipment has been extremely reliable both in the field as well as in the office. A vast majority of short-term outages are a result of loss of communication or interruption of electrical service to the field sites.
9. Washington, D.C.	**Maryland** CHART currently has traffic sensors at 1.0- to 1.5-mile spacing along some sections of I-70, I-83, I-95, I-270, I-495, I-695, I-795 and U.S. 50. The traffic sensors provide volume, occupancy and speed. Incident data is stored in a single Excel file record. U. of Maryland archives this data and compiles an annual operations evaluation report for CHART. Maryland SHA annually conducts customer surveys for the entire agency. A couple of questions regarding CHART are always included. CHART does not conduct a separate customer survey. U. of Maryland has developed a methodology for estimating the benefits of incident management programs, including estimating the amount of incident-related delay. This methodology is the first cut and is being improved. **Virginia** Virginia Transportation Research Center (VTRC) in Charlottesville receives all sensor data and archives it. VTRC conducts data quality checks. This function is being transferred to VDOT HQ. The Archived Data Management System developed for Hampton Roads is being extended to Northern Virginia. Several performance reports are available within the ADMS	**Maryland** Data quality checks are not yet being conducted for the sensor data. **Virginia** As part of the ADMS development, an extensive series of quality control checks are being performed on the sensor data. VTRC tested the accuracy of the loops in 2002. They were found to 95% accurate. The speed data was off on many detectors and it was found that the installation quality was poor (installers didn’t measure the length and widths). The improperly installed loops have been corrected.

Table A.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
10. Atlanta, Georgia	Operations performance data are being collected by the NaviGAtor system using a video detection system (VDS). The current detection system covers 222 centerline miles and consists of cameras covering each mainline travel lane at one-third-mile spacing. There are approximately 1,100 VDS detectors. The sensors collect data at 20 second intervals. Incident detection and verification are done by close-circuit television (CCTV) monitoring by TMC operators, calls to *DOT customer service representatives, radio calls from HERO drivers and by calls from 911 centers, who dispatch the local public safety responders. The TMC provides traffic and incident data in real time to the NaviGAtor web site. The web site information also is available to be sent to PDA or cell phone users upon request. The Archived Data Management System is being upgraded by GDOT currently. The primary focus of the archived is the speed detectors (VDS). The archived data management system will eventually include the incident management system records along with the detector records. When fully operational this system will enable the various sources of data (VDS, NaviGAtor actions, HERO activities, construction activities and weather information) to be integrated and geo-located.	GDOT recently completed an analysis of the VDS data quality. The findings of that analysis are summarized as follows: • 90% accuracy is required to support desired applications; • The VDS manufacturers specifications allow that level of accuracy; and • Field tests found that individual camera accuracy was highly variable. The analysis concluded that several improvements should be made to the VDS: • Revise system design to provide more accurate data; • Identify and treat systematic errors to achieve accuracy and coverage to support desired data products; • Generate metadata to clearly identify data availability and validity of data sample for the user; • Update maintenance procedures and make maintenance more frequent; • Integrate other data (incident data, speed data from other sources such GPS and toll tag readers); • Identify stations that have higher probability of reporting true values, move focus from single camera accuracy to station and segment accuracy – take advantage of redundancy and connectivity in the system; • Develop and use a data cleaning process; and • Generate truck percentage, VDS allows identification of trucks, but it currently is not used. GDOT currently is implementing the report's recommendations through an in-house VDS upgrade process.

Guide to Effective Freeway Performance Measurement

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1.0 Introduction

1.1 Purpose of This *Guidebook*

1.1.1 Scope

The objective of the effort documented in this *Guidebook* is: "to develop a guide on the effective use of freeway performance measures in operating the system and in meeting the information needs of a large spectrum of potential local, regional, and national users." This *Guidebook* presents a comprehensive approach to measuring the performance of urban and rural freeways. Freeways are defined as access-controlled highways characterized by uninterrupted traffic flow. The aspects of freeway performance covered by this *Guidebook* are as follows.

- The focus of the work is on congestion/mobility performance of freeways. This can be further defined as "quality of traffic flow or traffic conditions as experienced by users of the freeway." This category includes measures related to typical congestion levels, travel-time reliability, and throughput. It also includes supporting measures on the nature of roadway "events" that impede traffic flow: incidents, weather, and work zones. Most of the research conducted in preparing the *Guidebook* shows how these measures are developed from data and other analytic methods. Mobility is defined differently for urban versus rural freeways, as discussed later in this *Guidebook*. The rationale for focusing on congestion/mobility performance is that, of the major performance categories, it has the least amount of history with practitioners and is the least well formed. New concepts such as travel-time reliability and the deployment of transportation operations strategies in recent years underscore the emerging nature of this area.

- Despite the focus on congestion/mobility, other aspects of freeway performance also are covered, but not at the same level of detail. These areas (with the exception of customer satisfaction) have a much longer history of performance measurement in the profession. So, rather than "reinvent the wheel," the *Guidebook* uses references for much of its material. As a result, data and methods for other aspects of freeway performance are not covered in detail. Rather, the measures for each category are identified and methods for integrating them into a comprehensive freeway performance measurement program are presented, including their use in applications and decision-making. In some cases, these other performance aspects have or are developing their own performance measures, usually applied on an areawide basis. These additional aspects of freeway performance are:

- **Freeway Safety –** Especially safety aspects that are under the direct control of transportation agencies. Safety performance measures are now being considered as part of the recent emphasis on comprehensive highway safety plans;
- **Operational Efficiency –** Measures that relate to the activities and equipment used in freeway management;
- **Ride Quality –** Especially as it relates to the quality of traffic flow. Asset management information systems have long history of ride quality performance measures;
- **Environmental –** Emissions and fuel use are the areas covered in this *Guidebook*, although many other additional environmental aspects could be covered; and
- **Customer Satisfaction –** As transportation agencies adopt a stronger focus on their customers (i.e., users of the system), customer perceptions of performance are becoming important feedback on the effectiveness of transportation programs.

1.1.2 How to Use This *Guidebook*

In developing this *Guidebook*, a set of primary questions was developed surrounding freeway performance measurement. Answering these questions from the practitioner's point of view is the thrust of the *Guidebook* and serves as the basis for its structure.

- **Rationale for Freeway Performance Measurement: "Why are we doing this?"** Why is freeway performance important and why should its measurement be undertaken? What applications and uses can use freeway performance measures? What is the current state of the practice in freeway performance measurement? (Section 3.0)
- **Context for Freeway Performance Measurement: "How does it fit in?"** How does one establish and maintain a freeway performance measurement program? How does it mesh with other local, regional, state, and national activities in planning, operations, maintenance, and design? How should it evolve over time? (Section 4.0)
- **Performance Measures (Metrics): "What measures should be used?"** What aspects of freeway performance should be measured? What principles should be followed in establishing freeway performance measurement programs? What specific and quantifiable measures (metrics) should be used for each of these aspects? (Sections 5.0 and 6.0)
- **Supporting Data and Methods: "How are the measures developed?"** What data are required to support the development of freeway performance measures? (Section 7.0) What data collection mechanisms are available now or should be instituted? (Section 8.0) How should the data be processed and combined with analytic methods to create freeway performance measures? (Section 9.0)
- **Presentation and Communication: "How are the measures best presented?"** What are the options for presenting freeway performance measures to other professionals, decision-makers, and the public? How should freeway performance be explained and what is the significance of trends? (Section 10.0)

- **Use of Freeway Performance Measures in Decision-Making: "How are the measures used to support decisions?"** What should stakeholders' involvement be in using freeway performance measures? What are some examples of how freeway performance measures can be used in the decision-making process for setting policies and guiding investments? (Section 11.0; Section 12.0 for examples)

1.1.3 Intended Audience

Establishing performance measure themes is an important part of the development of freeway performance monitoring activities. Each audience should understand and use the themes to ensure understanding of the performance activities. This also ensures consistency in performance measurement. The themes should be informative and useful for all audiences. They ensure that everyone is "on the same page" and solving common problems.

Phrasing the performance measurement themes in the form of questions often makes them easier for all audiences (and the implementers) to understand, adopt, and implement. An illustrative example of typical questions, upon which themes can be based and/or identified, includes those identified in Table 1.1. Table 1.1 provides an easy-to-understand (and recall) summary of why and how the freeway performance measure activities are undertaken. This simple list of themes can be used to guide the development and implementation of the freeway performance measurement activities.

Audience for the Guide

An overview of audiences for the *Guidebook* is shown in Table 1.2. Table 1.2 also presents a description of typical reasons each audience type is interested in freeway performance monitoring activities.

1.1.4 Overview of Research Approach

The tasks conducted for the study are as follows:

- **Task 1.** Describe potential uses of freeway performance measures and list the performance measures that are likely to be most appropriate for each use.

- **Task 2.** Identify three to five metropolitan areas where exemplary use is being made of freeway performance measures.

- **Task 3.** Conduct benchmarking interviews based on the approved Task 2 plan.

- **Task 4.** Prepare a tentative set of appropriate performance measures, data requirements, and reporting techniques suitable for the uses identified in Task 1. The performance measures should support monitoring and evaluating (near-term and long-term) the performance of both individual freeways and the freeway system.

Table 1.1 Illustrative Example of Common Questions and Related Themes for Freeway Performance Measurement

Typical Question	Related Theme (Illustrative Answer)
Why are we doing this?	Provide accountability and improve operations program
How does it fit in with other performance monitoring activities?	Freeway performance report part of annual infra-structure report
How are the measures developed?	Task force to include external/internal stakeholder input
What measures should be used?	Travel-time based (total delay, Travel Time Index, and Buffer Index)
How are the measures used to support decisions?	Track trends to identify systemwide/corridor defi-ciencies and problem areas
How are the measures best presented?	Trend analysis and statistics both systemwide and for primary corridors (commutes) of interest

Table 1.2 Typical Audiences for the Guide Along With Associated Interests

Intended Audience	Typical Interests
Operations personnel (particularly those associated with TMCs and statewide coordination of operations activities)	Identifying successful/unsuccessful operations pro-grams and where/when to alter specific operations programs.
Highway designers	Identifying geometric constraints.
Highway programming personnel	Identifying necessary improvement projects.
State and MPO transportation planners	Identifying how well system is performing and ensuring regional and/or business plans are satisfied.
FHWA	Identify how national and statewide roadway networks are performing and to assist in Federal allocation of funding to needed projects.
Academia	Improve data sources and/or estimation procedures.
Legislators and other funding/policy decision-makers	Accountability – Ensure citizens they represent are receiving a good system for the dollars being spent.
Media	Accountability – Broadcasting successes, failures, and possible opportunities.
Agency oversight and accountability commissioners or boards	Accountability – Ensuring a benefit to funded programs and to what extent funded programs are successful.

- **Task 5.** Prepare an interim report on the information developed in Tasks 1 through 4, including an annotated outline of the guide.

- **Task 6.** Validate the information developed in Task 4 by presenting it to users of freeway performance information in several geographical areas, including at least one area that has limited experience with freeway operations.

- **Task 7.** Develop the guide based on the approved outline.

- **Task 8.** Submit a final report that documents the entire research effort and includes the Task 7 guide as a stand-alone document.

As shown, the research process was one of initial development (Task 1); obtaining input from practitioners (Tasks 2 and 3); refinement and enhancements (Tasks 4 and 5); obtaining feedback from practitioners (Task 6); and additional refinement and enhancements (Tasks 6 and 7).

■ 1.2 Performance Measure Definitions Used in This *Guidebook*

In the literature of performance measurement, a distinction is made between output and outcome types of measures:

- **Output** measures relate to the physical quantities of items; levels of effort expended, scale or scope of activities; and the efficiency in converting resources into some kind of product. Output measures are sometimes called "efficiency" measures.

- **Outcome** measures relate to how well the firm or agency is meeting its mission and stated goals. In the private sector, outcome measures relate to the "bottom-line" – the financial viability of the firm (e.g., profit and revenue). For transportation agencies, outcomes are more related to the nature and extent of the services provided to transportation users.

The research team and the project panel thought that, although the output/outcome dichotomy is well-established, it is confusing to new users. Therefore, an alternative naming convention was adopted:

- **"Quality of Service"** is a more intuitive term for the **outcome** category of measures; and
- **"Activity-Based"** is more apt for the **output** category of measures.

Figure 1.1 shows how this dichotomy for performance measures works in practice using highway safety as an example. The "bottom-line" for the agency is to improve the safety experience of users, and in this example, two quality of service measures have been selected to capture this directly: total crashes and number of fatalities. These measures indicate how well the system is performing. Supporting these measures is a large variety of activity-based measures; these relate to highway safety activities and have been selected because it is either known or postulated that, by improving them, overall highway safety also is improved. Note that in the example, one of the activity-based measures is "Miles of Guardrail" on the system. Some studies have shown that guardrail – especially improperly installed guardrail – actually can have a negative effect on safety.[1] Therefore, it is important to establish activity-based measures that link directly to quality of service measures. In other words:

Be careful what you measure – you just might get it!

1.3 Background on Freeway Performance Measurement

1.3.1 Issues Associated with Freeway Performance Measurement

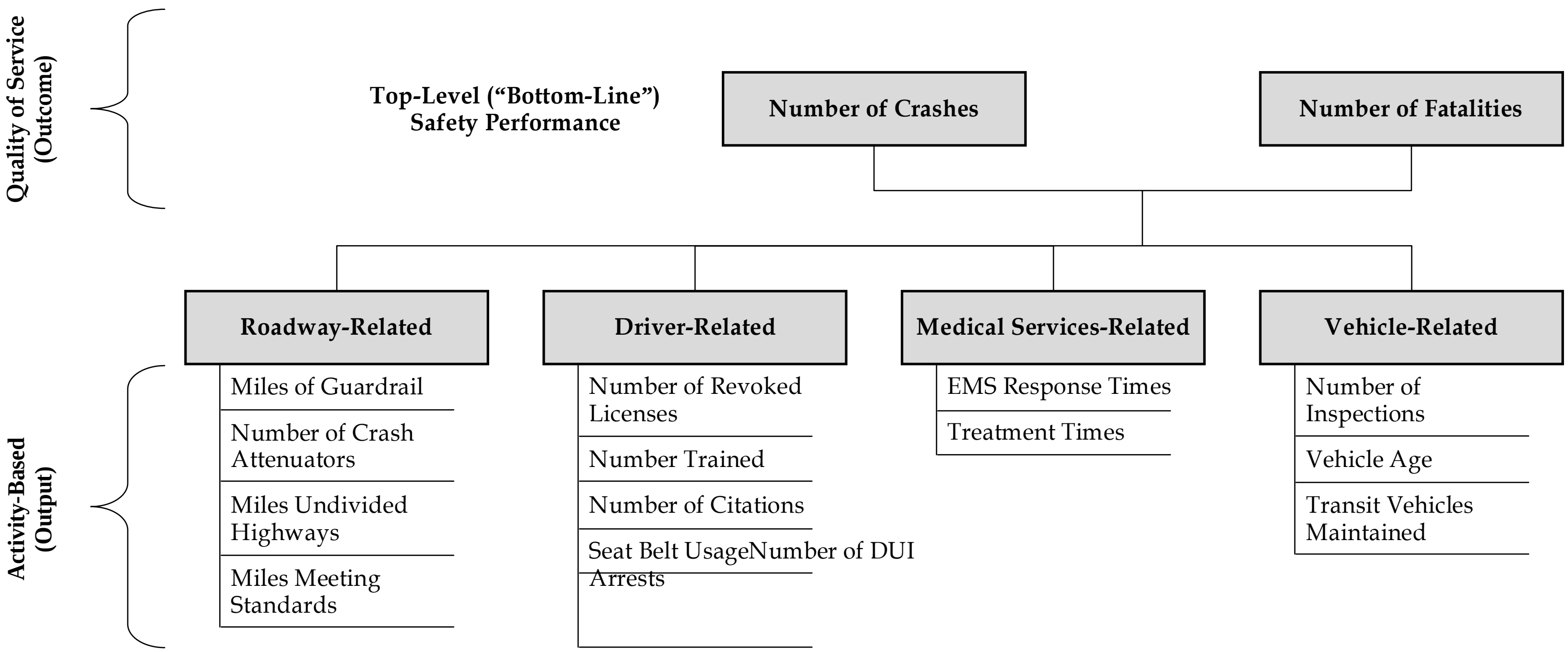
> **"Not everything that can be counted counts, and not everything that counts can be counted."**
>
> ***~ Albert Einstein***

The use of freeway performance measures has been growing in recent years, and ranges from site-specific operations analysis to corridor-level alternative investments analysis and to areawide planning and public information studies. In the past few years, the issue of performance monitoring has been elevated by transportation agencies to be responsive to the demands of the public and state legislatures and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). Simultaneously, the deployment of intelligent transportation systems (ITS) technologies has the potential to make a vast amount of data available for analysis.

However, many challenges lie ahead before freeway performance measurement becomes "standard practice" and is imbedded in the transportation decision-making process. These challenges include the following below.

[1] The connectivity of performance measures vertically (linking quality of service and activity-based measures) and horizontally (across applications and time horizons, such as trend analysis and long-range travel forecasting) is a major theme of this report and is repeated several times in the ensuing sections.

Figure 1.1 Relationship of "Quality of Service" and "Activity-Based" Performance Measures Using a Safety Example



Guide to Effective Freeway Performance Measurement

The transportation profession is only beginning to define and measure congestion/ mobility performance in objective terms. For more than 35 years, the *Highway Capacity Manual* (*HCM*)[2] has served as the focal point for defining quality of traffic flow. Prior to the 2000 edition of the *Manual*, performance was defined by broad ranges of "levels of service" (LOS). Even with the publication of the 2000 edition, freeway performance is still largely tied to the level of service concept. The 2000 edition of the *Manual* is beginning to address the "saturated flow regime" (i.e., congestion) in a comprehensive fashion, and to recognize that a single LOS category ("F") does not capture the nature and extent of congestion. At the local level, measuring and reporting congestion have often been done anecdotally without even the advantage of the limited application of the *HCM*. Future versions of the *HCM* will delve into this problem more deeply.

More detailed measures than *HCM*-based levels of service are required to capture the effect of operational strategies, which are often more subtle than capacity expansion projects. Implementing operational strategies usually never eliminate congestion, but rather improve it slightly. These effects are not captured with the broad LOS ranges recommended by the *HCM*.

Based on what data are available, congestion is growing in areas of every size. TTI's *2004 Annual Urban Mobility Report*[3] shows more severe congestion that lasts for a longer period of time, and affects more of the transportation network in 1999 than in 1982 in all urban population categories. The average annual delay per person climbed from 11 hours in 1982 to 36 hours in 1999, and delay over the same period quintupled in areas with less than 1 million people. The time to complete a trip during the congested period also continues to get longer. Further, congestion is consuming a greater part of the day in many metropolitan areas. The concept of a "peak hour" (rush hour) has been rendered irrelevant by travel patterns that have led to "peak periods" – multiple successive hours characterized by congestion.

Freeway performance must be viewed from several perspectives. A debate within the profession has arisen over the proper perspective for measuring performance. With regard to mobility performance, some have suggested that it is the view of the **user** (traveler) that is the most appropriate, while others argue it is the view from the **facility** that is the correct perspective. We have found this to be a specious argument: both perspectives are needed. The user perspective is important, because that is how transportation customers experience the system; this relates to characteristics of users' trips. The facility perspective is important, because transportation professionals mainly manage facilities; trips also are managed by such strategies as traveler information and demand management, but to a lesser degree than facilities. Further, the two perspectives are closely related in computation, data requirements, and the measures that can be applied. With regard to freeway performance, "trips" can be defined overextended segments. Freeway

[2] *Highway Capacity Manual*, Transportation Research Board, Washington, D.C., 2000.

[3] Schrank, David and Lomax, Timothy, *The 2004 Urban Mobility Report*, Texas Transportation Institute, September 2004.

performance measures can be useful in both planning (identifying evacuation routes) and operations (real-time management of evacuations).

The concept of "reliability" is growing in importance. There is growing recognition in the profession that not only does congestion occur on "typical" or "average" days, but it is the variability that occurs day to day that is important. Therefore, freeway performance must include the notion of reliability to be useful to both operators and planners.

While advances in freeway performance concepts have been made, data limitations hamper their implementation. As performance concepts become more sophisticated, the data requirements of supporting them become more onerous. In particular, reliability requires that data be collected nearly continuously. Even without considering reliability, more detailed data resolution is required to monitor changes due to operational strategies; traditional monitoring data, which are scattered and sampled, may be adequate for determining major capacity expansions, but lack the resolution to capture the effects of more modest operational improvements. Freeway surveillance data generated from ITS technologies can be used effectively for these purposes. But these data bring with them a variety of new issues, among them:

- The quality and completeness of archived data vary greatly from system to system. Lack of adequate maintenance for traffic sensors and/or communications infrastructure is a major barrier to providing quality data from freeway surveillance systems. Budget constraints and a high degree of redundancy are often cited as reasons why field sensors are not more intensively maintained. Further, not all of the freeway systems in metropolitan areas are covered by freeway surveillance.

- Traffic management operators have different data requirements than other archived data stakeholders. Traditional traffic management strategies, such as incident management, ramp metering, and identification of major queues, do not require the same level of resolution in performance data as trends monitoring. Many of the systems were developed to identify significant breakdowns in traffic flow, rather than subtle differences. The question is usually framed as: "are speeds 60 mph or 20 mph?" rather than, "are speeds 38 mph or 33 mph?" As operation strategies become more sophisticated (e.g., more refined traveler information is developed), this may change, but existing systems appear to be geared more to getting a coarse understanding of system performance.

- Data quality control procedures and analysis methods are not well developed. Additional work is required to identify best practices that can be applied consistently across the entire country.

- In most areas, local analysis of archived data has been a daunting task. Many data archiving systems are still considered "first generation," in which data is logged to an extremely large text file or thousands of smaller text files that are not readily accessible or usable by most data users. Plans are underway in many areas to improve the accessibility and ease of use of archived data.

- There are no clear findings regarding the optimum type of traffic sensor for freeway performance monitoring. Whatever sensors are used should be able to accurately measure speed or travel times and vehicle volumes at a relatively frequent spacing (0.5 to 1.0 mile). Accurately estimating spot speeds (and then travel times) from single loop detectors is problematic without adding special field hardware or using sophisticated software and estimation procedures. Vehicle probe systems (such as the AVI system in Houston) also present challenges for accurately estimating vehicle volumes for short time periods.

- Different data collection technologies produce different patterns and statistics. These could be misinterpreted as real differences in the transportation systems, when they are merely a function of the data collection devices. Some of these are easily understood, such as the difference between point detector speed estimates and roadway link travel times. Others that result from radar, single loops or double loops, or from data stored in a per-lane format or for the total road cross section are not well understood.

- Speed and travel time estimation equations can be improved. Several speed estimation procedures have been developed for use with single loop detectors, some of them very sophisticated. These might include time-of-day changes, traffic composition changes, or other traffic-adaptive procedures. The complexity, however, has been a hurdle for implementation. Some cities were not aware of the speed estimation procedures in their system, because they were embedded in the software and not clearly documented.

- The professional capacity is not yet present in most agencies to take advantage of the information that can be derived from archived data systems. The data are not readily accessible, the quantity of data can be daunting, and analysis techniques are not yet user-friendly. Training can solve some of these needs, but exposure to the benefits of using the data should significantly expand the interest in developing and attending training courses.

- In the short term, some combination of surveillance data, planning data, and modeling must be used to support freeway performance measurement. Since surveillance coverage is not complete and data problems will cause gaps in existing coverage, other means must be used to fill in the freeway performance picture. However, the system performance data derived from surveillance data may be significantly different from other estimates or modeling efforts. Combining freeway surveillance data with other data sources should be conducted only where the differences in each type of data are well understood, and where the need for a combination of data is unavoidable.

Communication of freeway performance monitoring results is critical. This involves not only selecting measures that are easily understood by a broad audience, but also conveying the results in formats that can be easily interpreted. Communication to both technical and lay audiences is a major part of our current efforts in this area, and we will build on this experience.

How freeway performance measures are to be used in the transportation decision-making process is still evolving. Most of the work to date on freeway performance monitoring has been in defining the concepts, measures, and data to support them. However, it is clear that the profession must move beyond the simple reporting of freeway performance trends – performance measures must be used to develop better investment decisions.

> **"I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot express it in numbers your knowledge is a meagre and unsatisfactory kind: it may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."**
>
> ***~ Lord Kelvin***

1.3.2 Relationship to Current Research Efforts

There currently is much activity in the area of performance measurement, particularly for congestion/mobility performance. Table 1.3 summarizes these efforts and indicates their relationship/value to the current project. Many of these projects have been drawn on in later sections to provide examples of freeway performance measurement. Note that only projects that are active have been included; these are the ones that may influence – and be influenced by – the current project. In addition, the Strategic Highway Research Program II (SHRP II) also may include projects related to freeway performance measurement.

Of the projects listed in Table 1.3, NCHRP Project 7-15 is the closest in nature of this project. The research team for this project has coordinated with the Project 7-15 team to ensure synergy and avoid duplication. The thrust of Project 7-15 is the use of travel time, delay, and reliability measures in a wide variety of applications undertaken by planners. Much detail on development of performance measures is given there, and in some ways the Project 7-15 report can be viewed as a companion document to this one.

Table 1.3 Relationship of NCHRP 3-68 to Other Current Performance Measurement Projects

Project	Description	Relationship to NCHRP 3-68
NCHRP 7-15, *Cost-Effective Measures and Planning Procedures for Travel Time, Delay, and Reliability*[a]	Developing analytic methods to compute travel time reliability measures, including when continuously collected data is not available. Delay by source of congestion also being considered.	Reliability measures will be compatible; analytic methods will be of value in computing freeway performance, especially for planning applications.
FHWA, *Urban Congestion Report (UCR)*[b]	Monthly reports on areawide freeway congestion developed from web-based speed maps and data.	Provides example of how to track trends at the metropolitan area level and develop performance measures from available data.
FHWA, *Mobility Monitoring Program*[c]	Annual reports (soon to be monthly) on corridor and areawide freeway congestion developed from archived and QC-passed surveillance data.	Similar to UCR for tracking trends, although corridors are the basic unit of analysis (more valuable to locals); special studies include "Lessons Learned" and analysis method to decompose congestion by source.
TTI, *Urban Mobility Study*[d]	Freeway and arterial areawide congestion trends for top 78 metro areas.	Long-standing history of congestion trends, widely accepted; pioneered new measures of congestion and develops them from planning-level data.
FHWA, *Work Zone Performance Measures*	Highly detailed performance measures and supporting data collection for monitoring work zone performance at the national and state levels.	Includes both outcome and output measures for 13 categories of work zone performance.
NCHRP 3-81, *Strategies for Integrated Operation of Freeway and Arterial Corridors*[e]	Project is to develop a manual of recommended strategies for integrating the operation of a freeway and arterial corridor, including their benefits and methods of implementing them.	Performance measures used to evaluate effectiveness of various strategies and serve as a basis for implementing them.
NCHRP 8-36/Task 47, *Effective Organization of Performance Measurement*	Studying: 1) how transportation organizations structure the performance measurement function; 2) how they organize and deliver performance information; 3) how performance measures are used to guide decisions at levels from top management down to operations; and 4) how measures are used in asset management.	Addressing the key issue of how performance measures are used in decision-making.
NCHRP 3-85, *Guidance for the Use of Simulation and Other Models in Highway Capacity Analyses*	This project will enhance the guidance in the *Highway Capacity Manual* for selection and use of simulation and other models.	Measures of effectiveness from model outputs are essentially performance measures (see Sections 4.4 and 5.0).

[a]http://www4.trb.org/trb/crp.nsf/e7bcd526f5af4a2c8525672f006245fa/62bad24780b7ac4b85256d0b005e07fb?OpenDocument.

[b]trb.org/Conferences/NATMEC/35-Wunderlich.pdf.

[c]http://mobility.tamu.edu/mmp/.

[d]http:/mobility.tamu.edu/ums/.

[e]http://www4.trb.org/trb/crp.nsf/e7bcd526f5af4a2c8525672f006245fa/e1818912cb5a8ade85256efd005b6770?OpenDocument.

2.0 Executive Summary

2.1 Purpose of This *Guidebook*

This report is structured as a *Guidebook* for providing transportation engineers and planners assistance in developing and maintaining a comprehensive freeway performance monitoring program. Multiple aspects of freeway performance are considered, but congestion and mobility performance is emphasized because of the lack of guidance and experience in this area. Other aspects of performance included safety, operational efficiency, ride quality, environmental, and customer satisfaction. A review of current practice, including that of the private sector, and 11 benchmarking interviews with state and local transportation agencies was conducted. Based on these results, the *Guidebook* is structured to answer four primary questions about freeway performance: 1) what measures should be used; 2) how can the measures be developed with data and models; 3) how should freeway performance be communicated; and 4) how are freeway performance measures used in decision-making. The draft *Guidebook* was developed as a series of nearly 400 annotated slides which were reviewed in five additional interviews with state and local agencies. This final *Guidebook* presents step-by-step procedures addressing the four primary issues associated with freeway performance monitoring. Ongoing freeway performance monitoring of recent trends is emphasized although the use of performance measures across project evaluations and analysis also is covered.

2.2 Background

The use of freeway performance measures has been growing in recent years, and ranges from site-specific operations analysis to corridor-level alternative investments analysis and to areawide planning and public information studies. In the past few years, the issue of performance monitoring has been elevated by transportation agencies to be responsive to the demands of the public and state legislatures and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). Reauthorization of Federal highway activities is likely to continue this emphasis on performance monitoring, particularly with regard to system operations and management. Simultaneously, the deployment of intelligent transportation systems (ITS) technologies has the potential to make a vast amount of data available for analysis.

However, many challenges lie ahead before freeway performance measurement becomes "standard practice" and is imbedded in the transportation decision-making process. These challenges include the following below:

- The transportation profession is only beginning to define and measure congestion/ mobility performance in objective terms;
- More detailed measures than *HCM*-based levels of service are required to capture the effect of operational strategies, which are often more subtle than capacity expansion projects;
- Based on what data is available, congestion is growing in areas of every size;
- Freeway performance must be viewed from several perspectives;
- The concept of "reliability" is growing in importance;
- While advances in freeway performance concepts have been made, data limitations hamper their implementation;
- In the short term, some combination of surveillance data, planning data, and modeling must be used to support freeway performance measurement;
- Communication of freeway performance monitoring results also is crucial; and
- How freeway performance measures are to be used in the transportation decision-making process is still evolving.

2.3 *Guidebook* Development

The *Guidebook* is structured to deal with the technical and institutional issues identified in the benchmarking interviews. The *Guidebook* addresses each stage in the freeway performance measurement process with step-by-step procedures for transportations to follow. The scope of the *Guidebook* covers:

- Urban and rural freeways: a comprehensive approach to freeway performance measurement;
- A focus on throughput/congestion/mobility of freeways, because of the lack of experience in these areas; and
- Discussion of additional aspects of freeway performance:
  - Freeway safety;
  - Operational efficiency;

- Ride quality – Affects quality of traffic flow (link to asset management information systems);
- Environmental – Emissions and fuel use; and
- Customer satisfaction.

A chapter of the *Guidebook* is devoted to each stage of the freeway performance measurement process:

- Rationale for Freeway Performance Measurement – "Why are we doing this?"
- Context for Freeway Performance Measurement – "How does it fit in?"
- Performance Measures (Metrics) – "What measures should be used?"
- Supporting Data and Methods – "How are the measures developed?"
- Presentation and Communication – "How are the measures best presented?"
- Use of Freeway Performance Measures in Decision-Making – "How are the measures used to support decisions?"

2.4 Benchmarking Interviews

A major part of this research effort is to ascertain what the more progressive agencies are doing in the area of freeway performance measures.

2.4.1 Motivations for Undertaking Freeway Performance Measurement

Four motivations exist for agencies to undertake freeway performance measurement:

- **Legislative Mandates**. State legislatures may require transportation (as well as other state) agencies to engage in a formal performance measurement and reporting process. Washington State is an example of this case. Freeway performance measures are undertaken initially primarily to feed the mandated reporting process, at least in Washington State's case, managers learn that there is intrinsic value in conducting freeway performance measurement for their own purposes (see reasons 3 and 4 below).

- **Agencywide Performance Measurement Initiatives.** Even in the absence of legislative intervention, DOTs and MPOs often initiate department-wide performance measurement programs for a variety of reasons. Usually these are ostensibly linked to the notion of "customer focus" and improved public relations and involvement. Like legislative mandates, these efforts result in Annual Performance Reports. Freeway performance is usually couched in terms of congestion/mobility in these reports and is usually summarized at the State or major metropolitan area level.

- **Formal Business Plan Linkage, Particularly for Operations.** Several agencies have taken a formal business plan approach to the actions. The undertaking of Business Plan can be dictated by DOT upper management or self-initiated by a champion.

- **Quantification of Benefits for Freeway Programs, Particularly for Operations.** Operations personnel are discovering that when it comes to competing for internal resources and visibility, they are at a disadvantage compared to other functional areas. Infrastructure programs have a long history of documenting the effects their program have users, as embodied in pavement, bridge, and maintenance management systems. "Not having the numbers" makes it hard to argue in favor of programs when others do have the numbers.

In two of the interview cities freeway performance measurement has not yet been undertaken, though there were signs that this may change (i.e., they may just be "late adopters"). None of the four motivations currently are present in these cities and local managers are not convinced of the cost-effectiveness of implementing performance measurement. In this sense, they are no different from the other cities – without strategic, legislative, or top management mandates/initiatives, it is doubtful that the other areas would have undertaken performance measurement.

2.4.2 Types of Performance Measures Used by Agencies

Both outcome and output measures are used by agencies. It is clear that agencies who have undertaken freeway performance measurement have accessed the literature on performance measurement because they use the outcome/output terminology.

For outcome measures, derivatives of speed and delay are commonly used by both operating and planning agencies. The Travel Time Index is a popular metric. Level-of-service as a metric is still in use in both planning and operations agencies, though it is not as widespread as it might have been 10 years ago. Reliability metrics have not yet found their way into widespread use. These metrics are usually formulated for short segments or at key locations. An exception is Seattle where a series of defined "freeway trips" have been defined – these can involve travel over multiple freeway routes for extended lengths. Output measures are used primarily by operating agencies, and then primarily for incident management activities and the operation of field equipment (e.g., sensors, cameras).

Many areas are beginning to define more sophisticated measures for measuring congestion/mobility performance but have not yet implemented them. Overall, there appears to be a trend away from the general categories of performance (LOS) and toward continuous measures that are based on delay and travel time. Further, consideration of travel time reliability is growing in acceptance, though its implementation is still problematic, primarily due to data requirements.

Customer satisfaction measures, where collected, are not used specifically for freeway performance measurement. Rather, they are instituted to gauge overall opinions about how well an agency is dealing with congestion.

2.4.3 Use of Performance Measures

Development of performance reports appears to be the major use right now for outcome-related freeway performance measures. The frequency of publication varies from weekly to annually, but annual reports are the most common. The linking of performance measures (more specifically, changes in them over time or their level relative to preset targets) and investment decisions are not well established. The best examples of actions taken based on performance measures is the tracking of detailed output measures for incident management programs – there is evidence that agencies act on these to modify activities such as service patrol routing and schedules. However, a linkage between major freeway investments and outcome measures (e.g., freeway delay) was not found. This may be due to the lack of experience with developing and applying the measures rather than with an unwillingness to use them to support investment decisions. It is true, however, that having better information on the scope and causes of congestion tends to lead towards more open thinking about what to fund to improve the situation. What it does not solve is the fact that the state and MPO planning processes choose large investments that are based on long-range needs rather than on short-term changes in performance measures (or the failure to meet current performance targets).

State DOTs and MPOs have not yet directly collaborate in joint efforts in developing freeway performance measurement programs. There seems to be a split of responsibility along traditional lines: DOTs tend to handle construction and operations while MPOs handle planning activities. Some MPOs and DOTs use common measures, but also develop measures unique to their applications.

2.4.4 Data Collection and Analysis

Metrics are developed through a variety of methods. Operations agencies (whose focus is primarily freeways) rely heavily on archived roadway surveillance data; the development of formal data archive management systems is on the rise. Planning agencies (whose purview includes all roadways in an area) use a mix of methods, including travel demand forecasting and other models, sample-based travel time runs from floating cars, and overlapping aerial photography. Planning agencies are just now starting to tap ITS data archives as a source of data for performance measures; this occurrence is not very widespread.

Universities within a state are commonly used to at least initially set up performance measurement programs and data archives. Sometimes these functions are passed on to the DOT, sometimes the universities retain control.

Integration of the various data sources available (ITS roadway surveillance, events (incidents, weather, work zones), and sample-based data) is not well very well advanced. However, there is recognition that this must occur, especially in areas that consider delay by congestion source (e.g., incidents) as an important measure.

Collection and use of incident data is becoming more common among freeway management systems. However, every area defines data elements and collects data differently. Work zones are occasionally collected as part of incident data. Collection of weather data is uncommon.

2.4.5 Data Quality

The quality of data from ITS roadway sensors is a major concern of agencies and has even caused trepidation in using the data for freeway performance measurement. Data quality problems can be traced primarily to two sources: 1) improper installation (including initial calibration and acceptance testing of equipment); and 2) inadequate detector maintenance due to funding shortfalls. This is a serious problem for freeway performance measurement, especially since ITS roadway sensors provide continuous data at the small time and geographic increments necessary to support sophisticated measures (reliability, congestion by source). The most extreme case is Houston which basically relies on probe readers for travel time estimates – they do not rely on the roadway sensors originally installed. As a result, since volumes are not available, not all the performance measures that are possible can be constructed.

When formal archived data management systems are implemented, data quality control checks are instituted. However, these are post hoc in nature – they can test for inconsistencies based on valid ranges, checks against theory, and checks against history, but subtle errors in accuracy still occur and are unknown. The only way to determine accuracy is to independently validate field measurements.

2.5 Basic Principles for Freeway Performance Measurement

In order to develop the suite of freeway performance measures, the research team developed a set of basic principles for guidance. Table 2.1 summarizes the principles. Consistent with the scope of the project, *the focus is on measuring the performance of freeways in terms of congestion/mobility and the activities related to improving traffic flow.* Detailed discussion of each principle appears in the *Guidebook*.

Table 2.1 Basic Principles for Freeway Performance Monitoring

Principle 1	Mobility performance measures must be based on the measurement or estimation of travel time.
Principle 2	Measure where you can – model everything else
Principle 3	Multiple metrics should be used to report freeway performance, especially for mobility.
Principle 4	Traditional HCM-based performance measures for mobility (V/C ratio and level of service) should not be ignored but should serve as supplementary, not primary measures of performance in most cases.
Principle 5	Both vehicle- and person-based performance measures of throughput are useful and should be developed, depending on the application.
Principle 6	Both quality of service (outcome) and activity-based (output) performance measures are required for freeway performance monitoring.
Principle 7	Activity-based measures should be chosen so that improvements in them can be linked to improvements in quality of service measures.
Principle 8	Customer satisfaction measures should be included with quality of service measures for monitoring freeway performance.
Principle 9	The measurement of travel time reliability is a key aspect of freeway performance measurement and reliability measures should be developed and applied.
Principle 10	Three dimensions of freeway mobility/congestion should be tracked with mobility performance measures: source of congestion, temporal aspects, and spatial detail.
Principle 11	Communication of freeway performance measurement should be done with graphics that resonate with a variety of technical and nontechnical audiences.
Principle 12	Continuity should be maintained in performance measures across applications and time horizons; the same performance measures should be used for trend monitoring, project design, forecasting, and evaluations.

■ 2.6 Recommended Freeway Performance Measures

The recommended performance measures fall into two categories: Core (Table 2.2) and Supplemental (Table 2.3). The Core measures represent those that should be developed by all agencies involved with freeway performance that have sufficient data available to them to undertake their development. In cases where data currently does not exist, agencies should strongly consider developing the data necessary to compute the Core measures.

Table 2.2 Recommended Core Freeway Performance Measures

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average (Typical) Congestion Conditions (Quality of Service)					
Travel Time	The average time consumed by vehicles traversing a fixed distance of freeway	Minutes	Specific points on a section or a representative trip only; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak-periods, midday, daily	Direct correspondence to NTOC measure, but distinction between “link” and “trip” travel time is not used
Travel Time Index	The ratio of the actual travel rate to the ideal travel rate[a]	None; minimum value = 1.000	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by BTOC
Total Delay, Vehicles	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions[b]	Vehicle-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak-periods, midday, daily	NTOC distinguishes between recurring and nonrecurring delay; delay by source recommended by *Guidebook* as supplements
Total Delay, Persons	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions[c]	Person-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak-periods, midday, daily	NTOC distinguishes between recurring and nonrecurring delay; delay by source recommended by *Guidebook* as supplements
Delay per Vehicle	Total freeway delay divided by the number of vehicles using the freeway	Hours (vehicle-hours per vehicle)	Section and areawide	Peak hour, a.m./p.m. peak-periods; daily	Not recommended by NTOC
Spatial Extent of Congestion No. 1	Percent of Freeway VMT with Average Section Speeds <50 mph[d]	Percent	Section and areawide	Peak hour, a.m./p.m. peak-periods	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Spatial Extent of Congestion No. 2	Percent of Freeway VMT with Average Section Speeds <30 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak-periods	
Temporal Extent of Congestion No. 1	Percent of Day with Average Freeway Section Speeds <50 mph	Percent	Section and areawide	Daily	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Temporal Extent of Congestion No. 2	Percent of Day with Average Freeway Section Speeds <30 mph	Percent	Section and areawide	Daily	
Density	Number of vehicles occupying a length of freeway	Vehicles per lane-mile	Section	Peak hour/periods for weekday/weekend	Not recommended by NTOC
Reliability (Quality of Service)					
Buffer Index	The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	Percent	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	NTOC recommends a “buffer time” which is the difference between the 95th percentile travel time and the average; conceptually the same as the *Guidebook*
Planning Time Index	The 95th Percentile Travel Time Index	None; minimum value = 1.000	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	

[a] Travel rate is the inverse of speed, measured in minutes per mile. The “ideal travel rate” is the rate that occurs at the free flow speed of a facility, or a fixed value set for all facilities that is meant to indicate ideal conditions or “unconstrained” (see text for discussion of the ideal/unconstrained/free flow speed).

[b] See text above for definition of “ideal.”

[c] See text above for definition of “ideal.”

[d] A freeway “section” is length of freeway that represents a relatively homogenous trip by users. Logical breakpoints are major interchanges (especially freeway-to-freeway) and destinations (e.g., Central Business District). The term “section” is sometimes used to describe this, but it usually implies additional parallel freeways and/or transit routes.

Table 2.2 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Capacity Bottlenecks (Activity-Based)					
Geometric Deficiencies Related to Traffic Flow (Potential Bottlenecks)	Count of potential bottleneck locations by type[e]	Number	Section and areawide	N/A	Not recommended by NTOC
Major Traffic-Influencing Bottlenecks	Count of locations that are the primary cause of traffic flow breakdown on a highway section, by type	Number	Section and areawide	N/A	Not recommended by NTOC
Throughput (Quality of Service)					
Throughput – Vehicle	Number of vehicles traversing a freeway in vehicles	Vehicles per unit time	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Direct correspondence to NTOC measure
Throughout – Persons	Number of persons traversing a freeway	Persons per unit time	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Direct correspondence to NTOC measure
Vehicle-Miles of Travel	The product of the number of vehicles traveling over a length of freeway, times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC
Truck Vehicle-Miles of Travel	The product of the number of trucks traveling over a length of freeway,[f] times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC
Lost Highway Productivity	Lost capacity due to flow breakdown – the difference between measured volumes on a freeway segment under congested flow versus the maximum capacity for that segment	Vehicles per hour	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC
Customer Satisfaction (Quality of Service)					
Worst Aspect of Freeway Congestion	(Defined by question)	1) happens every work day; 2) incidents that are not cleared in time; and 3) encountering work zones	Areawide or statewide	Annually; tied to survey frequency	Not recommended by NTOC
Satisfaction with Time to Make Long-Distance Trips Using Freeways	(Defined by question)	1) very satisfied; 2) somewhat satisfied; 3) neutral; 4) somewhat dissatisfied; 5) very dissatisfied; and 6) do not know	Areawide or statewide	Annually; tied to survey frequency	Direct correspondence to NTOC measure

[e] Bottleneck types are: Types A-C weaving areas (see HCM and Section 7.0); left exits; freeway-to-freeway merge areas; surface street on-ramp merge areas; acceleration lanes at merge areas <300 feet; lane drops; lane width drops >= 1 foot; directional miles with left shoulders <6 feet; directional miles with right shoulders <6 feet; steep grades; substandard horizontal curves. The shoulder categories are included because of the ability of more than 6-foot shoulders to shelter vehicles during traffic incidents.

[f] Trucks are defined as vehicles with at least six tires, i.e., FHWA Classes 5 through 13 plus any larger vehicles as defined by a state.

Table 2.2 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Safety (Quality of Service)					
Total Crashes	Freeway crashes as defined by the State, i.e., those for which a police accident report form is generated	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	Not recommended by NTOC
Fatal Crashes	Freeway crashes as defined by the State, i.e., those for which a police accident report form is generated, where at least one fatality occurred	Number			Not recommended by NTOC
Overall Crash Rate	Total freeway crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles			Not recommended by NTOC
Fatality Crash Rate	Total freeway fatal crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles			Not recommended by NTOC
Secondary Crashes	A police-reported crash that occurs in the presence of an earlier crash[g]	Number			Not recommended by NTOC
Ride Quality (Quality of Service)					
Present Serviceability Rating (PSR)	The general indicator of ride quality on pavement surfaces[h]	(Internal scale)	Section and areawide	Annually	Not recommended by NTOC
International Roughness Index (IRI)	Cumulative deviation from a smooth surface	Inches per mile	Section and areawide	Annually	Not recommended by NTOC
Environment (Quality of Service)					
Nitrous Oxides (NO_x) Emission Rate	Modeled NO_x attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Volatile Organic Compound (VOC) Emission Rate	Modeled VOC attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Carbon Monoxide (CO) Emission Rate	Modeled CO attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Fuel Consumption per VMT	Modeled gallons of fuel consumed on a freeway divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC

[g] See text for discussion.
[h] See: http://www.fhwa.dot.gov/policy/1999cpr/ch_03/cpg03_2.htm.

Table 2.2 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Incident Characteristics (Activity-Based)					
No. of Incidents by Type and Extent of Blockage	Self-explanatory	Type: 1) crash; 2) vehicle breakdown; 3) spill; and 4) other. Blockage: Actual number of lanes blocked; separate code for shoulder blockage	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Incident Duration[i]	The time elapsed from the notification of an incident to when the last responder has left the incident scene	Minutes (median)	Section and areawide	a.m./p.m. peak-periods, daily	Direct correspondence to NTOC measure
Blockage Duration	The time elapsed from the notification of an incident to when all evidence of the incident (including responders' vehicles) has been removed from the travel lanes	Minutes (median)	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Lane-Hours Loss Due to Incidents	The number of whole or partial freeway lanes blocked by the incident and its responders, multiplied by the number of hours the lanes are blocked	Lane-hours	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Work Zones (Activity-Based)					
No. of Work Zones by Type of Activity	The underlying reason why the work zone was initiated: 1) resurfacing only; 2) RRR; 3) lane addition w/o interchanges; 4) lane additions w/interchanges; 5) minor cross-section; 6) grade flattening; 7) curve flattening; 8) bridge deck; 9) bridge superstructure; 10) bridge replacement; and 11) sign-related	Number	Section and areawide	Daily	Not recommended by NTOC
Lane-Hours Lost Due to Work Zones	The number of whole or partial freeway lanes blocked by the work zone, multiplied by the number of hours the lanes are blocked	Lane-hours	Section and areawide	a.m./p.m. peak-periods; midday; night; daily	Not recommended by NTOC
Average Work Zone Duration by Type of Activity	The elapsed time that work zone activities are in effect	Hours	Section and areawide	Daily	Not recommended by NTOC
Lane-Miles Lost Due to Work Zones	The number of whole or partial freeway lanes blocked by the work zone, multiplied by the length of the work zone	Lane-miles	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC

[i]Since in many cases the actual time the incident occurred is unknown, the notification time is used to indicate the official "start" of the incident. On most urban freeways, through the use of cell phones by the public, the time between when the incident occurs and when it is first reported is very small.

Table 2.2 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Weather (Activity-Based)					
Extent of highways affected by snow or ice	Highway centerline mileage under the influence of uncleared snow or ice multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Extent of highways affected by rain	Highway centerline mileage under the influence of rain multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Extent of highways affected by fog	Highway centerline mileage under the influence of fog multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Operational Efficiency (Activity-Based)					
Percent Freeway Directional Miles with (traffic sensors, surveillance cameras, DMS, service patrol coverage)	One measure for each type of equipment deployed in an area	Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Percent of Equipment (DMS, surveillance cameras, traffic sensors, ramp meters, RWIS) in “Good” or Better Condition		Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Percent of total device-days out-of-service (by type of device)		Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Service patrol assists	Self-explanatory	Number	Section and areawide	Annually	Not recommended by NTOC

Table 2.3 Supplemental Freeway Performance Measures

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average Congestion Conditions (Quality of Service)					
Bottleneck ("Recurring") Delay	Delay that is attributable to bottlenecks[j]	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	NTOC defines two categories: recurring and nonrecurring; see text for discussion
Incident Delay	Delay that is attributable to traffic incidents	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	
Work Zone Delay	Delay that is attributable to work zones	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	
Weather Delay	Delay that is attributable to inclement weather	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	
Ramp delay (where ramp metering exists)	Delay that occurs at ramp meters	Vehicle-hours	Individual ramps and section as a minimum	Peak hour, a.m./p.m. peak-periods	
Abnormal Volume-Related Delay	Delay caused by abnormal high volumes[k]	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	
Volume-to-capacity ratio	The ratio of the demand volume attempting to use a short segment of freeway divided by the freeway's capacity, as defined by the *HCM*	None	Bottleneck locations only (freeway interchanges, lane-drops, bridges)	Peak-hour volume/peak-hour capacity Peak-period volume/peak-period capacity	Not recommended by NTOC
Traffic Demand Indicator	Ratio of actual traffic demand (volume) to average traffic demand[l]	None	Section and areawide	Peak Shoulder Periods	Not recommended by NTOC
Delay per Capita	Total freeway delay divided by the population of the area being studied	Vehicle-hours per person	Areawide and statewide	Peak hour, a.m./p.m. peak-periods; daily	Not recommended by NTOC
Average speeds by hour of the day (used primarily as an indicator of air quality)	The miles traveled by vehicles over a distance divided by the time it took to travel that distance (space mean speed)[m]	Miles per hour	Section and areawide	Peak hour, a.m./p.m. peak-periods; daily	NTOC defines "speed" as the time mean speed
Reliability (Quality of Service)					
Reliability: Failure Measure No. 1	Percent of trips (section or O/D) with space mean speeds <= 50 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC
Reliability: Failure Measure No. 2	Percent of trips (section or O/D) with space mean speeds <= 30 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC
Planning Time Index	95th percentile travel-time divided by the free flow travel-time	N/A	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC
Throughput (Quality of Service)					
VMT per capita	Freeway VMT divided by the population of the study area	N/A	Section and areawide	Peak hour, a.m./p.m. peak-periods, midday, daily	Not recommended by NTOC

[j] Delay is the excess travel-time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions; see text for a discussion of "ideal" conditions.
[k] May be due to either special events or normal variation due to daily/seasonal fluctuations in demand.
[l] See text for a more complete explanation.
[m] Although the *Guidebook* calls this space mean speed, depending on how the measurements are taken, it may be a "synthesized" space mean speed. That is, if the basic measurements are from point detectors, theoretically speaking, it is closer to being a time mean speed. See Section 9.0 for more discussion.

Table 2.3 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[n]	All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1 to 3 years				
Biggest concern about transportation[o]	Defined by survey question	Percent			Not recommended by NTOC
Most important thing the Department could do to improve congestion[p]	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to broadcast video images	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to traveler information about 1) congestion and 2) work zones	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to DMS messages	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to service patrols	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response to work zone management	Defined by survey question				Not recommended by NTOC
Percent of favorable response to freeway planning process	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with completed projects	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with air quality	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with long-distance travel	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with pavement condition	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with highway safety (how safe it is to travel?)	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with amount of salt used on main rural highways	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with environmental aspects of road construction	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with environmental aspects of road planning and design	Defined by survey question	Percent			Not recommended by NTOC

[n] Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.
[o] 1) Congestion, 2) poor road and bridge condition, 3) highway crashes, 4) transit not available.
[p] 1) Build more roads, 2) clear incidents faster, 3) reduce time that work zones are needed, 4) more effective snow removal, 5) better inform travelers about congestion they will encounter on their trips.

Table 2.3 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[q]	All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1 to 3 years				
Safety (Quality of Service)	All safety data defined by state police accident report (PAR)		All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Number of fatal, injury, and PDO crashes – total and by: 1) type of collision; 2) time of day; 3) relation to ramps; and 4) "first harmful event" (fixed object, rollover, etc.)		Number; distribution percents within each category			
High-crash locations[r]			Specific locations or short segments of freeway		
Alcohol-involved crashes (fatal, injury, total)		Number			
Commercial vehicle crashes (total and hazmat involved)		Number			
Commercial vehicle crash rate	Total number of commercial vehicle crashes divided by commercial vehicle VMT	Rate			
Crashes where speed was a contributing factor		Number			
Total Work Zone Crashes, Injuries, and Fatalities		Number			
Total Weather-Related Crashes, Injuries, and Fatalities		Number			
Incident Management (Activity-Based)					
First Responder Response Time	Time difference between when the incident was first detected by an agency and the on-scene arrival of the first responder	Minutes	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Notification Time	Time difference between when the incident was first detected to when the last agency needed to respond to the incident was notified	Minutes	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Total Response Time	Time difference between when the incident was first detected by an agency and the on-scene arrival of the last responder	Minutes	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Clearance Time	Time difference between when the first responder arrived on the scene and blockage of a travel lane is removed	Minutes	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
On-Scene Time	Time difference between when the first responder arrives and the last responder leaves an incident scene; also may be computed for individual responders	Minutes	Section and areawide		Not recommended by NTOC

[q] Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.
[r] Most states have procedures for identifying high-crash locations. Additional guidance may be available through software packages such as FHWA's *SafetyAnalyst*.

Table 2.3 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[s]	All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1 to 3 years				
Linger Time	Time difference between when the blockage of a travel lane is removed and the last responder leaves the incident scene	Minutes	Section and areawide		Not recommended by NTOC
Traffic Influence Time	Time between when an incident was first detected and the last responder leaves the incident scene	Minutes	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Detection Method (citizens, police, other agencies) per month	The method which incidents are detected or reported	Locally defined	Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Service patrol assists (total and by incident type)			Section and areawide	a.m./p.m. peak-periods, daily	Not recommended by NTOC
Work Zones (Activity-Based)					
Traffic volume passing through work zones	Self-explanatory; AADT estimates may be used in place of actual counts	Vehicles	Section and areawide	Daily	No work measures recommended by NTOC
Average Time Between Rehabilitation Activities by Type of Activity	Type of activity: 1) resurfacing only; 2) RRR; 3) lane addition w/o interchanges; 4) lane additions w/interchanges; 5) minor cross-section; 6) grade flattening; 7) curve flattening; 8) bridge deck; 9) bridge superstructure; 10) bridge replacement; and 11) sign-related	Months	Areawide	N/A	
Average Number of Days Projects Completed Late	"Late" is any time after the scheduled completion	Days	Areawide	N/A	
Ratio of Inactive Days to Active Days	"Active" is when some work zone activity was performed during a day	N/A	Areawide	Annually	
Crashes per lane-mile lost	Work zone crashes divided by the number of lanes lost	N/A	Section, areawide, and statewide	Annually	
Average Work Zone Duration by Work Zone Type by Lanes Lost	Time length of work zone activities by their severity in terms of traffic impact; Lanes lost = 0, 1, 2, 3, 4+	Hours	Areawide	Annually	
Average Number of Days That a Contract Work Zone is Active	"Active" is when some work zone activity was performed during a day	Days	Areawide	Annually	
Weather (Activity-Based)					
Number of incident responses during weather-related events	Self-explanatory	Number	Areawide	Monthly and annually	
Lane-miles and freeway miles officially closed due to weather or flooding	Self-explanatory	Lane-miles	Areawide	Monthly and annually	
Number of freeways with reduced speed limits by MP3 reductions	Self-explanatory	Number	Areawide	Monthly and annually	
Number of freeway ramps closed due to weather by weather event	Self-explanatory	Number	Areawide		

[s]Usually included in statewide surveys of public's attitudes towards transportation and service provided; also may be done at the local level.

Table 2.3 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)[t]	All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1 to 3 years				
Weather (Activity-Based)					
Time between two inches of snow accumulation and plowing (clearance)	Self-explanatory	Minutes	Areawide (lane-mile weighted)	Annually	
Lane-miles pretreated with chemical snow/ice control	Self-explanatory	Lane-miles	Areawide	Annually	
Lane-miles pretreated with chemical snow/ice control that experienced snow or ice conditions	Self-explanatory	Lane-miles	Areawide	Annually	
Weather event VMT ratio	VMT during event: VMT for recent same DOW	N/A	Areawide	Annually	
Weather event delay ratio	Delay during event: Delay for recent same DOW	N/A	Areawide	Annually	
Delay per lane-mile affected by major weather events	Self-explanatory	Rate	Areawide	Annually	
Crashes per lane-mile affected by major weather events	Self-explanatory	Rate	Areawide	Annually	
Operational Efficiency (Activity-Based)[u]					
Service patrol vehicles in operation per shift	Self-explanatory	Number	Section and areawide	User-specified	
Percent freeway miles with (electronic data collection, surveillance cameras, DMS, service patrol coverage)	Self-explanatory	Percent	Areawide	User-specified	
Number of messages placed on DMSs	Self-explanatory	Number	Section and areawide	User-specified	
Individuals receiving traveler information by source (511, other direct means)	Self-explanatory	Number	Section and areawide	User-specified	
Percent of equipment (DMS, surveillance cameras, sensors, ramp meters, RWIS) in “good” or better condition	Self-explanatory	Percent	Section and areawide	User-specified	
Percent of total device-days out-of-service (by type of device)	Self-explanatory	Percent	Section and areawide	User-specified	
Incident detection method	Self-explanatory	Number	Areawide	User-specified	
Number devices exceeding design life	Self-explanatory	Number	Section and areawide	User-specified	
MTBF for field equipment (by type of device)	Self-explanatory	Days	Section and areawide	User-specified	
Number of freeway miles instrumented with traffic data collection devices	Self-explanatory; directional miles	Miles	Areawide	User-specified	
Freeway construction projects completed within 30 days of scheduled completion	Self-explanatory	Number	Areawide	User-specified	

[t]Usually included in statewide surveys of public’s attitudes towards transportation and service provided; also may be done at the local level.

[u]A multitude of other operational efficiency measures resides in asset management information and performance measurement systems.

2.7 Data to Support Freeway Performance Measures

In a very large sense, performance measurement is all about data. It does little good to specify a complete and complex set of performance measures if accurate and timely data is not available to compute them. As such, the availability of data will directly reflect on what performance measures can be computed and reported, as opposed to what performance the agency/region would like to compute and report.

As a result, data availability needs to be a major element included in the development of the performance measures. Rarely is the majority of data required to perform performance measurement collected and made available specifically for that purpose. Of course, just because data is not currently available does not mean that desired performance measures should not be adopted. Adopting measures for which data currently cannot be provided simply means that the agency has been put on notice that additional data sources are needed to meet the roadway management and policy information needs of that agency or region.

The fact that the data is collected for purposes other than "performance monitoring" has two significant repercussions:

- To compute performance measures, the data must first be extracted from the systems which actually collect the data; and
- The raw data that is obtained must frequently be manipulated fairly extensively to produce the desired statistics.

2.7.1 The Steps Involving Collecting and Using Data

Obtain the Existing Data

Because most of the available performance data are collected for purposes other than reporting performance, obtaining data from existing traffic management and traveler information systems is often far more difficult than logic would indicate. Budgets for the development and deployment of the traffic management and traveler information systems are often smaller than needed, and a very common cost reduction strategy is to remove or significantly curtail the data archiving function that is needed to store, and efficiently retrieve, the data collected as part of that traffic management system. Consequently, creation of a performance monitoring system must often start with the construction of the software needed to efficiently store and retrieve data already "collected" by an existing traffic management system.

Develop Data Manipulation Procedures

Once obtained from the data archives, the data collected in the field can be:

- Used directly as a measure of performance (e.g., vehicle volumes, vehicle speeds);
- Combined with other data from other devices in the field to compute a new performance statistic (e.g., travel times computed from toll tag readers at different locations);
- Mathematically transformed into a different performance measure (e.g., point speeds at consecutive locations can be used to estimate travel times along a corridor);
- Combined with other directly measure data to produce more complex performance measures (e.g., vehicle volume and speed data can be used to compute vehicle hours of travel or vehicle hours of delay); and
- Used as input to various transportation modeling systems to estimate a wide variety of statistics that cannot be measured by the available sensor equipment (e.g., volume data used to feed a simulation model can produce estimates of pollution emissions).

Understand the Available Data

Once all of the "available" data have been identified, the next step is gaining a clear understanding of exactly how well those data represent the performance of the freeway they are being collected on, and how limitations in the data affect their use as performance measures. Understanding the strength, weakness, and holes in the available data helps determine what supplemental data need to be collected specifically for performance monitoring. It also defines the need for many of the data manipulation steps that are required (and discussed in the following section), and many of the assumptions that must be made to convert the available data into the required performance statistics.

Collect Supplemental Data

Once a clear understanding of the available data exists, it is possible to define the supplemental data collection that is needed to complete the data sets needed for the desired performance monitoring system. Supplemental data will be used to:

- Fill in the gaps in available data; and
- Provide information that help eliminate biases in the previously collected data.

Given the realities of performance monitoring budgets, supplemental data collection programs must often be phased in over time.

One common supplemental data program that may need to be implemented is a vehicle occupancy data collection effort. The number of people in each vehicle is not a commonly collected data item for traveler information or freeway control systems. However, statistics on carpool use are needed if the performance monitoring program needs to describe the effectiveness of policies designed to encourage shared ride travel.

A second supplemental data collection effort that is frequently needed is data on the public's perception of roadway performance. Again, these data are not required to operate or manage traffic control systems or traveler information systems, but they provide substantial insight into what the public views as important, how the public views the different traffic management programs being pursued, and how the public views overall performance of the roadway system. All of these are key inputs to the public decision-making process, and are therefore important performance reporting statistics.

A third supplemental type of data is on the number and/or percentage of trucks that are in the freeway traffic stream. Freight movement is a key policy issue, and the vast majority of freight moves by truck. Understanding how much freight moves on a given freeway is therefore important to the overall performance reporting for that road. Truck volume (by size of truck if possible) is also a key input to geometric, structural, and operational analyses for freeways. Thus, collecting data that describe the size and nature of trucking movements on a freeway is a strategically important supplemental data item.

Lastly, if special events or nonaccident incidents are major causes of congestion, supplemental data may need to be collected that describe when, where, and for how long these traffic disruptions occur. (Such data usually already exists for major accidents.) Without such data, it is not possible to determine the impacts these events have on facility performance, nor is it possible to determine how effective the programs are which were implemented specifically to reduce the impacts of these events on freeway performance.

2.8 Data Processing to Support Freeway Performance Measurement

The data for performance monitoring can be derived from two basic sources: 1) traditional traffic studies (e.g., "special studies") that rely on sampling performance data over time and by location; and 2) archived data that was originally collected for traffic operations purposes. Data processing is important regardless of the data source, but processing data archived from traffic operations systems may have special requirements above and beyond those from a traditional traffic study. For example, archived operations data may require additional computer resources because its detail is typically greater than that of typical traffic studies. Archived operations data may also require additional post-processing to adapt it for use in performance monitoring applications.

Because of the unique requirements and challenges, most of the material in this section of the *Guidebook* will focus on processing archived data from traffic operations systems. Where appropriate, this section will address data processing issues for traditional traffic studies. The section includes sections on quality control procedures, data management and fusion, and data analysis techniques.

2.8.1 Quality Assurance Procedures for Archived Data from Traffic Operations

Additional quality assurance procedures may be necessary if archived data will be obtained directly from traffic operations systems. To date, the quality of archived data from traffic operations systems has been influenced by two prevailing issues:

- The difficulty of maintaining extensive electronic field equipment (sensors and communication); and
- Real-time traffic operations applications that have different data quality requirements than historical uses of archived operations data.

The result has been that some managers and users of data archived from traffic operations have wrestled with data quality problems.

2.8.2 Improve Data Quality at the Source

In the long term, the most cost-effective way to improve data quality is to fix problems at the source. According to data quality professionals, "scrap and rework" (that is, a focus on fixing the low-quality data, instead of fixing the process that is producing low-quality data) should be avoided at all costs. Fixing problems at the source typically means improving the maintenance and calibration of traffic sensors, which can be difficult if the data consumers (e.g., planners) who want better data are functionally distinct from the data collectors (e.g., operations). Possible strategies for fixing data quality problems at the source include:

- Resource sharing between functional groups; and
- Focused resources at selected locations.

2.8.3 Apply Business Rules (Quality Control Checks)

The application of business rules (also known as quality control checks or screening rules) can automate the identification of suspect or invalid data values. These business rules describe the range of possible data values that are considered valid. Once suspect or invalid data are identified, they can be "flagged" as suspect or invalid and stored within the database, with the ability to exclude such data from subsequent calculations or analyses. Alternatively, suspect values can be reviewed by data archive managers who will make a final determination about the validity and future use of the "flagged" data.

Business rules can take numerous forms while addressing a variety of issues. In some cases, business rules are based on established theory or concepts, such as highway capacity or traffic flow. In other cases, business rules are based on intuition and "rules-of-thumb." Basic rules may only consider the minimum or maximum values for a single variable. Multivariate rules describe the interrelationships between two or more variables. Spatial or temporal rules address the possible range of values of space and time. For example, a business rule may prescribe the maximum percent difference that is considered valid for sensors in adjacent lanes or upstream/downstream locations. Or, a business rule might describe the maximum percent difference that is considered valid for traffic counts from consecutive years.

2.8.4 Visually Review and Confirm Data Quality

There are certain traffic patterns and trends that may be more suitable for manual visual checks. These checks may be difficult to automate, or data analysts may intrinsically value the ability to visualize the data to be used in the performance monitoring analysis. In these cases, a "human-in-the-loop" can be used to visually review a standard chart, graphic, or table to determine whether the represented data portrays a reasonable pattern or trend. These visual checks will require more staff-time, but are valuable in building confidence in the quality of the analysis database.

2.8.5 Communicate Data Quality Results to Data Collectors

As the previous sections indicated, a "scrap and rework" philosophy should not become part of the business rule process. The results of the business rule process should provide a feedback loop to the data collection personnel, such that suspect data are not always scrapped and reworked after running business rules. In the previous example, consider that the data archive manager might notice high failure rates in certain business rules. The manager will ultimately have to flag this data as invalid; however, the manager also should communicate the high failure rates to the appropriate data collection or equipment maintenance personnel, so that the data quality problems are fixed at the source.

2.8.6 Costs of Maintaining Quality Data

"Quality is free…What costs money are the unquality things…" This quote from an information quality guru does not really mean that improving or fixing data quality issues can be done at no cost. Instead, this quote should be interpreted to mean that the total costs for poor data quality (e.g., due to poor decisions, etc.) are much greater than the costs for improving data quality.

2.8.7 Metadata Specification

Metadata is "data about data" and typically describes the content, quality, lineage, organization, availability, and other characteristics of the data. Metadata is typically used to: 1) determine the availability of certain data (e.g., through searches of a data catalog or clearinghouse); 2) determine the fitness of data for an intended use; 3) determine the means of accessing data; and 4) enhance data analysis and interpretation by better understanding the data collection and processing procedures.

Metadata provides information necessary for data to be understood and interpreted by a wide-range of users. Thus, metadata is particularly important when the data users are physically or administratively separated from the data producers. Metadata also reduces the workload associated with answering the same questions from different users about the origin, transformation, and character of the data.

2.8.8 Data Archive Development

The key to developing data to support comprehensive and detailed freeway performance measures is a data archive, particularly for data being collected for real-time operations purposes. There are several resources that can be used in the development of data archives for performance monitoring or other applications. These resources are substantive; thus, a reference is provided here without including significant repetitive detail.

■ 2.9 Using Freeway Performance Measures

Performance measures are only worth reporting if they are used to inform decisions. When used properly, they inform the freeway agency's decision-makers about the condition of the facility. They describe the nature of problems on the facility, and when tracked over time, describe how those conditions are changing.

When produced in light of the policies being implemented, control systems being applied, and management actions being used, they become statistics that describe whether operational and policy goals are being reached, and whether management decisions are having the effects desired. This in turn leads to more informed decision-making as those decisions that improve system performance can be defended and continued, while those that have little impact or that actually hurt freeway performance can be abandoned or revised.

2.9.1 Key Considerations

Perhaps the most important consideration of performance measures is that they are measures of what has happened. By themselves, performance measures are not predictions of what will happen. As a result, they are particularly well suited for setting the stage for decisions, and they are excellent at measuring the impacts on freeway performance of the total range of policy decisions given the external factors (growth, weather, etc.) which detract from freeway performance.

Performance measures are not, by themselves, well suited to making decisions. They inform the decision-making process, but by themselves they cannot tradeoff the different priorities, interests, and values that must be incorporated in the decision-making process. However, having the information provided by a well designed performance measurement system greatly increases the chance that good decisions will be made.

Because performance measures require time and energy to produce, it is important that those in charge of computing those measures have an accurate understanding of what information is needed by, or useful to, decision-makers. With an understanding of the basic needs of the decision-makers, it is possible to prepare the statistics needed prior to the time they are needed, allowing for careful data review and analysis. A good way to gain this understanding is to think through what major policies are being considered and/or implemented. In addition, what subject areas are controversial? Once these topics are understood, select and report those performance statistics which describe freeway performance relative to those topics.

If performance measures inform key policy decisions, they will have high-visibility and high-levels of support from decision-makers and upper management. If the performance measures are not useful in addressing key policy issues, they will have much lower visibility and commensurately lower levels of support. Consequently, if only limited funding is initially available for performance measurement, make sure that the measures collected supply key information for policy-makers considering highly visible public decisions. Meeting such a visible need is likely to help create the upper management support for additional performance measurement funding. If the performance measurement process cannot meet the information demands of high-visibility decisions, little additional support is likely to flow towards the process, as the worth of the program cannot be effectively demonstrated.

2.9.2 Stakeholders for Freeway Performance Measures

Freeway operations are impacted by a wide variety of factors, and consequently affects, and is affected by, the actions of a large number of agencies and groups. Each of those agencies and groups is a potential stakeholder in freeway performance reporting. Each has an interest in freeway performance as it relates to their own operations. Among the obvious stakeholders are:

- The operator of the freeway, which contains multiple groups with different performance measure interests, including (but not limited to) staff involved in:
  - Transit agencies that provide service which use the freeway;
  - Transportation and land use policy-making bodies;
  - State, regional, and local planning groups that help identify, design, prioritize, and fund transportation improvement projects;
  - Regulatory bodies that oversee distribution of national and state funds;
  - The agencies that perform emergency response on the freeway;

- Police agencies that are responsible for law enforcement and major accident investigations;
- The local news media that wish to report on the condition and operation of the local freeway system;
- Private businesses such as trucking companies that routinely use the freeway system and whose business practices are therefore affected by the freeway's operational performance; and
- Individual taxpayers that either wish to use performance information directly, or desire that the freeway operating agency to use that information to develop and publicize travel information that improves the quality of their lives.

2.10 Use of Performance Measures in Decision-Making

There are two very different purposes for performance information reporting. One is for technical staff that plan, design, operate, and manage the roadway network. The other audience is the nontechnical people who actively use and/or are affected by the performance of those freeways. These nontechnical audiences include both the general public (including the media) and the political decision-makers who decide to fund the construction, maintenance, and operation of the system. Note that if the public is happy with how their money is spent, they also are more likely to vote for expanded programs and support leaders who vote for more spending or more innovative finance and operations programs. This is the connection between the two audiences and between the technical activities and public understanding.

Effective reporting often becomes the presentation of simple conclusions, backed up by good examples (taken from real life) that effectively illustrate the points that you wish to make as a result of very complicated and/or sophisticated analyses. With less technical audiences, the goal is to strip away the complexity and simply present an information summary that answers their real question or interest. This can be hard, but it is not impossible. It should be recognized that the audience does have an affect on the data, measures, and reporting styles. Experience suggests that once reporting begins, not only does the search for more knowledge continue, but as the importance of the data becomes clearer data quality also improves. Leadership commitment to using measures has a particularly significant effect.

2.10.1 Types of Measures

Begin with the end in mind. Everything that is or might be important should be considered in the measure development and data collection plans. The stories that might be told about the programs, projects, effects, and costs should be supportable by the measures that have been chosen.

Include measures to analyze and communicate information about the quality of service (how the public is being served) and agency activity (how well the transportation agencies are doing the actions that affect the quality of service).

- Quality of service measures are what the public experiences. They are the result of the interaction of basic infrastructure, operating strategies, the demand for travel and the outside influences on those three items. These measures tell how effectively the transportation system works.
- Agency activity measures describe the actions that are being taken and the efficiency and effectiveness of those programs.

Using both types of measures allows agency staff and the public to see whether the activities being produced are having the desired effect on the quality of service the public is experiencing. This process directly connects the evaluation of agency operations with the public's view of the results of the operations. Typically what happens as a result of this linkage is that many data collection items and processes are identified as having multiple uses, thereby improving the data collection efficiency and data quality.

2.10.2 Using the Measures – Consider the Future

Performance measure usage is an evolutionary process. A flexible set of measures and calculation tools provide the capability to compute a lot more measures than might be needed at any single time or for one type of report.

Evaluation efforts typically answer questions and judge the effect of new programs or changes in existing programs. Monitoring programs provide regular and periodic reporting on general and specific issues. Both of these usage types can provide information on any freeway performance attribute. Both types are important and should include trends that identify the current situation as well as the situation over time.

A few very important and illustrative measures should be selected for occasions where a Mayor, Governor, or board member asks for "the three measures that justify the operations and programs." The specific measures that are computed also will change with how those measures are used and to whom the results are communicated.

Show targets and levels. Determining targets may not be easy and in some situations it is not appropriate, but when possible a target focuses effort on measures that need improvement.

2.10.3 Measure Explanation

Explain the measure in easily understood terms. Measures and information do not have to be obvious, but they should be accompanied by a short, nontechnical explanation and example of the meaning.

Explain conclusions. Small text boxes or short statements should be used to provide focus on the ideas that should be derived from the measure values.

The measures and thresholds should be relevant. For example, residents of small cities do not expect to suffer the same congestion levels of very large metropolitan regions.

How is the measure connected with goals? The vision and goals for a system or society should be the beginning of measure development. The measure presentation should include this direct connection.

Connect the measures with explanatory data when possible and useful. Population and employment growth, traffic collisions and weather are among many factors that affect the service provided to users of the transportation system.

Identify where to go for more information. Web sites are excellent for this, but there should be some location to access more knowledge, especially when the measures are presented at a relatively light level of detail.

2.10.4 Measure Calculation

Detailed calculation steps should be shown in an appendix or resource material. Explaining the measure is more important than showing the formulas.

Weighting of links or trips is best done using terms that are common to many modes. Person-miles of travel and number of trips are good factors to weight condition and quality of service. Person-miles also can be used to combine road and public transportation travel conditions for system comparisons. Miles and lane-miles of road or route miles are good weighting factors for road condition or maintenance evaluation.

Aggregating system elements is best accomplished with section lengths that are significant to the audience and agencies. Travel-time over road sections between two and five miles or between major interchanges or activity centers are distances that are easy to understand and long enough to eliminate the small-time variations caused by minor detector calibration problems.

2.10.5 Data Used for Calculation

Use data that already is being used for internal agency decisions. The quality will be better, the cost of data collection will be minimized, and agency buy-in to using the measures will be easier to obtain. The data used in the analyses do not have to be simple for the measures to be simple. Likewise, simple measures do not have to be prepared from simple data.

Describe the differences. Where seasonality or change in system is an issue, conditions should be explained. It may be tempting to remove, add, or adjust the base data to reflect the "similar system" comparison, but this is usually not a good idea. It is better to explain why they are different and show the revised statistics in another graph. This avoids the appearance of attempting to change history. This is a different issue than acquiring better data, correcting errors, or changing methodologies to produce more accurate statistics.

Attempt to develop a flexible dataset that supports as many uses as possible, but recognize that data needs and uses will expand as users become familiar with the data.

All time periods can be important. Peak-period and offpeak analyses can both be useful and can point to different improvement needs.

2.10.6 Reporting Frequency

Another consideration in the presentation and communication of freeway performance measures is the frequency of reporting. This will vary depending upon the intended purpose (and audiences). It is often outlined in a strategic or business plan. Typical frequencies include annual, seasonal, or monthly. Most of these considerations apply to short- and long-term reporting rather than real-time which is defined by its nature, and operations which also has an immediate focus.

Timing is important. Quarterly performance reports will have more effect than annual reports.

One-page summaries are not inherently evil. They present a challenge to provide technical information without significant explanations, but they also can provide an attractive "front page" to the wealth of information available about transportation's importance.

2.10.7 Display and Presentations

Only the most curmudgeonly person is not swayed to some extent by packaging. The cost of a 30-second commercial during the Super Bowl shows that marketing and appearances are important to consumers. Data and analyses will form the basis of any program, but pictures, tables and graphs are the "face" that most nontechnical audiences will see and the view that many technical readers will use to identify problems.

Colors are good, but graphs should work with black and white copiers or those readers with color viewing problems. Light colors or open characters are intuitively associated with good conditions or low volumes.

- Stories – Narrative reporting to describe projects and programs in plain language that nontechnical audiences understand.

- Data – Must be credible and form the basis for stories and measures; data sources should be cited and data quality control should be a part of every step of the process.

- Graphics – The design of the document and charts and diagrams should not distract from the content; should both answer and ask questions; use maps to connect what readers are familiar with to the data; colors can be used, but the charts should work in black and white as well; clearly label the axes and use pointers rather than legends where possible.
- Timing – Timely and frequent information.
- Software – Capable of good formats and graphics.
- Include targets for measures where they have been determined.
- Use real-time data as often as possible.
- Measure the causes of the problems. Congestion, safety and other factors have causal factors – many of them are related. Problems with different causes may have different solutions.

2.10.8 Interpreting and Explaining Performance Measures

The key to any freeway performance measurement program is the ability to document and explain the costs and benefits of improvement programs as they relate to congestion and safety and to detect trends in these effects. Supplemental data, other performance measures, or additional studies can be used to further explain resulting trends or outcomes as required. The reality is that not all measures will be needed for every report. But it is important to think about being able to produce them, because the measures may be needed at some point and flexible systems require more planning. The selection of a set of measures is only partly to define which data should be collected. The process also is designed to identify how the measures should be presented to meet the communication needs of the analysis and the understanding of the audience.

Reporting needs change over time as audience understanding grows. This may appear as a "moving target" problem, but in most cases it is a reaction to the new knowledge and increased interest in understanding the effectiveness of improvement projects and programs. Once an important question has been answered, the public and elected leaders may stop asking about it and either ask for more information or move to another subject. The performance measures used to answer those questions may become less important or the need for reporting may become less frequent. Similarly, when a new issue becomes important, there may be a need to start reporting on that instead, with new performance measures. In some cases, the measure values begin to have less relevance and readers begin to examine the change in measure values or the relationship to targets or goals.

3.0 Goals and Characteristics of Freeway Performance Measurement

3.1 Introduction

3.1.1 Purpose of Chapter

Understanding what the measures will be used for and what the community wants the freeway and/or the improvements to accomplish is the beginning of the process of selecting freeway performance measures. Some of the measure selection will be assisted by an understanding of how other agencies, companies, or groups have identified their measure set. Freeway performance measurement activities should be coordinated with other performance measurement activities being performed by the agencies involved (e.g., other infrastructure elements). The four temporal periods that are used throughout the *Guidebook* to illustrate the process, decisions, and measures are identified in this chapter.

3.1.2 Background and Overview

Key Considerations

This chapter begins the discussion of developing a freeway performance measurement program by describing the goals and characteristics of freeway performance measurement. Sections of this chapter describe why agencies undertake freeway performance measurement, the history and state of the practice of freeway performance measurement in transportation agencies, and the political context for performance measurement.

Relationships to Other Freeway Performance Activities

Upon completion of this chapter, the reader will have an adequate background for Chapter 4.0 that begins the discussion of performance measurement as part of the planning and investment process.

3.2 Why Undertake Freeway Performance Measurement?

The primary reasons for implementing freeway performance measurement are:

- To ensure the highest level of transportation service by understanding what travel conditions are like and how they are changing (customer focus);
- Accountability; and
- Public relations.

Table 1.2 of Chapter 1.0 included the typical audiences for the *Guidebook* and their associated interests. The interests described in that table all fall within the three primary reasons for undertaking freeway performance measurement listed above.

Traditionally, freeway performance measurement has been described as addressing transportation needs arising from either a "planning," "operations," or "design" perspective. While addressing key problems in each of these areas is an important element of freeway performance measurement, Table 3.1 provides a slightly different perspective on the characteristics of freeway performance measurement. It categorizes applications, measures and the audience for performance measurement at different timescales. For example, a common application is traveler information, which requires travel time information from a continuous source; therefore, the timescale is real-time. Table 3.1 also presents the fact that as the timescale increases, the respective applications/audiences rely more on indices or total values (e.g., Travel Time Index, Buffer Index, total delay, and total travel time), rather than travel time itself.

Table 3.1 Characteristics of Freeway Performance Measurement Program Timescales

Timescale	Typical Applications	Typical Performance Measures	Audience
Real-time (continuous)	Traveler information, algorithms to alert operators of slow freeway speeds (incidents, bottlenecks)	Travel time	Travelers, commuters, TMC operators, highway designers/ transportation planners (data use)
Near term (~2-7 days)	Temporary work zones, weather mitigation	Travel time, Travel Time Index	TMC operators, emergency response, maintenance crews, highway designers
Short range (~1-5+ years)	Facility/corridor planning (investment decisions, B/C computations)	Total travel time, total delay, Travel Time Index, Buffer Index	Highway programmers, asset managers, highway designers
Long range (~5+ years)	Long-range planning (impacts of transportation and land use decisions on air quality, regional mobility)	Total travel time, total delay, Travel Time Index, Buffer Index	Statewide operations program supervisors, elected officials, decision-makers, transportation planners

Most of the audiences mentioned in Table 3.1 were first presented in Table 1.2 (Chapter 1.0). They represent typical users that would use freeway performance measurement for a given timescale.

3.3 Current State of the Practice in Freeway Performance Measurement

3.3.1 Benchmarking Interviews

The original benchmarking interviews (Task 3; summer 2004) and the validation interviews (Task 6; fall 2005) revealed much activity in the area of freeway performance measurement, as well as performance measurement in general. At the statewide level, with the exception of congestion measurement, aspects of freeway performance is likely to be subsumed within a broader context that covers multiple aspects of agency performance, usually at the statewide or network level. That is, measures relating to aspects like safety and ride quality are likely to be reported for all state-owned roads or all principal arterials. It is not uncommon for simple summary reporting procedures, such as "dashboards," to be used to convey trends and to compare performance to preset targets at the statewide level. (Chapter 10.0 presents more details on the dashboard and other communication mechanisms.) At this agencywide view of performance, considering the performance of individual highways or class of highways is less common – performance is bound up in achieving broad agency goals. Freeway congestion is the exception, due to the interest at the statewide level in them and, not insignificantly, because much data exist that can be used to measure congestion. A good example is the Minnesota DOT's (Mn/DOT) report of a congestion measure for use by the Mn/DOT Commissioner: the percent of the Twin Cities' freeway system congested during peak-periods (speeds less than 45 mph).

At the same time, units within state DOTs, as well as metropolitan planning organizations (MPOs), are establishing performance measurement activities more specifically focused on freeways. In addition to "central office" personnel who have an interest in statewide performance measurement, the benchmarking interviews targeted staff at freeway traffic management centers (TMCs) and MPOs, because it was felt that these organizations would have the need for detailed performance measures.

Introduction

A major part of this research effort is to ascertain what the more progressive agencies are doing in the area of freeway performance measures. From these interviews, it is then possible to borrow selected best practices and weave them into the eventual *Guidebook*. It is also possible to get an understanding of what will and will not be palatable to agencies in terms of the *Guidebook* procedures.

The original scope for the project stated that agencies in three to five areas be interviewed. However, we determined that it was possible to interview more than five areas for the project, because of the geographic spread of the Research Team and by combining visits on other Operations-related projects. Therefore, the team interviewed agencies in 11 areas (described below), 5 of which involved multiple agencies (at least operations and planning) in freeway performance measurement and the remainder involved operations personnel only.[1]

To prepare for the interviews, the Team assembled a notebook that depicts what various states are doing in the area of performance measurement, with a focus on freeways where applicable. These materials were meant to show interviewees what other areas are doing and what is possible.

Interview Plan

To help frame the questions for the interviews, the Research Team conducted a pilot interview with Georgia NaviGAtor personnel. After this interview, the Team constructed two interview guides – one for operations agencies and one for planning agencies.

Areas Selected and Why

Table 3.2 shows the areas that were selected for interviews, along with the justification for selecting these areas. Also shown are the agencies interviewed in each area. Note that the agencies were selected primarily because they were believed to have "exemplary" performance measure programs. Therefore, these are the agencies that are probably in the forefront of the field. While by no means comprehensive – several other areas are probably at least as well progressed in performance measurement – many transportation agencies are not as advanced in the performance measurement programs.

Summary and Analysis of Benchmarking Interviews

Appendix B presents the results of the interviews by the major topics covered in the interview guides. From these interviews, several themes and trends can be observed, as discussed below.

[1] One of the areas, San Antonio, did not have an appreciable performance measures program as of this writing. Therefore, the information summarized here is derived from the remaining 10 areas.

Table 3.2 Agencies Participating in the Benchmarking Interviews

Metro Area	Reasons for Selection	Agencies Interviewed
Multiple Agency Interviews		
1. Minneapolis-St. Paul, MN	Mn/DOT has been collecting and using performance and efficiency data for many years – they were an early leader in performance measures, earning themselves the title of "Land of 10,000 performance measures." Mn/DOT Ops aggressive at using operations data and information for decision-making. Long history of active freeway management and data collection. Location of high-profile public debate on operational policy (ramp metering), and location of significant transit technology test (buses on narrow shoulders)	Metro District Operations, Mn/DOT Center for Transportation Studies, University of Minnesota Metro Council
2. Seattle, WA	WSDOT very actively pursuing performance measures as a means of selling O&M program. Very active public reporting process, active experimentation in performance measure development, and freeway performance is a key subject in proposed ballot initiatives.	WSDOT HQ Traffic Office WSDOT NW Region WSDOT HQ Strategic Planning and Programming Puget Sound Regional Council
3. Hampton Roads, VA	Field Operational Test aimed at developing a comprehensive archive data management system (ADMS) being conducted here. Multiple stakeholder groups actively engaged in use of the archive; performance measurement at different levels a major thrust. CS is leading the evaluation.	Hampton Roads STC, VDOT Hampton Roads Planning District Commission
4. Milwaukee, WI	WisDOT embarked on aggressive use of information for operations and planning	WisDOT District 2 Operations WisDOT Central Office University of Wisconsin-Madison WisDOT District 2 Planning
5. Phoenix, AZ	MAG beginning a performance measurement program (planning); Maricopa County DOT also interested in warehousing data and providing performance reports. MAG has recently provided significant funding for improved data collection for performance reporting. Arizona DOT Traffic Operations Center currently monitors 50% of freeways in Phoenix and Tucson metro areas (100 centerline miles). Real-time information is provided to web site and 511. A quarterly report is published internally on freeway congestion in the Phoenix area and how well departmental objectives are being met. ADOT currently spends $2.25 million a year on its Traffic Operations Center plus $1.25 million a year on detector maintenance.	ADOT/Intermodal Transportation Division ADOT/Transportation Planning Division Maricopa Association of Governments

Table 3.2 Agencies Participating in the Benchmarking Interviews (continued)

Metro Area		Reasons for Selection	Agencies Interviewed
Multiple Agency Interviews (continued)			
6.	Los Angeles, CA	Caltrans HQ actively involved in performance measurement for both Operations and planning activities. Caltrans currently is funding development of an arterial monitoring system to supplement the freeway monitoring system. Real-time freeway congestion information currently is posted to the web.	Caltrans, Freeway Operations, District 7 Southern California Association of Governments Caltrans, Planning
Operations Interviews Only			
7.	Portland, OR	Portland has a very active freeway management effort, an ongoing performance measure development effort with Portland State University, and considerable public pressure to improve roadway performance.	See Note[a]
8.	Houston, TX	TxDOT/TRANSTAR currently prepares an annual performance report.	Houston TRANSTAR
9.	San Antonio, TX	TxDOT Operations has shown interest in better exploiting their data resources.	See Note[b]
10.	Washington, D.C.	CHART very active in incident management performance measures; expansion of Hampton Roads ADMS being planned for Northern VA	CHART (Maryland) VDOT Northern Virginia District
11.	Atlanta, GA	NaviGAtor actively using incident management performance measures. Business Plan being developed tied to multiple performance measures	GDOT, Office of Traffic Operations

[a] No formal interviews were conducted as part of NCHRP 3-68. Rather, the team relied on other work conducted by TTI on performance measures. As part of this effort ODOT assembled a Technical Advisory Committee (TAC) made up of individuals from ODOT sections of traffic management, transportation planning and analysis, transportation data, traffic operations, and internal audit/performance measures. The TAC also included individuals from the MPO in Portland (Metro) and the Eugene/Springfield area (Lane Council of Governments), academia, and the local Federal Highway Administration (FHWA) office.

[b] Initial conversations with TransGuide indicated that they currently are not using performance measures nor are they planning on developing them in the near future. TransGuide does have an extensive sensor system (485 lane-miles) and a formal incident management program from which detailed performance measures could be developed, however.

Motivations for Undertaking Freeway Performance Measurement. Four motivations exist for agencies to undertake freeway performance measurement:

1. **Legislative Mandates**. State legislatures may require transportation (as well as other state) agencies to engage in a formal performance measurement and reporting process. Freeway performance measures are undertaken initially, primarily to feed the mandated reporting process, but managers learn that there is intrinsic value in conducting freeway performance measurement for their own purposes (see Reasons 3 and 4 below).

2. **Agencywide Performance Measurement Initiatives.** Even in the absence of legislative intervention, DOTs and MPOs often initiate department-wide performance measurement programs for a variety of reasons. Usually, these are ostensibly linked to the notion of "customer focus" and improved public relations and involvement. Like legislative mandates, these efforts result in Annual Performance Reports. Freeway performance is usually couched in terms of congestion/mobility in these reports, and is usually summarized at the state or major metropolitan area level.

3. **Formal Business Plan Linkage, Particularly for Operations.** Several agencies have taken a formal business plan approach to the actions. The undertaking of Business Plan can be dictated by DOT upper management or self-initiated by a champion.

4. **Quantification of Benefits for Freeway Programs, Particularly for Operations.** Operations personnel are discovering that when it comes to competing for internal resources and visibility, they are at a disadvantage compared to other functional areas. Infrastructure programs have a long history of documenting the effects their program have users, as embodied in pavement, bridge, and maintenance management systems. "Not having the numbers" makes it hard to argue in favor of programs when others do have the numbers. Maryland SHA and Wisconsin DOT are two examples of this.

In two of the interview cities – San Antonio and Houston – freeway performance measurement has not yet been undertaken, though there are signs that this may change (i.e., they may just be "late adopters"). None of the four motivations currently are present in these cities and local managers are not convinced of the cost-effectiveness of implementing performance measurement. In this sense, they are no different from the other cities – without strategic, legislative, or top management mandates/initiatives, it is doubtful that the other areas would have undertaken performance measurement.

In applying performance measurement concepts, it appears that public agencies mirror those in the private sector, based on the scan in Section 3.3. Implementation of the concepts is the difficult part for public agencies. Once the institutional hurdle of establishing a performance measurement program is passed, many technical difficulties still lie ahead, as discussed below.

Types of Performance Measures Used by Agencies. Both quality of service (outcome) and activity-based (output) measures are used by agencies. It is clear that agencies who have undertaken freeway performance measurement have accessed the literature on performance measurement because they use the outcome/output terminology.

For quality of service measures, derivatives of speed and delay are commonly used by both operating and planning agencies. The Travel Time Index is a popular metric. Level of service as a metric is still in use in both planning and operations agencies, though it is not as widespread as it might have been 10 years ago. Reliability metrics have not yet found their way into widespread use. (Seattle and Minneapolis are exceptions.) These metrics are usually formulated for short segments or at key locations. An exception is Seattle where a series of defined "freeway trips" have been defined – these can involve travel over multiple freeway routes for extended lengths. Some of the more interesting metrics used by agencies include:

- Number of very slow trips (one half of free-flow speed) that occurs each year by time of day and major trip (Seattle);
- Percentage of reduction in incident congestion delay; and
- Percent of freeway lane-miles below congested volumes (based on volume per lane).

Activity-based measures are used primarily by operating agencies, and then primarily for incident management activities and the operation of field equipment (e.g., sensors, cameras).

Many areas are beginning to define more sophisticated measures for measuring congestion/mobility performance but have not yet implemented them. Overall, there appears to be a trend away from the general categories of performance (LOS) and toward continuous measures that are based on delay and travel time. Further, consideration of travel-time reliability is growing in acceptance, though its implementation is still problematic, primarily due to data requirements.

Customer satisfaction measures, where collected, are not used specifically for freeway performance measurement. Rather, they are instituted to gauge overall opinions about how well an agency is dealing with congestion.

Use of Performance Measures. Development of performance reports appears to be the major use right now for outcome-related freeway performance measures. The frequency of publication varies from weekly to annually, but annual reports are the most common. The existence of dashboards was not found in any of the areas, though Mn/DOT is in the development phase.

The linking of performance measures (more specifically, changes in them over time or their level relative to preset targets) and investment decisions is not well established. The best examples of actions taken based on performance measures is the tracking of detailed output measures for incident management programs – there is evidence that agencies act on these to modify activities such as service patrol routing and schedules. However, a linkage between major freeway investments and outcome measures (e.g., freeway delay) was not found. Washington State seems to be farthest along on this matter, but even there the correlation is not direct. This may be due to the lack of experience with developing and applying the measures rather than with an unwillingness to use them to support investment decisions. It is true, however, that having better information on the scope and causes of congestion tends to lead towards more open thinking about what to fund to improve the situation (at least in the case of Washington State). What it doesn't solve is the fact that the state and MPO planning processes choose large investments that are based on long-range needs rather than on short-term changes in performance measures (or the failure to meet current performance targets).

State DOTs and MPOs do not directly collaborate in joint efforts in developing freeway performance measurement programs. There seems to be a split of responsibility along traditional lines: DOTs tend to handle construction and operations while MPOs handle planning activities. Some MPOs and DOTs use common measures, but also develop measures unique to their applications.

Data Collection and Analysis. Metrics are developed through a variety of methods: operations agencies (whose focus is primarily freeways) rely heavily on archived roadway surveillance data; the development of formal data archive management systems is on the rise. Planning agencies (whose purview includes all roadways in an area) use a mix of methods, including travel demand forecasting and other models (e.g., HERS); sample-based travel time runs from floating cars; and overlapping aerial photography. Planning agencies are just now starting to tap ITS data archives as a source of data for performance measures; this occurrence is not very widespread.

Universities within a state are commonly used to at least initially set up performance measurement programs and data archives. Sometimes these functions are passed on to the DOT, sometimes the universities retain control.

Integration of the various data sources available (ITS roadway surveillance, events {incidents, weather, work zones}, and sample-based data) is not well very well advanced. However, there is recognition that this must occur, especially in areas that consider delay by congestion source (e.g., incidents) as an important measure.

Collection and use of incident data is becoming more common among freeway management systems. However, every area defines data elements and collects data differently. Work zones are occasionally collected as part of incident data. Collection of weather data is uncommon.

Data Quality. The quality of data from ITS roadway sensors is a major concern of agencies and has even caused trepidation in using the data for freeway performance measurement (e.g., Atlanta). Data quality problems can be traced primarily to two sources: 1) improper installation (including initial calibration and acceptance testing of equipment) and 2) inadequate detector maintenance due to funding shortfalls. This is a serious problem for freeway performance measurement, especially since ITS roadway sensors provide continuous data at the small time and geographic increments necessary to support sophisticated measures (reliability, congestion by source). The most extreme case is Houston which basically relies on probe readers for travel-time estimates – they do not rely on the roadway sensors originally installed. As a result, since volumes are not available, not all the performance measures that are possible can be constructed.

Several agencies have done formal studies of data quality. One strategy to deal with data quality (identified by GDOT) is to concentrate calibration and maintenance on "key" detectors, with the idea that these can be used to detect major problems (e.g., at known bottlenecks). The key detectors can then be used to adjust measurements from the remaining detectors. However, it is unclear how the adjustments will be done and how well this procedures will work to improve data quality. Further, developing performance measurements from a few isolated detector locations is also highly problematic – since most of the detailed performance measures are based on converting detector measurements to travel times in a corridor, the efficacy of this approach is in doubt.

When formal archived data management systems are implemented, data quality control checks are instituted. However, these are *post hoc* in nature – they can test for inconsistencies based on valid ranges, checks against theory, and checks against history, but subtle errors in accuracy still occur and are unknown. (The only way to determine accuracy is to independently validate field measurements.)

A little over a year after the benchmarking interviews, a second round of practitioner visits was made to:

- Portland, Oregon (also a 2004 benchmarking city);
- Phoenix, Arizona (also a 2004 benchmarking city);
- Minneapolis, Minnesota (also a 2004 benchmarking city);
- Atlanta, Georgia (also a 2004 benchmarking city); and
- Albany, New York.

The intended purpose of these visits was to gather feedback on the draft *Guidebook*, which had been written as a series of nearly 400 annotated slides. However, it was activity in performance measures had accelerated greatly in the intervening year. In Minnesota and New York State, at the urgings of the DOTs, the attendee list was expanded and the meetings were used as a forum for discussing performance measurement within the agencies. (A "performance measures summit" was the term used in Albany.) In Minnesota and Georgia, much work had been done since the 2004 visits on developing performance measures. In Minnesota these were developed for statewide reporting, policy, and programming purposes. In Georgia, they were developed to aid the activities of the Atlanta freeway TMC ("NaviGAtor") and thus include a wide variety of activity-based measures. Tables 3.3 and 3.4 show the most recent incarnation of performance measures for these two areas.[2] Note that in Table 3.3, Mn/DOT uses the outcome/output classification scheme, and adds a category called "input." Actually, those measures in the input category can be thought of as outputs since they are the result of deployment activities.

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[2] These two areas are highlighted because in the 2005 interviews they appeared to be the most sophisticated in terms of performance measure development. Appendix B has a complete description of the performance measures in use by the benchmarking cities for 2004.

Table 3.3 Draft Statewide Performance Measures Proposed for Use by Mn/DOT, 2005

Level	Measure or Indicator	Target	Audience	Application	Source
Mn/DOT Mobility Measures – Metro Areas & Regional Trade Centers					
Investment Planning					
Outcome – System	Congestion – Percent of Metro Freeway System (MUFS) congested during peak-periods (<45mph)	X	Public, legislature, executive, Metro planners	Public information Investment planning decisions	State Plan 6 Freight Plan
Outcome – System	Congestion – Percent of Metro Arterials (<2/3 of posted speed)	–	Public, legislature, executive, planners	Investment decisions	District Plan
Outcome – System	Travel Time Index – Twin Cities ranking among metro areas – ratio of peak to free-flow travel time	–	Public, legislature, executive	Information	State Plan 6 Freight Plan
Outcome – System	Travel Time Reliability – Percent longer than acceptable	–	–	Tested, not developed	State Plan 6 Freight Plan
Output	Bottlenecks – total number; – projects to relieve/ remove	–	Executive, public	Information, planning	Exec
Output	Freight Connectors to IRCs – Percent adequate	–	Freight/CVO, Metro	Under development	State Plan 4, Freight Plan
Perception	Congestion Tolerance – perception tracking survey	–	Executive, Metro, RTMC	Planning info	Metro
Traveler Information					
Outcome - Corridor	Travel Time – selected freeway trips point to point	-	Travelers	Real-time traveler info	RTMC
Outcome – System	Congestion and Incidents – MUFS	-	Travelers–web map, radio, TV	Real-time traveler info	
Operations & Operations Planning					
Outcome – Operations	Incident Clearance Time – Metro Freeways – average time, weekdays 6:00 a.m.-7:00 p.m.	35 min	Public, legislature, executive, RTMC	Real-time operations & planning	State Plan 3
Input	Incident Response Coverage – Percent of instrumented MUFS covered by a FIRST team	100%	Legislature, executive, RTMC	Budget decisions	HSOP 3.3
Input	Flow Mgmt – Percent of PA miles that are managed	–	–	not developed	State Plan 3

Table 3.3 Draft Statewide Performance Measures Proposed for Use by Mn/DOT, 2005 (continued)

Level	Measure or Indicator	Target	Audience	Application	Source
Mn/DOT Mobility Measures – Metro Areas & Regional Trade Centers (continued)					
Operations & Operations Planning (continued)					
Input	Incident Management System Coverage – Percent of MUFS system instrumented with cameras & sensors	100%	Legislature, executive, RTMC	RTMC investment decisions	HSOP 3.3
Output-Operations	Planned Lane Closures – Percent of planned maintenance closures done at night	–	Metro maintenance	Budget decisions	HSOP 3.3
Output-Operations	Unplanned Lane Closures – maintenance clearance time for unplanned lane blockages (major blockages)	–	Metro maintenance	Budget decisions	HSOP 3.3
Output-Operations	Signal Retiming – average years	4 yrs	Metro traffic	Budget decisions	HSOP 3.3
Output-Operations	Traffic Signal & Lighting Maintenance – response time	–	Metro traffic	Budget & operations decisions	HSOP 3.1
Perception	Satisfaction with Traveler Info & Traffic Mgmt Tools – Customer perception tracking study	–	Metro, RTMC	Operations decisions	Metro & RTMC
Output – System	Bus Shoulders – miles built or rebuilt annually	20/yr	Executive Staff, Metro Planners, Public	Investment decisions	State Plan 4
Output – Operations	Usage of Bus Shoulders – annual bus-miles utilizing hardened shoulders (proposed new measures)	–	Executive Staff, Metro Planners, Public	Investment decisions	Exec staff
Outcome – System	Greater MN Regional Trade Centers Congestion – RTCs with AADT exceeding thresholds (>15,000 2-lane, etc.)	–	District Operations, District Planners	Planning & Investment decisions	District Plans

Table 3.4 Advanced Performance Measures for TMC Use: GDOT NaviGAtor Performance Measures

Performance Measure	Implementability/ Priority	Usage	Measurement Units
Freeway Management			
Ramp Meters			
Number of ramps metered	Easy/Low	Internal	Ramps
Percent of time meters are operational	Hard/Low	Internal	Percent of hours
Number of vehicles metered	Hard/Low	Internal	Vehicles
Average vehicle delay	Hard/Low	Internal	Vehicle delay per vehicle
Increase in travel time reliability in metered corridors	Hard/Low	Internal	Percent change in buffer index vs. normal flow
Decrease in incidents in metered corridors	Hard/Low	Internal	Percent change in incidents per VMT vs. unmetered corridors
HOV Management			
HOV lane miles	Easy/High	Public	Miles
HOV lane volume	Easy/High	Public	Vehicles
HOV lane speed vs. SOV lane speed	Easy/High	Public	Mph
HOV lane occupancy vs. SOV lane occupancy	Easy/Medium	Internal	Percent of time detector zone is occupied
HOV lane throughput	Easy/Medium	Internal	Passengers per hour
CMS Messages			
Number of messages by type	Hard/High	Public	Messages
Percent time by message type	Hard/High	Internal	Messages per sign
Reliability of travel time messages	Hard/Medium	Internal	Travel time in minutes
CMS readability	Easy/Medium	Internal	Percent of signs with acceptable brightness, working pixels, etc.
CMS Message Usefulness	Easy/Medium	Internal	Message usefulness
Number of system generated messages that are operator modified	Hard/Medium	Internal	Number of messages modified
Planning Data			
Freeway total (all lanes) volumes	Easy/High	Public	Vehicles
Travel speed	Easy/High	Public	Mph
Travel time	Easy/High	Public	Time in minutes
Travel time index (ratio of travel time in peak hour vs. free-flow travel time)	Easy/High	Public	
Buffer Index (reliability measure – expresses extra "buffer" time needed to on time 95% of the time)	Easy/High	Public	
Number of hours in congested conditions	Easy/High	Public	Hours
Percent of Congested Travel	E high	Public	Network congestion, when travel times exceed 130% free flow on 20% of the system

Table 3.4 Advanced Performance Measures for TMC Use: GDOT NaviGAtor Performance Measures (continued)

Performance Measure	Implementability/ Priority	Usage	Measurement Units
Freeway Management (continued)			
Volume/capacity ratio	Easy/High	Public	
Percent trucks	Easy/Low	Public	Percent of trucks
Special Events Management			
Assistance to police managing special events	E medium	Internal	Assistance in CMS messages, equipment, HEROs
Incident Management			
NaviGAtor System			
Number of incidents	Easy/High	Public	Incidents
Detection method by type	Easy/High	Public	Percent of incidents
Reliability of PDS detectors	Easy/Medium	Internal	Ratio of positive detections to false detections
Incident duration	Hard/High	Internal	Time in minutes
Detection time	Hard/High	Internal	Time in minutes
Verification time	Hard/High	Internal	Time in minutes
Verification time in areas without CCTV coverage	Hard/High	Internal	Time in minutes
Dispatch time	Hard/High	Internal	Time in minutes
Response time	Hard/High	Internal	Time in minutes
Interval response time times as blocked lanes are opened during incident	Hard/High	Internal	Time in minutes
Clearance time	Hard/High	Internal	Time in minutes
Return to normal traffic flow time	Hard/High	Internal	Time in minutes
Automated response implementation time	Hard/Medium	Internal	Time in minutes
Number of incidents cleared by HEROs without other agency assistance	Hard/High	Internal	Incidents
Number of potential incidents not confirmed	Hard/Medium	Internal	Incidents
Tasks accomplished by automated process vs. manual process	Easy/Medium	Internal	Ratio of automated tasks to manual tasks
Number of towing dispatches	Hard/High	Internal	Dispatches
Tow truck response time	Hard/High	Internal	Time in minutes
Number of external agencies directly connected to NaviGAtor	Easy/High	Public	Agency
Utilization of cameras for security surveillance by external agencies	Hard/Medium	Public	Security incidents
Utilization of cameras for incident management by external agencies	Hard/Medium	Public	Percent of time CCTV is used in hours
Effectiveness of TIME program	Easy/High	Public	Effectiveness
Utilization of NaviGAtor resources for planned evacuation activities	Hard/Medium	Internal	Equipment

Table 3.4 Advanced Performance Measures for TMC Use: GDOT NaviGAtor Performance Measures (continued)

Performance Measure	Implementability/ Priority	Usage	Measurement Units
Incident Management (continued)			
HERO Operations			
Number of HERO assists	Easy/High	Public	Assists
Assistance duration	Easy/High	Internal	Minutes
Response time	Easy/High	Public	Minutes
Number of assists without dispatch	Easy/High	Internal	Assists
Number of times HERO is first responder	Easy/High	Public	Assists
Number of incidents HERO are unable to respond	Easy/High	Internal	Incidents
Number of incidents with HERO route calloff	Easy/High	Internal	Incidents
Traveler Information Dissemination			
Call Center Operations			
Call duration	Easy/High	Internal	Time in seconds
Call answer time	Easy/High	Internal	Time in seconds
Number of calls taken	Easy/High	Public	Calls
Number of call abandoned/overflow	Easy/High	Internal	Calls
Type of info requested	Easy/High	Internal	
Customer satisfaction	Easy/High	Internal	Satisfaction
CSR man-hours per shift	Easy/High	Internal	Man-hours
Web Site Operations			
Number of visits to site	Easy/High	Public	Visits
Page usage	Easy/High	Internal	Percent of visits
Session duration	Easy/Medium	Internal	Time in minutes
Referring web sites for NaviGAtor information	Easy/Medium	Internal	Web sites
Top 5 pages viewed	Easy/Medium	Internal	Page
Top 10 cameras viewed	Easy/Medium	Internal	Page
Top 10 CMS viewed	Easy/Medium	Internal	Page
Page load time	Easy/Medium	Internal	Seconds
Web-based customer survey usage	Easy/Medium	Internal	Visits
Kiosk Operations			
Number of devices deployed	Hard/Low	Public	Devices
Number of visits to site	Hard/Low	Public	Visits
Page usage	Hard/Low	Internal	Percent of visits
Session duration	Hard/Low	Internal	Time in minutes
Call Box Usage			
Number of call boxes	Easy/Low	Internal	Call boxes
Call box usage	Hard/Low	Internal	Calls

Table 3.4 Advanced Performance Measures for TMC Use: GDOT NaviGAtor Performance Measures (continued)

Performance Measure	Implementability/ Priority	Usage	Measurement Units
Traveler Information Dissemination (continued)			
Broadcast Media Coordination			
Number of radio, TV stations using NaviGAtor data	Easy/High	Internal	Stations
Number of broadcasters using media room during peak hours	Easy/High	Internal	Broadcasters
Utilization of CCTV images	Easy/High	Internal	Uses of images
Number of users of NaviGAtor data through broadcast media proxy	Easy/High	Internal	Listeners
Operations and Maintenance			
Field Device Maintenance			
Number of centerline miles instrumented	Easy/High	Internal	Miles
Number of devices in failure by type	Easy/High	Internal	Devices
Number of routine maintenance jobs	Hard/High	Internal	Maintenance tasks
Number of nonroutine jobs	Hard/High	Internal	Maintenance tasks
Number of hours lanes restricted due to routine maintenance	Hard/High	Internal	Hours
Number of hours lanes restricted due to non-routine maintenance	Hard/High	Internal	Hours
Device down time	Hard/High	Internal	Time in hours
NaviGAtor System Maintenance			
Number of devices in system by type	Easy/High	Public	Devices
Number of devices operating	Hard/High	Internal	Devices
System software module failures	Hard/High	Internal	Failure
System hardware failures	Hard/High	Internal	Failure
Subsystem software module failures	Hard/High	Internal	Failure
Subsytem hardware failures	Hard/High	Internal	Failure
TMC Staffing			
Operator man-hours	Easy/High	Internal	Man-hours
HERO dispatch man-hours	Easy/High	Internal	Man-hours
HERO operator man-hours	Easy/High	Internal	Man-hours
CSR man-hours	Easy/High	Internal	Man-hours
Maintenance technician man-hours	Easy/High	Internal	Man-hours
Employee turnover	Easy/High	Internal	Percent of employees leaving

Table 3.4 Advanced Performance Measures for TMC Use: GDOT NaviGAtor Performance Measures (continued)

Performance Measure	Implementability/ Priority	Usage	Measurement Units
Operations and Maintenance (continued)			
HERO Operations			
Vehicles in operation per shift	Easy/High	Internal	Vehicles
VMT by vehicle	Easy/Medium	Internal	VMT
VHT per vehicle	Easy/Medium	Internal	VHT
Vehicle fluids used	Hard/High	Internal	Gallons
Vehicle maintenance required	Hard/Medium	Internal	
Supplies used	Hard/Medium	Internal	
Work Zone Management			
Number of work zones reported	Hard/Medium	Internal	Work zones
Number of work zones	Hard/Medium	Internal	Work zones
Reliability of work zone reports	Hard/Medium	Internal	
Incidents reported in work zones	Hard/Medium	Internal	Incidents
Number of DOT/Contractors injuries in work zones	Hard/Medium	Internal	Injuries
Lanes closures due to work zones	Hard/Medium	Internal	Closures by lane
Congestion due to work zones	Hard/Medium	Public	Percent change in delay caused by work zones
Road Weather Management			
Number of weather stations deployed	Easy/Medium	Internal	Stations
Number of responses due to weather detection	Easy/Medium	Internal	Responses
Number of times weather station saved GDOT staff response	Hard/Medium	Internal	Responses
Other Systems			
Electronic Payment			
Traffic volume through toll booth	E low	Public	Vehicles
Number of Cruise Card tolls	E low	Public	Vehicles
Number of Cruise Card Lane Violations	E low	Internal	Vehicles
Information Management			
Number of records stored	H medium	Internal	Records
Number of requests for data by other agencies/ divisions	H medium	Internal	Requests
Number of requests for data by ISPs or media	H medium	Internal	Requests
Requests for data for GDOT studies	E medium	Internal	Requests
Amount of storage required	E medium	Internal	Storage space (GB)

Table 3.4 Advanced Performance Measures for TMC Use: GDOT NaviGAtor Performance Measures (continued)

Performance Measure	Implementability/ Priority	Usage	Measurement Units
Other Systems (continued)			
ITS/CVO			
Number trucks bypassing weigh stations using Pre-pass	E low	Internal	Trucks
Number of visitors to the Truck Only section of the NaviGAtor web site*	E low	Public	Requests
Number of trucks utilizing enhanced truck stops and incentives[a]	E low	Public	Processed incentives
Reduction in the truck percentage on interstates during peak-periods	E low	Internal	Vehicles
Education and Training			
Number of external education or training contacts TMC/HERO staff	E medium	Internal	Contacts
Number of tours to TMC	E medium	Internal	Tours
Number of man-hours in training	E medium	Internal	Man-hours

[a] These are measures that are anticipating the implementation of strategies from the GDOT truck study.

3.3.2 National Efforts Related to Freeway Performance Measurement

In addition to the independent activities of transportation agencies in developing and using performance measures, the National Transportation Operations Coalition (NTOC) also initiated a Performance Measures Initiative in September 2004. The purpose was to develop a few good performance measures for transportation operations.[3] The process followed by NTOC was similar to that used by the International City/County Management Association (ICMA) in developing performance measures for a wide variety of governmental functions. The recommended NTOC performance measures appear in Table 3.5. These measures relate to quantifying congestion and characteristics, and are therefore highly relevant for this project, and they have been used as input in developing the many of freeway performance measures recommended in this report.

[3] *National Transportation Operations Coalition Performance Measures Initiative – Final Report*, July 2005, http://www.ntoctalks.com/ntoc/ntoc_final_report.pdf.

Table 3.5 NTOC Recommended Performance Measures for Operations

Measure	Definition	Sample Units of Measurement
Customer Satisfaction	A qualitative measure of customers' opinions related to the roadway management and operations services provided in a specified region.	Very satisfied Somewhat satisfied Neutral Somewhat dissatisfied Very dissatisfied Don't know/Not applicable
Extent of Congestion – Spatial	Miles of roadway within a predefined area and time period for which average travel times are 30% longer than unconstrained travel times.	Lane miles of congested conditions or Percent of congested roadways Calculated as a ratio = 100% x (Congested Lanes Miles)/(Total Lane Miles)
Extent of Congestion – Temporal	The time duration during which more than 20% of the roadway sections in a predefined area are congested as defined by the "Extent of Congestion – Spatial" performance measure.	Hours of congestion
Incident Duration	The time elapsed from the notification of an incident until all evidence of the incident has been removed from the incident scene.	Median minutes per incident
Nonrecurring Delay	Vehicle delays in excess of recurring delay for the current time-of-day, day-of-week, and day-type.	Vehicle-hours
Recurring Delay	Vehicle delays that are repeatable for the current time-of-day, day-of-week, and day-type.	Vehicle-hours
Speed	The average speed of vehicles measured in a single lane, for a single direction of flow, at a specific location on a roadway.	Miles per hour, feet per second, or kilometers per hour
Throughput – Person	Number of persons, including vehicle occupants, pedestrians, and bicyclists traversing a roadway section in one direction per unit time. May also be the number of persons traversing a screen line in one direction per unit time.	Persons per hour
Throughput – Vehicle	Number of vehicles traversing a roadway section in one direction per unit time. May also be the number of vehicles traversing a screen line in one direction per unit time.	Vehicles per hour
Travel Time – Link	The average time required to traverse a section of roadway in a single direction.	Minutes per trip
Travel Time – Reliability (Buffer Time)	The Buffer Time is the additional time that must be added to a trip (measured as defined by "Travel Time – Trip"), to ensure that travelers making the trip will arrive at their destination at, or before, the intended time 95% of the time.	Minutes This measure also may be expressed as a percent of total trip time or as an index
Travel Time – Trip	The average time required to travel from an origin to a destination on a trip that might include multiple modes of travel.	Minutes per trip

A few differences should be noted between the two efforts, however:

- With the possible exception of incident duration, all of the NTOC measures are quality of service (outcome) measures while this report deals with both quality of service and activity-based measures;
- The NTOC measures are supported with general guidelines on how to develop them, whereas this report discusses data and methods in detail; and
- The NTOC report does not venture into how the measures should be communicated and used, a major thrust of this report (although NTOC is conducting a follow-on implementation phase that may get at this issue).

Basically, this report can be seen as an extension of the NTOC effort in terms of the above points.

A committee (E17.54) of the American Society for Testing and Materials (ASTM) has been involved with developing standards for archiving ITS-generated data for several years.[4] As of early 2006, this committee is specifying several performance measures derived from ITS traffic monitoring devices in the standard's data dictionary. These are congestion-related performance standards and include:

- **Volume.** A count of the number of vehicles traversing the detector during the interval.
- **Flow Rate.** The hourly equivalent of the volume. For example a volume of 1,000 vehicles per 15 minutes produces a flow rate of 4,000 vehicles per hour for the same interval.
- **Detector Occupancy.** The proportion of time that a detector is occupied generally expressed in percent.
- **Speed.** The average speed of all vehicles passing the detector during the time intervals. There are two definitions of average speed that may be applied to different purposes:
  - Time-mean speed. The arithmetic mean of the individual vehicle speeds, and
  - Space-mean speed. The geometric mean of the individual speeds.
- **Percentile Speed.** The 50th percentile (median) speed and the 85th percentile speed are of interest for traffic engineering purposes.
- **Pace.** The speed increment (usually 10mph) that includes the largest number of observations

[4] http://www.astm.org/cgi-bin/SoftCart.exe/COMMIT/SUBCOMMIT/E1754.htm?L+mystore+qgyo4410.

- **Percent within Pace.** A measure of dispersion of speed, considered to be related to safety.
- **Travel Time.** Estimated from the space mean speed at a series of detector stations.
- **Traffic Density (vehicle/mile) or vehicle/lane-mile).**
- **Level of Service (LOS).** A measure defined for each type of facility by the HCM. For freeways, LOS is based on traffic density, with specified thresholds applied.
- **Number of stops.**
- **Stopped delay.**

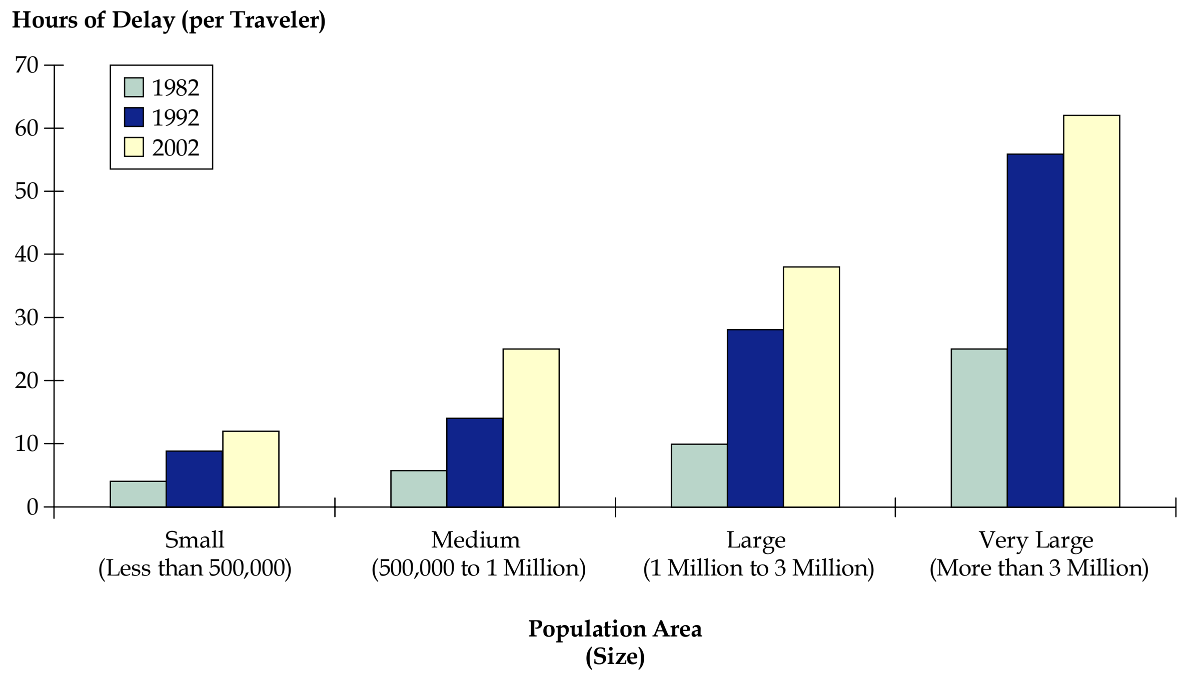
3.4 The Political Context for Performance Measurement

Freeway improvement programs are being pursued in several areas in the United States and in other countries. There are both expansions of capacity using free and priced projects and operational improvements. Performance measures have roles in all these programs and must be flexible enough to address the problems and effect of the solutions that might be employed. With congestion increasing in cities of all sizes (see Figure 3.1), there is a need for an analysis of the full range of congestion reducing treatments. Estimating the amount of projects, programs, and policies required to achieve congestion reduction can help focus the public discussions on mobility targets and alternative investment levels. The public input process can identify those programs that the public will support, the role of alternative funding strategies, and the needs for mobility improvements.

Regional planning efforts and state plans are being modified to incorporate the several types of mobility improvement programs, which is in line with the general approach of using all available technologies and programs. This multiple approach also requires a range of flexible performance measures that speak to a variety of different audiences with consistent messages. The analyses may be conducted using several technical measures and detailed data, but it is clear that the technical measures must build and support a set of generally understandable measures as well.

Recent activities at national, state, and local levels indicate that reliability in many forms is an important concept for these communication and analysis programs. Implementing programs and projects in timely stages and staying within time and cost budgets is one reliability element. Communicating the effect of the treatments during public comment periods and after operation begins is another. And reducing the variation of travel times from day-to-day is a key reliability goal of many improvement programs.

Figure 3.1 Congestion Growth Trend



If reliability is a concept that links the performance measure needs, accountability is a main force for the implementation of performance measure programs. Business leaders, elected officials and the public wish for their transportation funds to be spent wisely, and with performance measures there are better ways to create that assurance.

Improved monitoring, in both construction and program implementation, and in performance of transportation systems, can provide a variety of informational elements that can be used in several ways:

- **Improved Performance.** Using the information from operating systems can be used by the operating agencies to alter hours or methods of operation to improve the system.
- **Improved Communication.** Performance measures that include travel time, delay, or other easily understood concepts can provide better ways to communicate the system conditions. These can target, for example, before/after effects of recent programs or the amount of productivity lost from congested conditions.
- **Program Justification.** Performance measures and a before/after data collection program can be very effective at identifying the effect of a range of freeway management actions. Many of these actions are not as easily modeled in Highway Capacity Manual-type analyses.

- **Funding Enhancements.** In most recent campaigns for funding increases, pricing projects or increased funding flexibility, performance measures have played two key roles. They can be used to demonstrate improved conditions with the use of existing funds to show that current agency actions are appropriate and beneficial. The measures and data also can be used in public accountability pledges to demonstrate the effect of the proposed programs. Perhaps the most significant lesson from the review of performance measurement activities over the last two decades is that all performance measures and measurement systems have evolved. The changes have been the result of legislative interests, accountability efforts, new data sources, estimation procedures, changes in knowledge about traffic conditions and perhaps most importantly, growth in interest for the information once reports and data are used. The effect of this lesson is that transportation staff and leaders should experiment with measures and data and presentation techniques.

To some extent, pavement and bridge evaluations are perceived as being more complete than congestion analyses. Over one or two decades of condition assessments and visual inspections, the procedures and data sources have been refined and the presentation of information has been improved. A substantial amount of this progress has been the result of improving existing practices. While the initial data and calculation procedures may have "stretched" the state of the practice, they also allowed improvement opportunities to be identified. Certainly the requirements for the management systems in some states and cities for performance measurement programs developed slowly, but once begun, the refinements have been part of continual progress not revolutionary change.

The challenge for agencies currently not using performance measures is to start: somewhere. With the best data and estimation processes available. Pavement and bridge management systems are being held up as models for freeway operations measurement systems. The infrastructure condition investments are easier to support with improved performance measures. Freeway performance measures can likewise play a more important role in operations and capital spending programs if they are developed with the best available data, best methods and procedures and the proper caveats to describe the use and interpretation of the information.

A discussion about the political context of performance measures is not complete without mention of possible political pressures that may be present throughout performance measurement activities. Implementers cannot alter the process or the results to make freeway managers and improvements "look good." Despite possible political pressures, it is imperative that the performance monitoring activities remain objective. Maintaining the integrity of the individuals, and the process itself, is essential. Loss of integrity can quickly lead to loss of trust for the process, agency, and individuals involved.

4.0 Performance Measurement as Part of the Planning and Investment Process

4.1 Introduction

4.1.1 Purpose of Section

This section discusses the steps needed to formalize the freeway performance measurement process within the traditional planning and programming processes. While many analyses begin somewhere in the middle of this list, this section provides an explanation for following the process and considering each element. There are fewer instances of data or measures requiring reexamination when processes similar to this have been followed.

4.1.2 Background and Overview

Key Considerations

The previous section described why performance monitoring activities are typically performed, established four timescales that will be used throughout the *Guidebook* for performance activities, described the current state of the practice and history of performance measurement in transportation agencies, and then described the political context of performance measurement. With this information as a background, this section describes how performance measurement is part of the transportation planning and investment process, including the typical steps in implementing performance measurement activities, how to design and implement a freeway performance measurement program, ongoing monitoring, and the relationship to other agency performance measurement activities, and relationship to strategic and business plans.

Relationships to Other Freeway Performance Activities

After this section, the reader will have sufficient information for the next sections that describe the basic principles for freeway performance measurement (Section 5.0), development of measures (Section 6.0), and understanding the data necessary to support freeway performance measures (Section 7.0).

4.2 Linkage to Traditional Planning and Programming

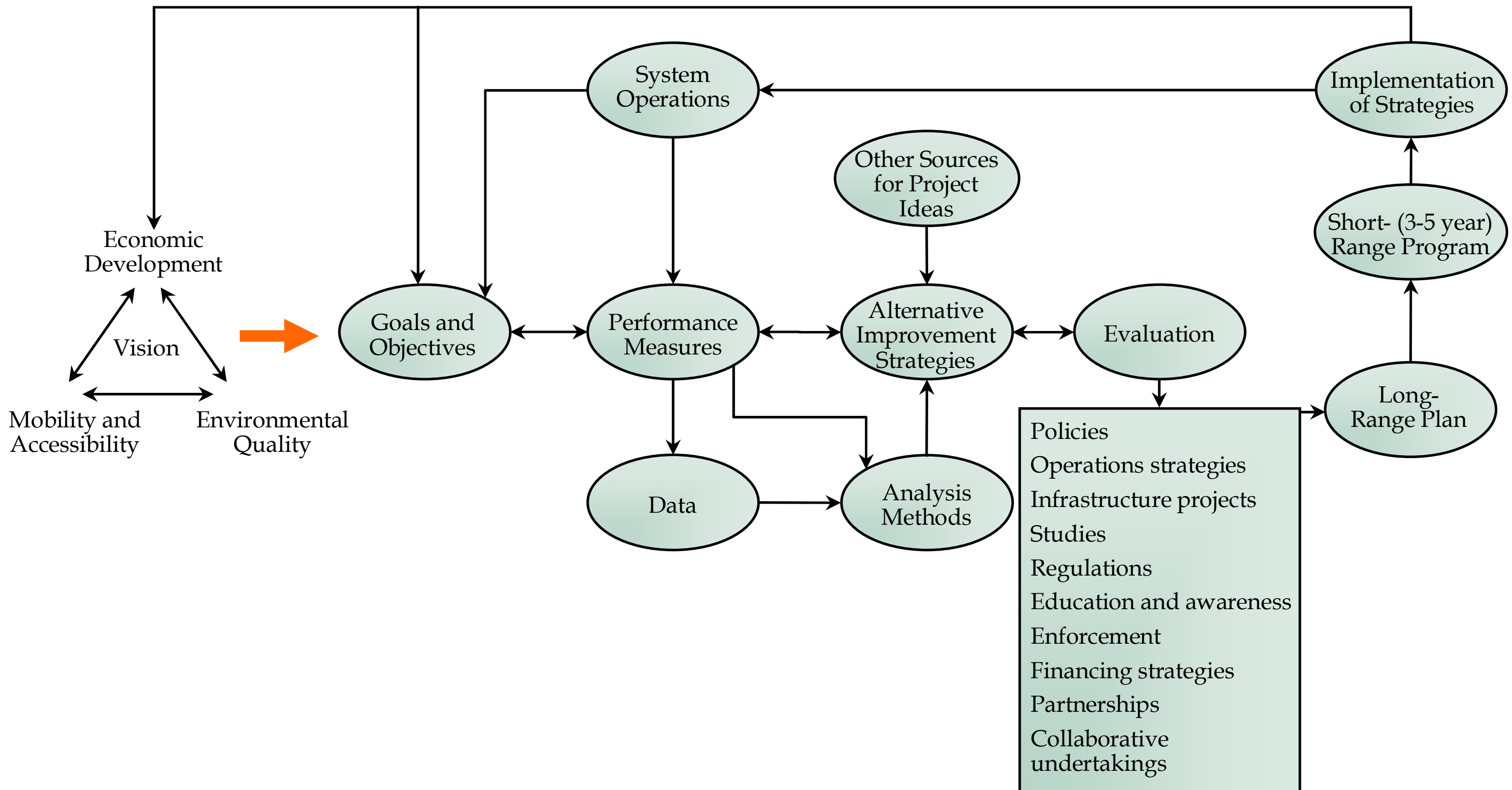
Measuring freeway performance levels is a task performed in a variety of different types of analysis for many purposes. While some measures may be dictated by legislative or regulatory mandates, it is useful also to select measures that provide internal or detailed operational and planning data beyond that normally required for reporting purposes. Understanding the range of needs and uses is important in the process of identifying the measures, as the key elements listed in this section show. As with any process, the continuous evaluation of key steps and procedures should be pursued so that improvements can be identified in the measures, data, actions, and communication devices.

Figure 4.1 shows that performance measures should play a central role in the traditional transportation planning process. Performance measures are used to implement and quantify the goals and objectives set earlier in the planning process. That is, they describe in numeric form the general concepts put forth in goals and objectives. Figure 4.2 illustrates how general goals are turned into more specific objectives, which, in turn, are assigned more specific and quantitative performance measures. The final step is to develop performance "target" values for the performance measures, which can be stated in absolute terms (a fixed number) or in relative terms (e.g., annual percentage reductions). Setting performance targets usually means that some analysis of current conditions and past trends be conducted to determine what conditions are and what realistic targets should be.

Figure 4.1 also indicates the feedback process (evaluation) that underlies performance measurement programs. Once projects are implemented, the system must be operated. Operations have a direct link to performance measures and operational strategies may be altered without going back through the entire process. (However, major new operational investments certainly do.) As an example, consider the implementation of service patrols for incident management. Performance measures can be used to "tweak" service patrol characteristics (such as redefining schedules and routes) without changes to planning documents. Major new investments in service patrols, which performance measures could indicate are needed, would be fed back through the process. The example of operational improvements illustrates how the traditional planning model is changing as there is more focus on the short term, particularly through the implementation of operational improvements. Evaluation and monitoring for these situations are relatively new activities.

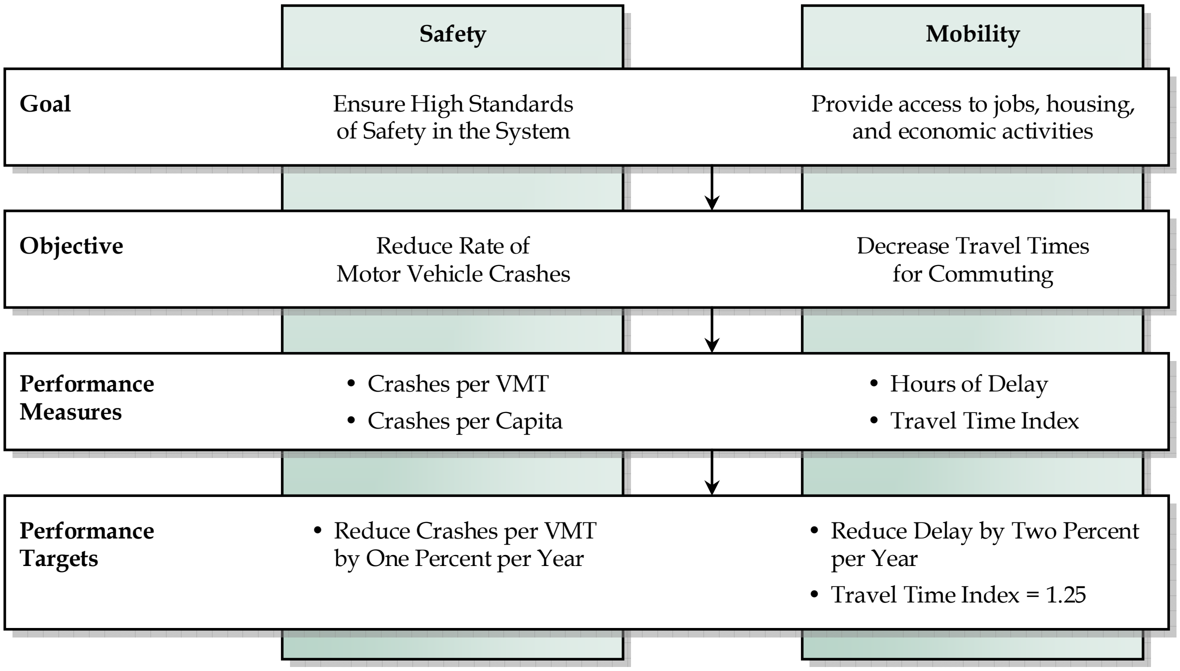
With regard to freeway performance measures, the process shown in Figure 4.2 can be characterized with the sequential steps outlined in the following sections.

Figure 4.1 Performance Measures Play a Key Role in the Traditional Planning Process



Source: Meyer, Michael and Miller, Eric J., *Urban Transportation Planning*, McGraw-Hill Science/Engineering/Math; 2nd edition, December 20, 2000.

Figure 4.2 Performance Measures Provide a Quantifiable Means of Implementing Goals and Objectives from the Transportation Planning Process



4.2.1 Identify the Vision and Goals

There are several sources that might be used to identify the freeway performance levels that the public, businesses, and elected officials would like to see developed. These wishes may be modified by economic, environmental, funding, and other constraints, but the "vision" element should be the start of the performance measure selection process. This information may be in the long-range transportation plan, public surveys, web site feedback, or election campaign and media information. In order for the programs and projects to move the region toward the vision, the measures must identify the proper type and scale of transportation improvements.

This approach also should apply at the individual level (e.g., freeway route, bus service, or operational treatment). While the improvement options may not be as broad and the financial investment may not be as great, it is always instructive to think about possible outcomes before beginning the analysis. This ensures that all options are considered and the set of measures are more likely to evaluate the full range of alternatives.

It is essential, therefore, that performance measures be consistent with the goals and objectives of the process in which they are being employed. Understandable and easily communicated performance measures are the key to a variety of process outcomes, whether the measures are used for selecting alternatives, congestion management, growth management or optimizing the operation of the freeway systems. For example, within an annual reporting process, performance measures might be used for problem identification and assessment, evaluation and comparison of alternative strategies, demonstration of effectiveness of various programs and projects, and ongoing real-time system monitoring and reporting.

4.2.2 Identify the Project or Program Objectives

The project or program should have a set of objectives based on the likely effect of the implementation and the ability of the planning, designing, or operating agencies to carry those actions through to completion. The objectives should be in terms that are relatively easy to understand and technically accurate. Since freeway actions may have an effect on the adjacent street system, the objectives, and the data collection and measurements might include parallel and intersecting routes or key streets.

4.2.3 Identify the Uses and Audiences

The analyses and potential targets of the performance measurement process must be determined before the proper measures can be selected. The set of measures must be technically capable of illustrating the problems and the effect of the potential improvements. They also must be able to be composed into statistics that are useful for the variety of potential audiences. Increasing the flexibility of the measures also may improve the ability to use the information beyond the particular analysis. Corridor statistics also may satisfy annual reporting requirements, for example.

The uses that significantly influence the needs for performance measurement include the scope of the analysis, location of the improvement, travel modes that will use the system, time of day that might be affected, the year or years that are the subject of the analysis and the level of detail and the subjects included in the analysis (e.g., planning, operations).

The audiences are similarly broad, but in general can be divided into technical and non-technical groups, and into groups defined by the information needs, time, and locations. Real-time freeway users require more targeted and recent information than annual performance reports, but the measures can be drawn from the same dataset.

4.2.4 Develop a Set of Freeway Performance Measures

Many analyses, especially multimodal alternatives or regional summaries, require more than one measure to describe the problem. Analyses of corridor improvements might require travel time and speed measures to be expressed in person and freight movement terms. Some analyses are relatively simple, and it may be appropriate to use only one measure. Analyses of adding a freeway lane through restriping where bus/carpool treatments are not part of the improvement options may not require person movement data. Travel time and speed information can provide transportation professionals the information to select the best project, program or strategy and can then check (using evaluation results) that the goals and objectives are best served by the solutions.

4.2.5 Identify the Performance Targets

The targets should at least reflect congestion and reliability performance goals. Access to jobs and other transportation statistics may be relevant and identified in the output from travel models or other estimation processes. The targets also may need to be related to other areawide goals such as population and employment growth, home prices, education quality, etc. The range of possible targets is very broad and some are elements that the transportation agencies cannot control, but it is useful to identify the role of transportation in supporting the broader community vision.

The individual mode or program targets also should be set and related to "output" or agency performance goals. These might include the number and type of metered entrance ramps or the average response and clearance time for freeway vehicle crashes. These types of goals are good for agency operators and planners because they might be more directly relevant to the day-to-day activities.

At this stage, it is important that local or regional target values be coordinated with state-wide target values for similar freeway performance monitoring activities. It is possible that a local area may have target values that differ from statewide target values because they are specific to the local community's goals and objectives, and statewide targets are set to satisfy different uses and/or audiences than the local area.

4.2.6 Compare Potential Projects, Programs, and Policies to the Measures

Before data collection begins, it is useful to revisit the selected measures and compare them to the possible improvements that may be evaluated and the uses and audiences. Typical questions to consider include:

- Will the measures illustrate the effect of the improvements;
- Are there aspects of the projects, programs, or policies that will not be identified by the measures;
- Are the measures understandable to all the audiences; and
- Are the uses of the measures appropriate and will the procedures yield reliable information?

These questions should be evaluated with prototype results of the analysis.

4.2.7 Collect or Estimate Data Elements

Data collection is a process of selecting the best sources of information, and ensuring that the level of precision and statistical reliability are consistent with the uses of the information and with the data sources. Estimates or modeling processes may be appropriate additions to traffic count and travel time and speed data collection efforts. Statistical sampling procedures may be useful for regional analyses, as well as for validating models and adapting them to local conditions. Directly collected data is more widely available now in many cities from a variety of sources, including specific corridor studies, real-time data collection and annual surveys of travel time routes, but there are many types of analyses that cannot evaluate an in-place system.

4.2.8 Identify Action Areas

The data and measures can be used to identify the problem areas or situations and possible solutions. These should be compared to observations about the system to make a reasonableness check – the measures should identify well known problem areas. The data will provide information about the relative size of the mobility problems so that an initial prioritization for treatment can be made.

4.2.9 Test Solutions

Testing the potential solutions against the mobility measures during data collection (or during archived data analysis) may improve the data collection effort, identify other data archives that should be examined, and/or improve the reliability of the results. Even after the analysis is complete, the measures should be evaluated before similar projects are performed. Inconsistencies or irregularities in results are sometimes a signal that different procedures or data are required to produce the needed products.

4.2.10 Ongoing Performance Measurement

As indicated by the feedback process in the traditional planning process, this process and related procedures are ongoing. The process will continually be refined and improved as data sources and procedures improve. In addition, as the measures are computed over several years, analysts will be able to perform temporal and spatial trend analysis on the freeway system with the performance measure results.

4.3 Getting Started: How to Design and Implement a Freeway Performance Measurement Program

4.3.1 Getting Started

Initially, the task of designing and implementing a freeway performance measurement program can seem daunting. The themes established in Section 1.0 can guide the development and implementation of the freeway performance measurement activities. In the early development of the program, it is possible to get bogged down in details. It is important for the practitioner to keep in mind that their initial goal is to "get started," and not become bogged down in these details. The process will continue to evolve, and it will improve over time.

The common denominator of these points is the fact that simply getting started is key. Even if all of the minor details have not been worked out, it is important to get the program started. As described in Section 3.0, even bridge and pavement measurement programs, now held as somewhat of a model for performance measurement, are the result of an evolutionary process that has improved over time as data sources and estimation procedures have improved.

4.3.2 Roles and Responsibilities

Several different agencies and individuals are involved to ensure a successful implementation of freeway performance measurement. Table 4.1 summarizes the more common parties involved along with their typical responsibilities.

4.3.3 Policies

Policies are often enacted to provide guidance for the measurement programs and to ensure accountability. The policies can originate and/or be "policed" from many places, including legislative, transportation agency or agencies, MPO, or municipalities.

4.3.4 Multi-Year Performance Plan and Program Evolution

It is important to have a multi-year plan for the freeway performance measure program. Such a plan documents the recognition that performance monitoring is a process, and that it is not initially "rolled out" in full. Such a plan can include intended milestones at various stages of program implementation.

Table 4.1 Typical Roles and Responsibilities in Freeway Performance Measurement

Agency or Group	Typical Roles and Responsibilities
Elected Officials	• Provide funding support • Often a champion for accountability of programs
Business Community	• Provide coordination with development community • Assist with improvement districts (existing or planned) • Supportive of economic improvements
Private Sector	• Develop/administer program (software development, data collection activities)
General Public	• Provide input throughout the process, including establishing targets and operational improvement alternatives
Academia	• Research interests (data collection or estimation procedures)
Transportation Agencies (Federal, state, and local)	• Organizing/specifying details of the program • Work in concert with private entities on specific program elements • Departments include planning, operations, design, internal audit, performance measures

The key point is remembering that the performance measurement process is inherently evolutionary. Program evolution is beneficial as it ensures feedback into the process as data, data collection and/or estimation procedures improve. In addition, the performance measures must be adaptive (i.e., sensitive to updates/improvements in data collection and estimation methods improvements).

Occasionally there are concerns of "rolling out" results from a performance measurement program that is in its infancy, particularly if there are data concerns upon which the measures are based. Identifying and fixing data issues are often an inevitable part of the start-up process. One consideration is to identify early program processes as "beta" or "prototype" and the measure results as "preliminary." These designations, along with the appropriate caveats, allow for a review of the process as the procedures and measures are initially implemented and improved.

The evolutionary nature of freeway performance measurement estimation activities make it important to keep a consistent source of speed data (and subsequently computed performance measures), particularly at the statewide or regional level, because this value will change over time, and it is important to understand the extent that this measure(s) is changing due to the measurement versus due to operational improvements. For example, if a speed-estimation model is used to estimate speeds in a region to quantify performance measures, this "estimated speed" should be kept from year to year as a data element.

When supplemental speed information is available (e.g., floating car studies, real-time data), they can be kept in the database next to the "estimated speed." This would provide the opportunity to see trends not only in operational performance from year to year, but also to see how these speed values may differ by data source. This would allow for the calibration of the speed estimation values with any other data sources that might be present.

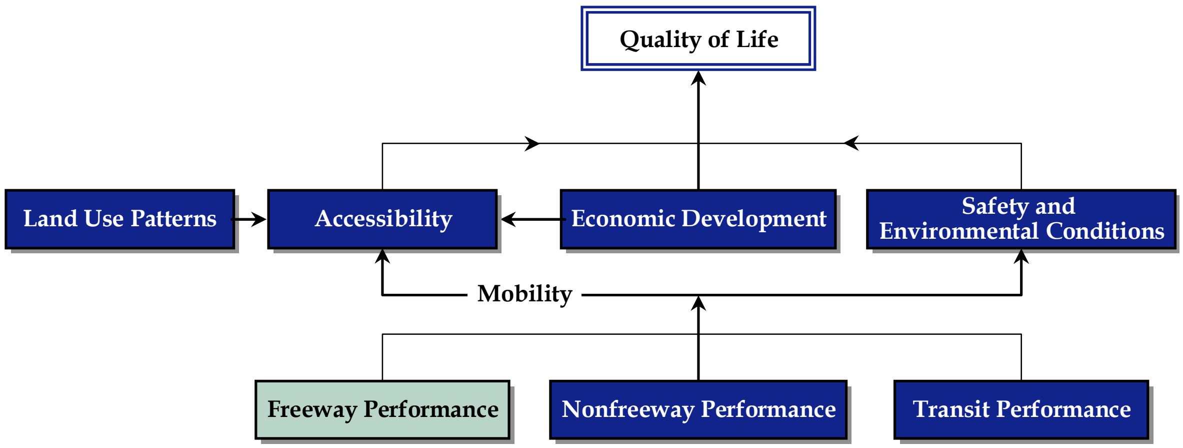
4.4 Performance Measures for Monitoring Trends versus Measures of Effectiveness

Highway capacity and traffic simulation analyses have long used the term "measure of effectiveness" (MOE) to identify model outputs that indicate the nature of traffic flow being modeled. Typical MOEs from model outputs include travel time, average travel speed, delay, number of stops, density, queue length, vehicle-miles of travel, and levels of service. Models are typically used to compare design alternatives and the effect of policies, often for both present and future year conditions. In contrast, performance measurement is a relatively new term in the transportation profession, and the implication is that it refers to measuring (as in, observed measurements rather than modeled results) current conditions or the recent past (e.g., performance for the last 12 months). For the purpose of this study, however, there is no clear line between the two. In fact, in terms of the actual metrics used, there is more commonality than differences. Furthermore, it is useful to maintain continuity across applications, as discussed in Section 5.0. Therefore, for the purpose of this report, *no distinction is made between "performance measures" and "measures of effectives" – more practical purposes, they are essentially the same thing.* The report will continue to use "performance measures" when discussing the actual metrics being used in applications. Although MOEs are typically associated with models, as will be shown later, models also may be used to generate performance measures associated with current conditions or the recent past.

4.5 The Broader Context for Freeway Performance Measurement

From the perspective of citizens, freeway performance is only a part of much larger system that influences their lives. Figure 4.3 shows how freeway performance fits into this larger setting. This report is concerned with the immediate characteristics of freeway performance: mobility (congestion), safety, and environmental aspects of freeway use. These aspects are "inputs" to a larger system that taken together, determine the quality of life available to residents of an area. Note that the notion of accessibility is only partially determined by the mobility (congestion) levels on the transportation system; accessibility also is a function of the opportunities for where residents live and the location of their activity choices (e.g., where to work or shop).

Figure 4.3 Freeway Performance Is Part of the Larger Context for the Quality of Life



Why is this important? For one thing, it relates to the mission of the agency – what is the agency trying to achieve. Missions can be very different depending on the agency. For example, an MPO which is part of a broader regional planning agency may be more concerned with quality of life issues for its constituents. A TMC, on the other hand, is probably narrowed focused on making the freeways under its control perform better. In the MPO's case, making freeways perform better may be of secondary interest; if accessibility is its main pursuit, then it might be able to achieve its goals by focusing on land use patterns, for example. Freeway performance is still an input, but the agency has decided to invest its attention elsewhere, in this instance.

4.6 Relationship to Other Agency Performance Measurement Activities

Freeway performance measurement activities provide accountability and identify needs. The driving forces for implementing performance monitoring are often the result of agencywide accountability or performance measurement activities. For example, a state department of transportation may be implementing performance monitoring for accountability in all areas (e.g., design, operations, planning, maintenance, construction, bridge, pavement).

With this in mind, it is important to note that the agency needs for freeway improvements cannot be performed in a vacuum. Freeway improvements must be coordinated with programming of all other activities.

4.7 Relationship to Strategic and Business Plans

The primary performance measurement activities are accountability and identifying improvement areas. These also are typically fundamental components of local agency or regional business plans. Therefore, freeway performance measurement activities should echo strategic business plans. These may be the plans of an individual agency or agencies, or regional plans that incorporate multiple agencies (e.g., MPO).

4.8 Private Sector Experience with Performance Measurement

Much of the current emphasis on performance measurement with transportation agencies can be traced to the private sector, where use of performance measures has existed for many years. This section presents a review of the most relevant business practices that are relevant for freeway performance measures.

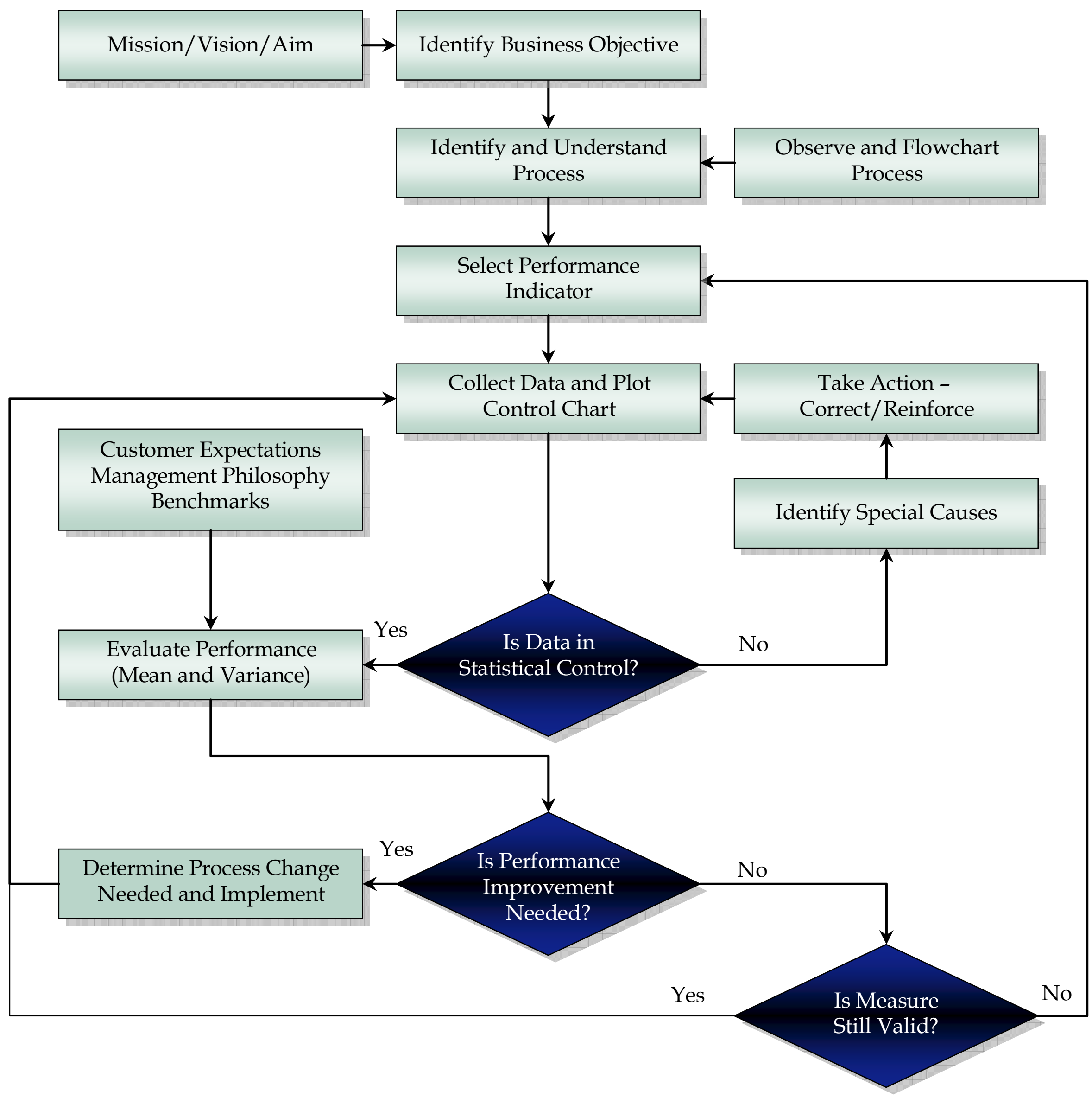
The performance measurement process in business practice is remarkably similar to the one outlined above for the transportation planning process and operations. Figure 4.4 presents the sequence of events in a business-oriented performance measurement process – note how similar the steps are to those presented in Figure 4.1 for the transportation planning process. The similarities are to be expected since much of the public sector work on performance measures borrowed heavily from the business world. Even without this borrowing, chances are that the public and private entities have such overlapping needs and characteristics that convergence was inevitable.

A slightly different take on the performance measurement process is embodied in the "Balanced Scorecard" approach to strategic management, developed in the early 1990s by Drs. Robert Kaplan (Harvard Business School) and David Norton.[1] Kaplan and Norton describe the innovation of the balanced scorecard as follows:

> The balanced scorecard retains traditional financial measures. But financial measures tell the story of past events, an adequate story for industrial age companies for which investments in long-term capabilities and customer relationships were not critical for success. These financial measures are inadequate, however, for guiding and evaluating the journey that information age companies must make to create future value through investment in customers, suppliers, employees, processes, technology, and innovation.

[1] The Balanced Scorecard Institute, Cary, North Carolina and Rockville, Maryland, http://www.balancedscorecard.org/.

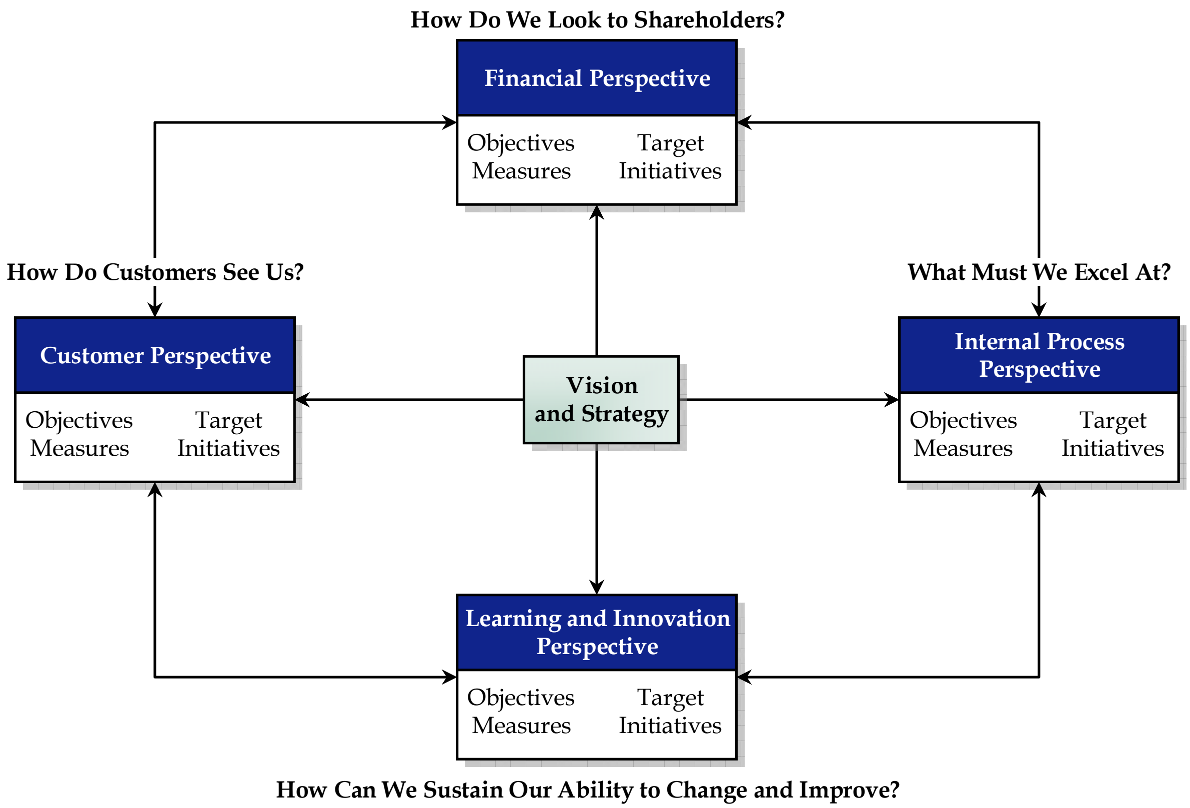
Figure 4.4 Conceptual Model of Performance Measurement in the Business Sector
Performance Indicator Flow



Source: Deming, W. Edwards, *The New Economics For Industry, Government, Education*, 2nd edition. Published by the Massachusetts Institute of Technology, 1994, ISBN 0-911379-07-X.

The Balanced Scorecard suggests the organization be viewed from **four** perspectives, and also suggests that metric development, data collection, and analysis be done for each of them, as shown in Figure 4.5.

Figure 4.5 The "Balanced Scorecard" Approach to Performance Measurement Used in Private Sector Management



Source: "Balanced Scorecard," Norton and Kaplan.

- **Learning and Innovation Perspective –** Includes employee training and corporate cultural attitudes related to both individual and corporate self-improvement.
- **Internal Process Perspective –** Allows managers to know how well their business is running, and whether its products and services conform to customer requirements.
- **Customer Perspective –** Poor performance from this perspective is thus a leading indicator of future decline, even though the current financial picture may look good.
- **Financial Perspective –** This is the traditional focus of performance measurement and has dominated how companies evaluate their business. While still important, financial performance must be balanced against the perspectives which provide more complete insight into the firm's performance.

With regard to the actual metrics developed for each perspective, the value of metrics is in their ability to provide a factual basis for defining:

- Strategic feedback to show the present status of the organization from many perspectives for decision-makers;
- Diagnostic feedback into various processes to guide improvements on a continuous basis;
- Trends in performance over time as the metrics are tracked;
- Feedback around the measurement methods themselves, and which metrics should be tracked; and
- Quantitative inputs to forecasting methods and models for decision support systems.

Although the Balanced Scorecard approach has introduced four main areas of interest for business performance measurement, the same basic steps as found in the transportation planning process (Figure 4.1) are intact: a vision, goals (each of the four perspectives are essentially goals), objectives, performance measures, performance targets, and initiatives (or projects, in the transportation world). The five purposes of performance metrics listed immediately above also translate directly to transportation agencies. Likewise, each of the four perspectives can be easily adapted to public sector transportation; the first three directly transfer while the financial perspective might be recast as system performance (since this is a transportation agency's "bottom line," much like financials are for a business).

While it is possible to see how these principles could be adapted to transportation agencies, it is clear that most (if not all) agencies lag behind the business ideal. The transportation literature usually classifies performance measures into two categories: outcome and output measures.[2] (Section 1.3 discusses these within the context of transportation agencies.) Outcome measures are usually cast in terms of system performance (the companion to measures in the "financial perspective" in the Balanced Scorecard). Output measures correspond to the "internal process perspective." Customer satisfaction measures have been classified as both.

Finally, the feedback loops in the Balanced Scorecard approach mirror those in the transportation planning process, although the Balanced Scorecard emphasizes feedback throughout the business cycle rather than just at the end as shown in the transportation planning process. These feedback loops are extremely important for transportation agencies. It means that *direct linkages must exist between the various performance categories, whether we use the Balanced Scorecard or the outcome/output framework.* This is especially crucial for the outcome/output linkage (or the financial/internal process linkage in business). Since

[2] For example, NCHRP Report 446, *A Guidebook for Performance-Based Transportation Planning*, Transportation Research Board, 2000.

outcomes are a transportation agencies bottom line, output measures must be constructed (and revised) so that the things they measure actually result in positive changes to the bottom line. For example, consider that an agency has a safety outcome measure "number of fatal plus injury crashes per year" (with a target of reducing them by say, one percent every year). The output measures – those that measure the activities related to safety – should either be known to have an effect or postulated to have an effect (if no prior research experience exists). So, if a safety output measure is "number of left turn bays added at intersections," field managers may devote most of their efforts to adding turn bays, whether they are warranted or not. This will probably detract from making other improvements at individual intersections that would have a more positive effect on crashes. A more effective output measure might be "number of estimated crashes reduced" – this would allow more flexibility in treatment. As one author in the business sector put it: "… the old saw that says 'Be careful what you wish for, you may get it,' has a business version: 'Be careful what you measure, you may get it – and it may kill you.'"[3]

The above discussion illustrates the concept (brought up repeatedly in the business literature) that performance measures must be linked to actions (or initiatives or projects):

The purpose of measuring is not to know how a business is performing but to enable it perform better. Measurement must be neither an end nor an activity in itself but part of an integrated system for enhancing business performance. Therefore a contemporary measurement system should provide no data without a rationale and purpose; people must know why things are measured and, more important, what they are supposed to do about them.[4]

To help construct what performance measures should be constructed, one author offers several criteria against which they should be judged[5]:

- **Purpose –** The measure is worth collecting and answers a question to support decision-making;
- **Validity –** Measures what it claims to measure;
- **Precision –** Returns consistent value with each measurement;
- **Accuracy –** Matches the true value of the attribute; and
- **Cost-Effectiveness –** Is not too costly to track and report.

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[3] Hammer, Michael, Ibid.

[4] Hammer, Michael, Ibid.

[5] Hack, Becki, *Designing Performance Measures and Metrics*, http://www.bettermanagement.com/library/library.aspx?libraryid=7078.

Another major initiative in business management is the so-called "*Six Sigma*." Literally, it refers to the reduction of errors to six standard deviations from the mean value of a process output or task opportunities, i.e., about one error in 300,000 opportunities. In modern practice, this terminology has been applied to a quality improvement methodology for industry. Six Sigma is a rigorous, focused, and highly effective implementation of proven quality principles and techniques. Incorporating elements from the work of many quality pioneers, Six Sigma aims for virtually error free business performance. (The "stretch goal" of trying to achieve zero fatalities on the highway system, as expounded by some European countries and being considered in the United States, may be an indication of this approach in the public sector.)

Six Sigma takes a handful of proven methods and trains a small cadre of in-house technical leaders, known as Six Sigma Black Belts, to a high level of proficiency in the application of these techniques. To be sure, some of the methods used by Black Belts are highly advanced, including the use of up-to-date computer technology. But the tools are applied within a simple performance improvement model known as DMAIC, or Define-Measure-Analyze-Improve-Control. DMAIC can be described as follows:[6]

- **Define** the goals of the improvement activity. At the top level the goals will be the strategic objectives of the organization, such as a higher ROI or market share. At the operations level, a goal might be to increase the throughput of a production department. At the project level goals might be to reduce the defect level and increase throughput. Apply data mining methods to identify potential improvement opportunities.

- **Measure** the existing system. Establish valid and reliable metrics to help monitor progress towards the goal(s) defined at the previous step. Begin by determining the current baseline. Use exploratory and descriptive data analysis to help you understand the data.

- **Analyze** the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. Apply statistical tools to guide the analysis.

- **Improve** the system. Be creative in finding new ways to do things better, cheaper, or faster. Use project management and other planning and management tools to implement the new approach. Use statistical methods to validate the improvement.

- **Control** the new system. Institutionalize the improved system by modifying compensation and incentive systems, policies, procedures, MRP, budgets, operating instructions and other management systems. You may wish to utilize systems such as ISO 9000 to assure that documentation is correct.

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[6] Pyzdek, Thomas, *The Six Sigma Revolution,* http://www.qualityamerica.com/knowledgecente/articles/PYZDEKSixSigRev.htm.

Six Sigma is relevant for freeway performance measures in several ways. First, it is a data-driven approach to improving performance with a strong emphasis on analysis and prediction, just like many of the other business practices discussed here. Second, the idea of measuring performance is a keystone of the Six Sigma approach. Third, because it deals with reliability of a process, it may have applicability to travel time reliability, discussed later in this section.

Finally, a widely used private sector technique is the creation of "*dashboards*" aimed at providing measurement snapshots. As with a car dashboard, a measurement snapshot presents a quick overview of key operating details such as key drivers, enablers, and results. Dashboards are data-driven, are updated frequently (sometimes daily), and are usually linked to a few key outcome measures (e.g., profits, sales). Dashboards are similar to Balanced Scorecards, but dashboards are driven primarily by a desire to enhance the information systems available to a management team and to give managers quicker, more immediate access to operational data. There is no bright line separating strategic scorecards from operational dashboards.[7]

[7] Henchey, Paul, *Six Questions to Ask Before Selecting a Dashboard or Scorecard Solution*, http://www.bettermanagement.com/library/library.aspx?libraryid=10797&pagenumber=1.

5.0 Basic Principles for Freeway Performance Measurement

5.1 Introduction

5.1.1 Purpose of Section

The first step in defining specific performance measures (metrics) and other aspects of freeway performance measurement is to define guiding principles that should be followed. These principles are designed to be easily communicated, remembered, and incorporated into regular practice by transportation professionals. The research team has incorporated them into the development of the *Guidebook*. In addition to guiding the work presented in this *Guidebook*, the principles are relevant for transportation agencies to apply in developing their own performance measurement program.

5.1.2 Background and Overview

Key Considerations

The major considerations for establishing guiding principles for the development of performance measures are:

- What is the history of performance measurement in the profession and what are agencies likely to do?
- What is needed to supply performance measures for a full range of applications?
- Is there any guidance from the private sector that can be adapted?

Relationships to Other Freeway Performance Activities

This section was formulated using input from Section 3.0 (*Goals and Characteristics of Freeway Performance Measurement*) and Section 4.0 (*Performance Measurement As Part of the Planning and Investment Process*). In particular, the benchmarking and *Guidebook* review interviews with practitioners – and the review of private sector principles – was extremely useful in formulating the principles. The principles, in turn, form the basis for the remainder of the *Guidebook* in terms of the measures (metrics) recommended; the data and methods used to develop the measures; and the presentation and use of the measures.

5.2 Guiding Principles for Freeway Performance Measures

In order to develop the suite of freeway performance measures, the Research Team has developed a set of basic principles for guidance. The principles are discussed in the following section where they have been pulled out of the main text, numbered, and highlighted. Table 5.1 summarizes the principles.

Table 5.1 Basic Principles for Freeway Performance Monitoring

Principle 1	Mobility performance measures must be based on the measurement or estimation of travel time.
Principle 2	Measure where you can – model everything else
Principle 3	Multiple metrics should be used to report freeway performance, especially for mobility.
Principle 4	Traditional HCM-based performance measures for mobility (V/C ratio and level of service) should not be ignored but should serve as supplementary, not primary measures of performance in most cases.
Principle 5	Both vehicle-based and person-based performance measures of throughput are useful and should be developed, depending on the application.
Principle 6	Both quality of service (outcome) and activity-based (output) performance measures are required for freeway performance monitoring.
Principle 7	Activity-based measures should be chosen so that improvements in them can be linked to improvements in quality of service measures.
Principle 8	Customer satisfaction measures should be included with quality of service measures for monitoring freeway performance.
Principle 9	The measurement of travel time reliability is a key aspect of freeway performance measurement and reliability measures should be developed and applied.
Principle 10	Three dimensions of freeway mobility/congestion should be tracked with mobility performance measures: source of congestion, temporal aspects, and spatial detail.
Principle 11	Communication of freeway performance measurement should be done with graphics that resonate with a variety of technical and nontechnical audiences.
Principle 12	Continuity should be maintained in performance measures across applications and time horizons; the same performance measures should be used for trend monitoring, project design, forecasting, and evaluations.

Consistent with the scope of the project, ***we have focused on measuring the performance of freeways in terms of congestion/mobility and the activities related to improving traffic flow.***

5.2.1 Principle 1: Mobility Performance Measures Must Be Based on the Measurement of Travel Time

The performance of the highway system in terms of how efficiently users can traverse it may be described in three basic terms: congestion, mobility, and accessibility. While researchers have different definitions of these terms, we have found it useful to define them as follows:

- **Congestion** – Describes the travel conditions on facilities;
- **Mobility –** Describes how well users can complete entire trips; and
- **Accessibility –** Describes how close opportunities are spaced in terms of the user's ability to access them through the transportation system.

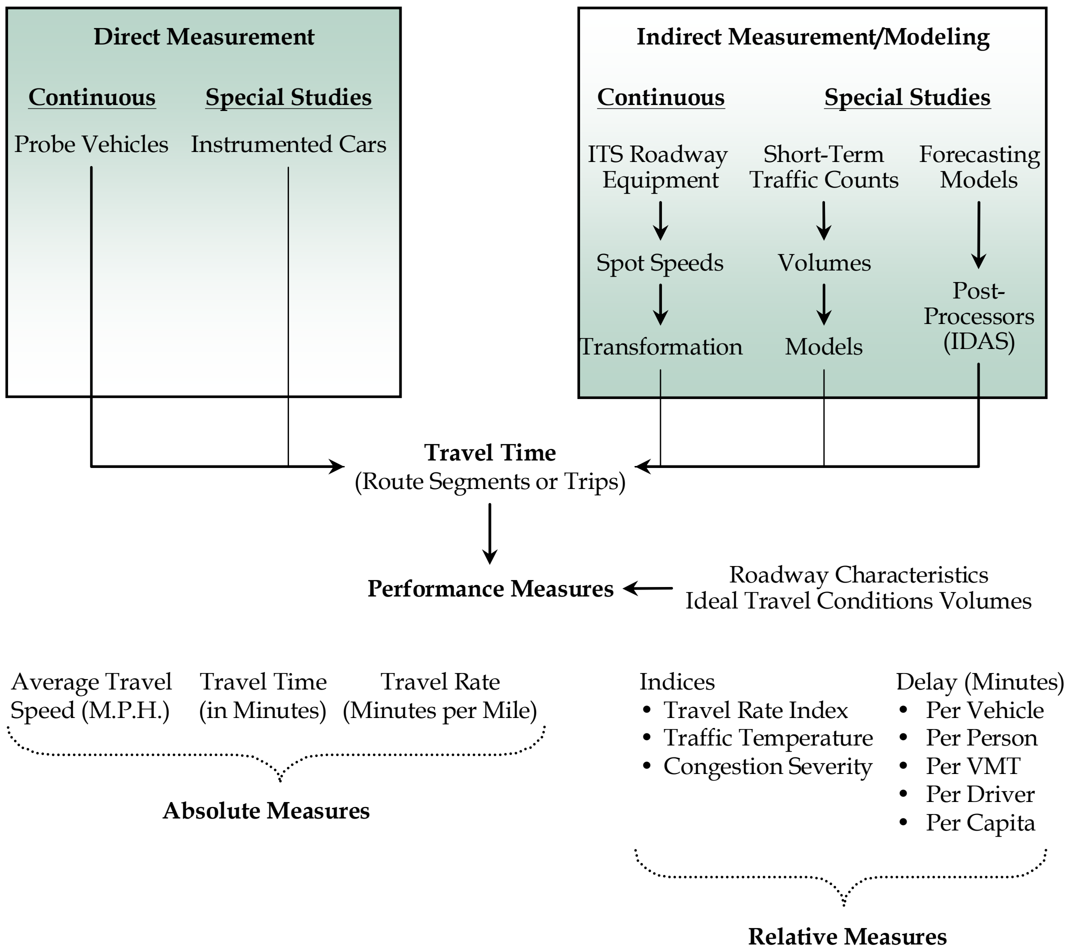
Because this *Guidebook* is focused on freeway performance measures, accessibility is clearly outside of the scope. Since most trips occur on multiple highway types, mobility is a bit of a stretch as well. However, we have found that the same metrics and concepts can be used to monitor both congestion and mobility. There, we have used the terms "congestion" and "mobility" interchangeably throughout this *Guidebook*.

Travel times are easily understood by practitioners and the public, and are applicable to both the user and facility perspectives of performance. Figure 5.1 shows how travel times can be developed from data, analytic methods, or a combination. Clearly, the best methods are based on direct measurement of travel times, either through probe vehicles or the more traditional "floating car" method. However, both of these have drawbacks: probe vehicles currently are not widely deployed and the floating car method suffers from extremely small samples. Further, since many performance measures require traffic volumes as well, additional collection effort is required to develop the full suite of performance measures. Use of ITS roadway equipment addresses these issues, but this equipment does not measure travel time directly; ITS spot speeds must be converted to travel times first. Other indirect methods of travel time estimation use traffic volumes as a basis, either those that are directly measured or developed with travel demand forecasting models.

Figure 5.1 also shows how basic travel times can then be converted into a variety performance measures using a few fundamental prices of information about the environment where travel times were measured (roadway characteristics, "ideal" travel speeds, and traffic volumes). This implies that travel time-based performance measures are extremely similar in their basic nature, although some researchers have tended to exaggerate the differences. Travel time-based performance measures can be thought of as two types: 1) absolute measures and 2) relative measures. Relative measures require comparison to some base conditions, usually "ideal" or "free flow" conditions.

The performance measures shown in Figure 5.1 are only examples of the many that may be created from a travel time base. As presented later in this report, many more are available. This leads us a second principle:

Figure 5.1 Travel Time Is the Basis for Defining Mobility-Based Performance Measures



5.2.2 Principle 2: Measure Where You Can – Model Everything Else

Direct measurements of the underlying phenomena are highly preferred to synthesizing performance measures with analytic methods and models. However – particularly for mobility – current data collection programs may not provide enough freeway coverage. In these cases, analytic methods may be used. The lack of directly measured mobility data should not discourage agencies from embarking on a freeway performance measurement program. However, agencies should aspire to the use of direct measurements and should wean their programs off of model estimates as data collection systems are deployed.

5.2.3 Principle 3: Multiple Metrics Should Be Used to Report Freeway Performance

There is no need to focus on a single metric because different metrics convey different parts of the situation. A "flagship" or "marquee" metric is useful for consistency and public consumption, but practitioners need more information than can usually be communicated in a single metric.

It is recognized that, by focusing on travel time-based performance measures, some practitioners who are used to capacity-based measures may be alienated. For example, the volume-to-capacity ratio and levels of service are widely used by the profession and are difficult to replace. Further, their widespread and historical use means that there is a large audience for such measures, especially for certain applications, which leads directly to Principle 4.

5.2.4 Principle 4: Traditional HCM-Based Performance Measures for Mobility Should Not Be Ignored But Should Serve as Supplementary, Not Primary, Measures of Performance in Most Cases

The *Highway Capacity Manual*[1] has served as a basis for mobility performance measures for many years. Prior to the latest edition of the *Manual*, level of service (LOS) – broad ranges of performance that could be related to delay – was the primary performance measure used. Level of service has proven to be a highly useful concept for practitioners and has even been used as a threshold in local ordinances. Volume-to-capacity (V/C) ratio is another metric with its foundation in highway capacity analysis that is widely used, especially by transportation planners.

A strong point of the LOS concept is that it uses ranges instead of "hard" numbers to convey performance, which is easy for laypersons to grasp and is consistent with the uncertainty in the estimates. A problem is that with ranges, observations at the boundaries of two ranges may be unfairly classified. A bigger problem is that for congested flow ("saturated" flow, in *HCM* terms), only a single category exists (LOS F), meaning that facilities are either congested or they're not, which masks the widely different degrees of congestion that can exist.

The 2000 edition of the *HCM* recognizes these problems and recommends more direct and objective performance measures such as speed and delay (it emphasizes performance measures throughout, a shift from past editions). However, given their long history, LOS and V/C ratio are likely to be used in many applications by practitioners. For this reason, the *Guidebook* recommends that these be used as supplemental measures to more objective travel time-based measures.

[1] *Highway Capacity Manual 2000*, Transportation Research Board, 2000.

5.2.5 Principle 5: Both Vehicle-Based and Person-Based Performance Measures of Throughput Are Useful and Should Be Developed

Throughput – the amount of demand that is served over a period of time – can be applied to either the passage of persons or vehicles. Vehicle-based measures provide insight to how the facility is operating. Person-based measures provide the capability of comparing different modes, including high-occupancy vehicles. Generally, the conversion of vehicle-based measures to person-based measures is straightforward: the product of the number of vehicles and either actual or average vehicle occupancy rate.

5.2.6 Principle 6: Both Quality of Service (Outcome) and Activity-Based (Output) Performance Measures Are Required for Freeway Performance Monitoring

In the literature, a distinction is made between output and outcome types of measures:

- **Output** measures relate to the physical quantities of items; levels of effort expended, scale or scope of activities; and the efficiency in converting resources into some kind of product. Output measures are sometimes called "efficiency" measures. This *Guidebook* refers to these measures as ***activity-based performance measures.***

- **Outcome** measures relate to how well the firm or agency is meeting its mission and stated goals. The mobility measures discussed above can be classified as outcome measures since they document how the transportation system is performing from the user's (customer) perspective, and thus are reflective of the mission of transportation agencies. This *Guidebook* refers to these measures as ***quality of service performance measures.***

In the private sector, both quality of service and activity-based measures are used for monitoring business performance. Typical quality of service measures relate to corporate profits, total sales, total revenues, or some other top-level measure of the financial health of the company. Activity-based measures in the private sector relate to the routine activities undertaken by employees, e.g., time between service calls, customers served per day, number of times the assembly line is stopped. This model is directly analogous to performance measures for transportation agencies, and leads to Principle 7 below.

5.2.7 Principle 7: Activity-Based Measures Should Be Chosen So That Improvements in Them Can Be Linked to Improvements in Quality of Service Measures

The linkage among "tiers" of performance measures is an extremely important principle and is used throughout this *Guidebook*. In the private sector, it is highly important to make sure that activity-based measures are linked to outcomes. (Hence the saying, "Be careful what you measure – you just might get it.") For example, if one monitors time between service calls, it is either postulated or known that reductions in this time will lead to higher profits, more sales, etc. This model is directly transferable to freeway performance monitoring, as shown in Figure 5.2. Note that traffic incidents are used as an example: similar structures exist for each of the other sources. Figure 1.1 in Section 1.0 has already shown how such a model may be applied to transportation. The recommended performance measures presented in Section 6.0 also follow this model.

5.2.8 Principle 8: Customer Satisfaction Measures Should Be Included with Quality of Service Measures for Monitoring Freeway Performance

In addition to the quality of service measures based on measuring travel time or one of its variants, it is clear that customer satisfaction measures provide useful feedback for improving freeway performance. These can be classified as quality of service (outcome) measures, though they are subjective in nature (e.g., a rating of how congestion is perceived by users) as opposed to "hard" measures (e.g., average speed in a corridor). In the larger scheme of agency operations, though, maintaining a high level of customer satisfaction is extremely significant; this can often make a telling difference in the ability of transportation agencies to sell new programs.

5.2.9 Principle 9: The Measurement of Travel Time Reliability Is a Key Aspect of Freeway Performance Measurement and Reliability Measures Should Be Developed and Applied

Definition of Travel Time Reliability

Travel time reliability is growing in significance and use in the transportation profession. The F-SHRP Reliability Research Program[2] defined reliability this way:

> …from a practical standpoint, *travel time reliability can be defined in terms of how travel times vary over time* (e.g., hour-to-hour, day-to-day). This concept of variability can be extended to any other travel time-based metrics such as average speeds and delay. For the purpose of this study, travel time variability and reliability are used interchangeably.

A slightly different view of reliability is based on the notion of a *probability or the occurrence of failure* often used in to characterize industrial processes. With this view, it is necessary to define what "failure" is in terms of travel times, in other words, a threshold must be established. Then, one can count the number of times the threshold is not achieved or exceeded.

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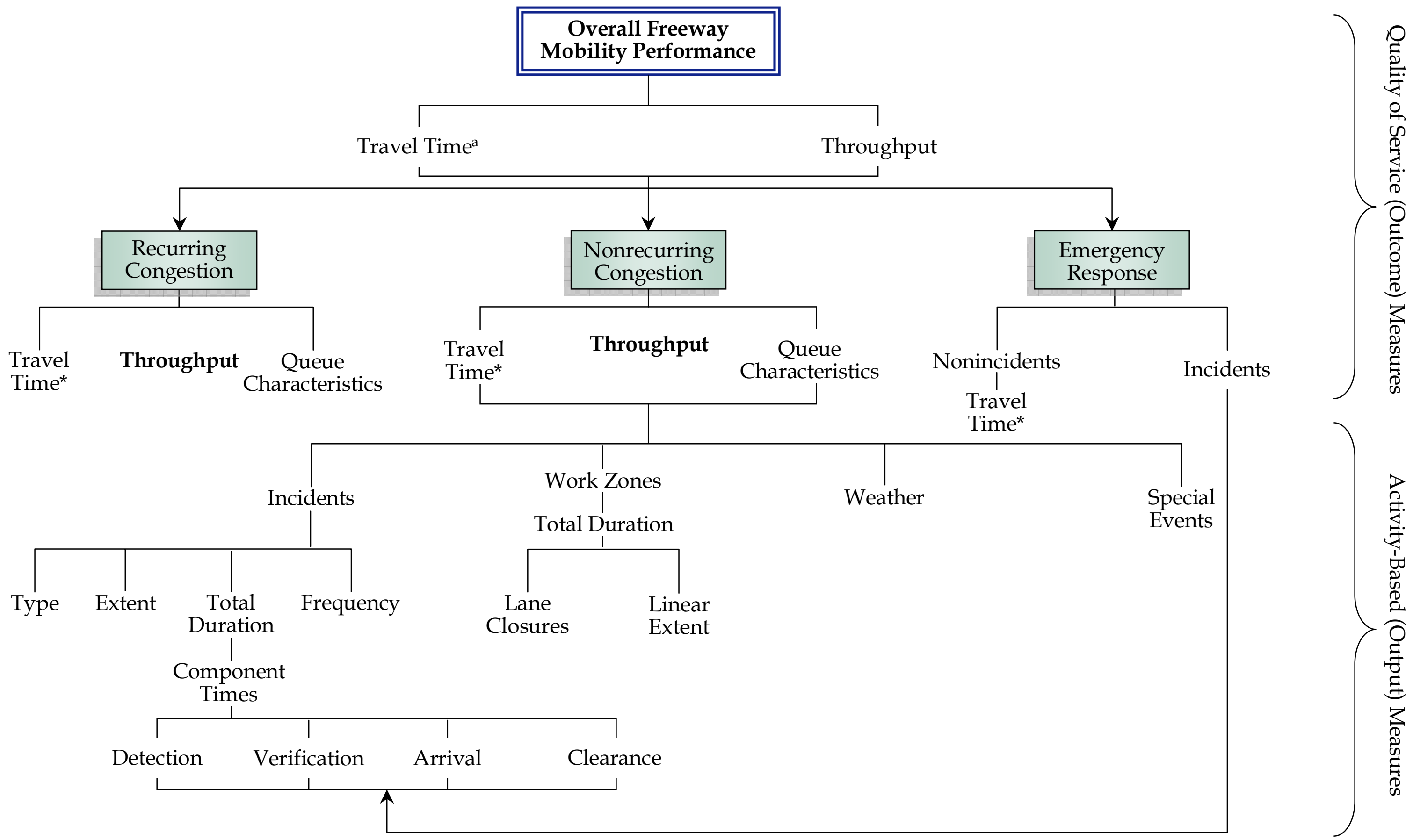
[2] *Providing a Highway System with Reliable Travel Times*, report for NCHRP Project 20-58(3), September 2003, http://trb.org/publications/f-shrp/f-shrp_webdoc_3.pdf.

Figure 5.2 Example Structure for Mobility and Efficiency Freeway Performance Measures



[a] Travel time refers to any number of the travel time-based metrics.

The variability and failure definitions have a common underlying theme – they both imply that a ***history or distribution of travel times*** exists. The history over which travel times are measured must be sufficiently long so as to capture the variations that occur to due the random and planned events that occur on the roadway system. Once this distribution is established, it is possible to construct any number of measures to describe its size and shape. Figure 5.3 shows a travel time distribution for a freeway segment (I-75 in Atlanta, Georgia) derived from ITS detector data for the afternoon peak period on weekdays. The general shape of this distribution (roughly a log-normal distribution in statistical terms) is typical of weekday peak periods – a long tail is evident indicating some days with extremely long travel times. Both traditional measures of variation (95th percentile, standard deviation, coefficient of variation) and an "occurrence of failure" measure (percent of trips that occur at half the free flow speed) can be defined with this distribution.[3]

This leads to a more general definition of travel time reliability:

> ***Travel time reliability is defined as the level of consistency in travel conditions over time, and is measured by describing the distribution of travel times that occur over a substantial period of time.***

What Causes Travel Times to Be Unreliable?

Conditions are never the same from day-to-day on the highway system. Some days may have higher than normal volumes, some days may see traffic incidents (and some of these may be extreme), bad weather can occur, and a work zone may be in place for a period of time. The interaction of these roadway "events" cause travel times to be unreliable. A more complete discussion on this phenomenon is given in Section 6.3.4.

A number of empirical studies have demonstrated that traveler's value not only the time it *usually* takes to complete a trip, but also the reliability in travel times. For example, many commuters will plan their departure times based on an assumed travel time that is greater than the average to account for this unreliability. Some studies suggest that travelers value the variability in travel times at a higher rate than the norm.[4] Also, because reliability is directly related to the events on the highway system, its measurement can provide insight into how much of an influence these events have on congestion.

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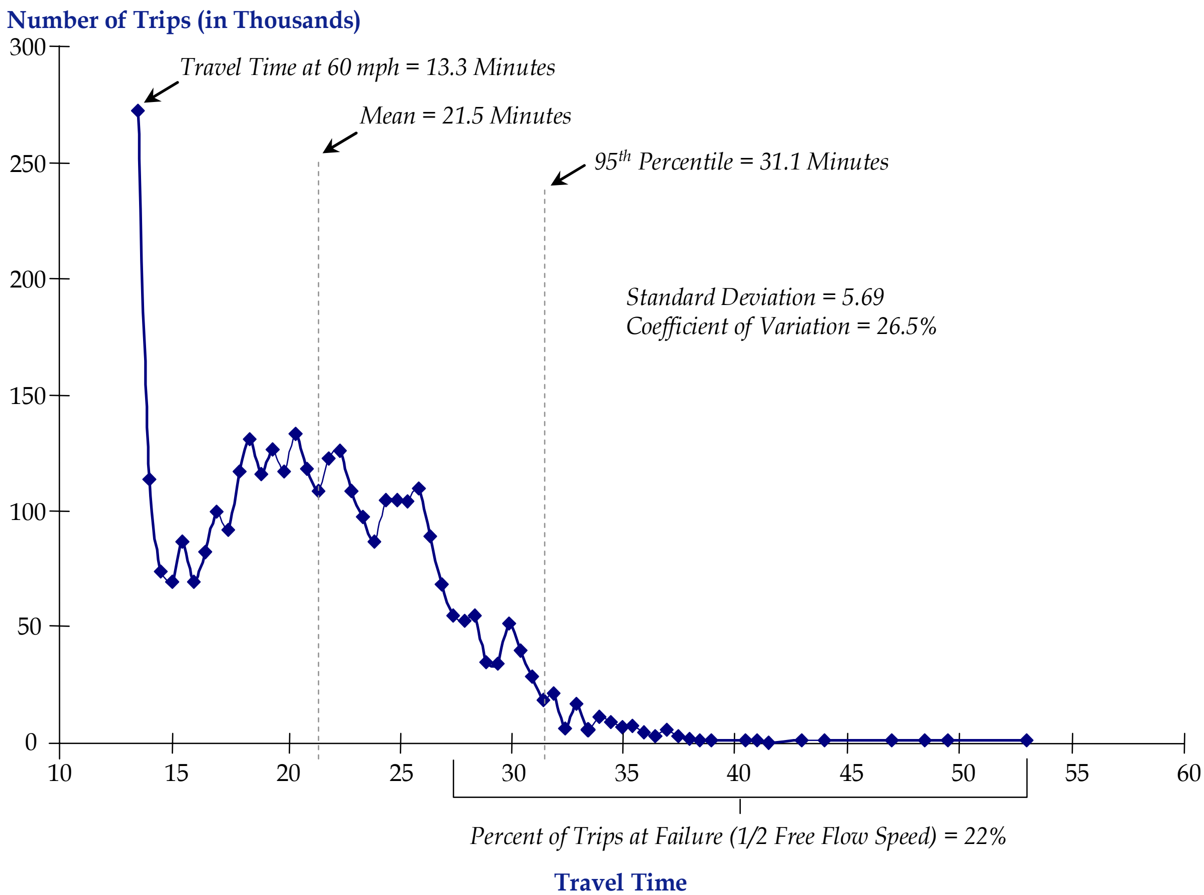
[3] These measures are used as example only; see Section 6.0 for the recommended reliability measures.

[4] Cohen, Harry, and Southworth, Frank, *On the Measurement and Valuation of Travel Time Variability Due to Incidents on Freeways*, Journal of Transportation Statistics, Volume 2, Number 2, December 1999, http://www.bts.gov/jts/V2N2/vol2_n2_toc.html.

Figure 5.3 Travel Time Reliability Is Determined by the Distribution of Travel Times

Example Measures Only

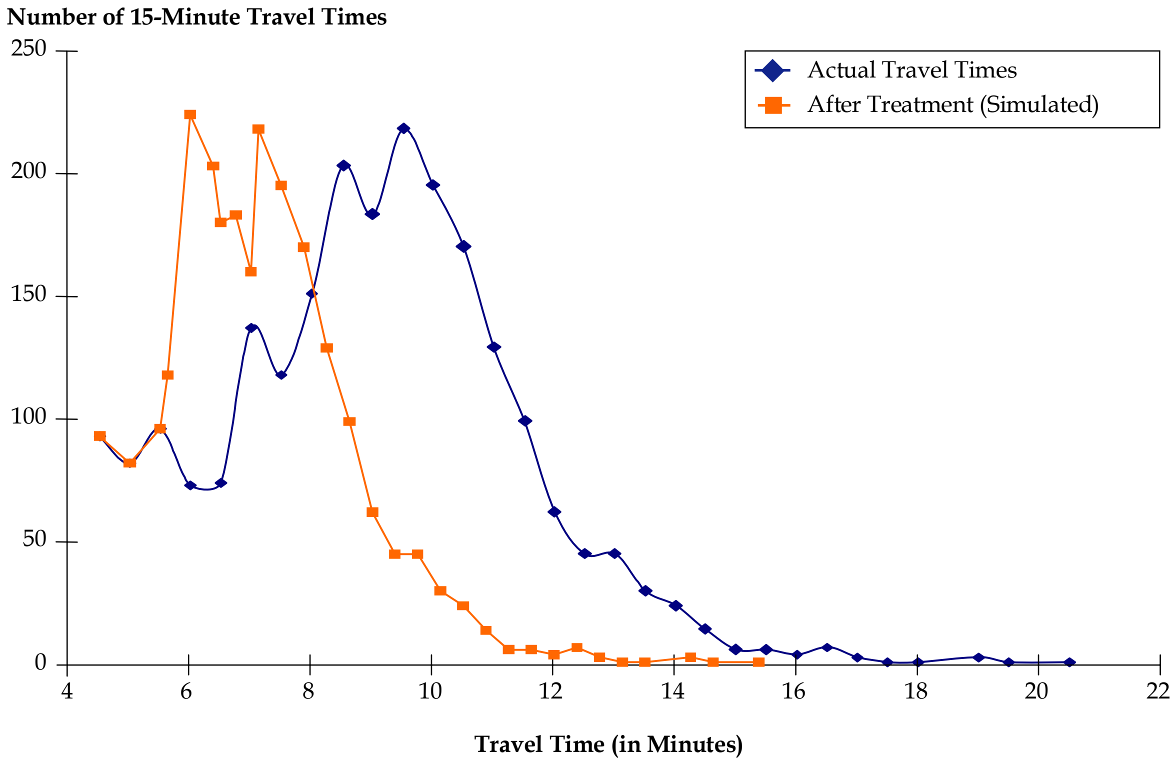


Source: Analysis of Navigator data (Atlanta, Georgia): I-75 Northbound from I-285 to Wade Green Road (13.33 miles). 5-7 P.M. Weekdays, 2004. Total number of trips for time period = 3.485 million (each point on the line represents a 30-second travel time increment)

Effects of Improving Travel Time Reliability

If it is possible to reduce the impact of these events on travel, a double benefit is realized: not only are conditions made more "reliable" (that is, less variable), but overall delay is reduced as well. This is because extreme events, especially in combination, lead to high congestion. As a proof of principle, we examined what effect this would have on travel times in a congested freeway corridor in Atlanta (Figure 5.4).[5] We reduced all of the abnormally high travel times (those greater than seven minutes for the 4.05-mile corridor) by an across-the-board 25 percent.

Figure 5.4 Actual and Improved Peak-Period Travel Times on I-75 Southbound
Central Atlanta, 2002



Source: The data plotted above for "Actual Travel Times" came from the NaviGAtor system in Atlanta, Georgia. The highway segment covered by these data is 4.05 miles long. Average travel times for vehicles moving along this segment were computed at 15-minute intervals for the 3-hour period from 4:00 p.m. to 7:00 p.m. on weekdays for 2002. (This time slice is usually called the "afternoon peak period.") A total of 12 15-minute intervals are therefore present each weekday. If trips were able to be made at 55 mph, they would take 4.4 minutes to complete.

However, the average travel time for the 4:00 p.m. to 7:00 p.m. period is about nine minutes, indicating that (on average) peak-period trips are made at 27 mph on this segment. Many trips take much longer – a few took as long as 20 minutes (an average travel speed of about 12 mph). Others were made in shorter amounts of time. ***This large variability in***

[5] Cambridge Systematics and the Texas Transportation Institute, *Traffic Congestion and Reliability: Linking Solutions to Problems*, prepared for FHWA, August 2004.

observed travel times is due to traffic-influencing events occurring on different days, added on top of an already congested system. (The I-20 interchange at the south end of this stretch is a known bottleneck.) Traffic incidents may happen on some days but not on others. Bad weather and temporary work zones may compound the effect of traffic incidents or may happen by themselves.

The "After Treatment" travel times show the effect of reducing all travel times above seven minutes by 25 percent (hypothetically). This was done to simulate the effect of reducing the impacts of traffic-influencing events on travel. The "tighter" (less spread-out) distribution for the "After Treatment" case indicates that reliability (variability) has been improved. Also, since the majority of trips now have lower travel times, total delay also is reduced. This is indicated by the "After Treatment" curve's shift to the left. More specifically, the average travel time is now about seven minutes in the "After Treatment" case, reduced from nine minutes.

Reliability statistics also can be computed from these data, for both actual conditions and the hypothetical case of reducing abnormally high travel times (Table 5.2). These statistics verify what we observed in Figure 5.4 – that both delay and reliability are improved by treating "extreme" events. ***Operational strategies – which treat these extreme events – therefore have the effect of not only improving reliability but reducing total congestion as well.***

Table 5.2 Effect of Hypothetically Treating Unreliable Travel Times on I-75 in Central Atlanta

	Southbound, 4:00 p.m. to 7:00 p.m.	
Travel Time Measure	**Observed Travel Times**	**Abnormally High Travel Times Reduced by 25 Percent**
Average Travel Time (Minutes)	9.0	7.1
95th Percentile[a] (Minutes)	13.1	9.8
Buffer Time Index[a]	46%	39%

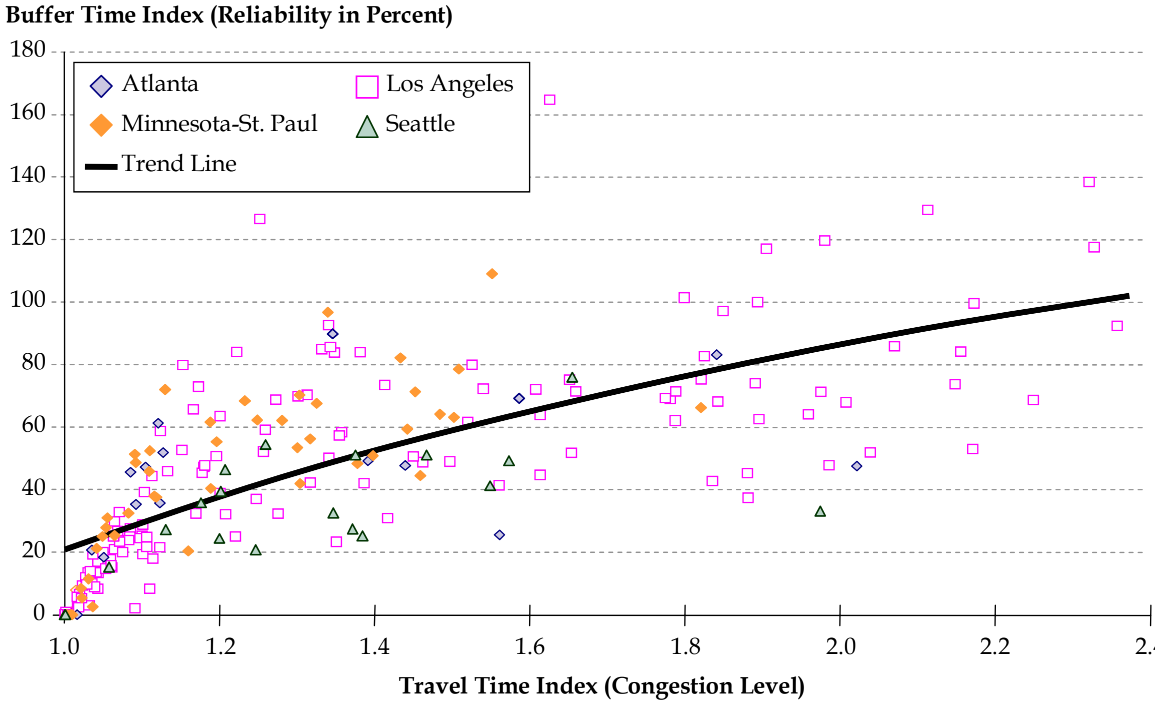
[a] The Buffer Time Index is the 95th percentile travel time normalized to the average travel time (see Chapter 8). For both the 95th percentile travel time and the Buffer Time Index, high values indicate unreliable travel times.

Relationship of Reliability and General Congestion Level

Figure 5.5 shows the Buffer Time Index plotted against the Travel Time Index for highway corridors in four cities. The plot reveals that as the average congestion level (Travel Time

Index) increases, travel times become less reliable (as indicated by an increasing Buffer Time Index).[6] Why does this occur? As congestion builds (i.e., the Travel Time Index increases above 1.0), the highway becomes more "vulnerable" to disruptions caused by events such as bad weather, work zones, and traffic incidents. That is, once traffic has broken down to stop-and-go conditions, throwing an additional event on top causes even greater problems. In other words, ***"congested highways also are unreliable highways."***

Figure 5.5 Relationship Between Congestion Level and Reliability



Source: Analysis of data from FHWA's *Mobility Monitoring Program* (see Appendix A for a description of this data source). Each point on the graph came from individual freeway corridors in Atlanta, Minneapolis, Los Angeles, and Seattle.

The **Travel Time Index** is a measure of the total amount of congestion. It is the ratio of the peak-period travel time to the travel time under ideal conditions. A Travel Time Index value of 1.3 indicates that peak-period travel takes 30 percent longer than under ideal conditions. Another way to think of this measure is as a "multiplier." That is, the value of the Travel Time Index is the amount you would multiply the "ideal" travel time by to get the actual travel time you experienced. Thus, "Travel Time Multiplier" would be an alternate name for this term.

The **Buffer** Time Index is a measure of reliability, or more appropriately, unreliability. As it increases, travel times become more unreliable. Although conditions vary from highway-to-highway and city-to-city, a general relationship between congestion level and reliability is present in these data – as congestion increases, so does unreliable travel.

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[6] See Section 6.0 for a more thorough discussion of these measures.

How Travelers, Operators, and Planners View Reliability

Despite our simple definition of travel time reliability as the level of consistency in travel times over history, different perspectives exist:

- Travelers want to know information about the specific trip they are about to make and how it compares to their typical or expected trip;
- Similarly, operators want to know how the system is performing now in relation to typical conditions; and
- Planners want to know how the system performed last month or last year in comparison to previous time periods.

Some days are better (or worse) than others in terms of congestion, and there is quite a bit of variation from average or typical conditions on any given day. Figure 5.6 displays this variation from the traveler and operator points of view. Shown are travel times in the heavily congested I-75 corridor in central Atlanta for all Thursdays in 2003. The average and 95th percentile travel times are shown along with the actual travel times from two specific Thursdays. January 16 was clearly a "bad" day in this corridor while September 4 was "better than average." For both travelers and operators, a constantly updated display of travel conditions compared to baselines would be valuable information to have. In fact, at least one traffic management center (Houston TRANSTAR) posts this sort of information on their web site in real time.[7] It should be noted that currently we do not have the ability to predict what is going to happen – a difficult task given the uncertainty of unpredictable events like incidents or sudden, intense weather. We can only compare what is happening now to historical conditions, but research is currently underway on this topic.

Still, the ability to ***predict with some certainty*** what travel time will be in the near future is of great interest to operators and travelers. Why is this important? If a commuter has a routine activity that must occur every day – such as picking up children from day care – they must plan on an extra amount of trip time just to be sure they do not arrive late. The same goes for local trucking firms engaged in pickup and delivery of goods. Looking again at the data in Figure 5.6, if a traveler starts in the corridor at 5:30 p.m., on the average Thursday the trip will take about 12 minutes. But history has shown that to be safe, they have to plan for about 18 minutes (50 percent more) to have only a small chance of arriving late; they have to build in a ***buffer***. These are not huge numbers – but this is a short corridor (four miles). The difference is, however, a large percentage. If similar conditions exist over the rest of the commute, then the extra time starts to add up quickly. With this simple approach, an extreme event can cause great problems for an individual trip, but at least we can compute a reasonable probability of arriving on time.

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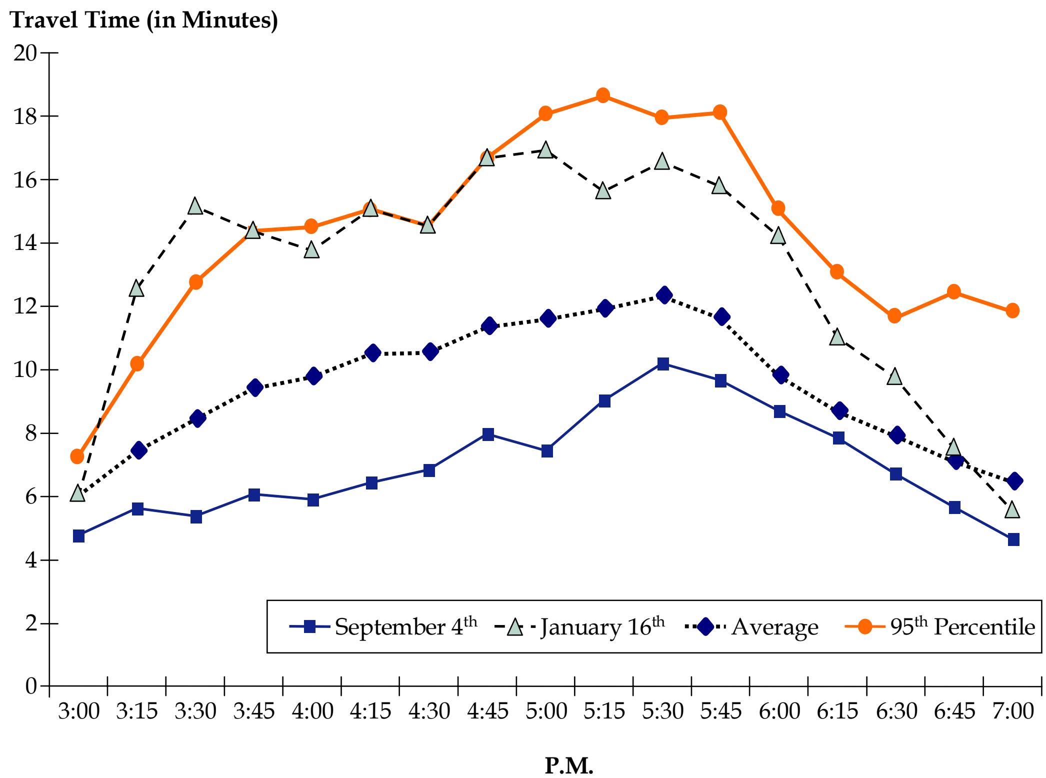
[7] http://traffic.houstontranstar.org/layers/.

Figure 5.6 Is It a Good Day or Bad Day for Commuting – Comparing Current Travel Times to Historical Conditions

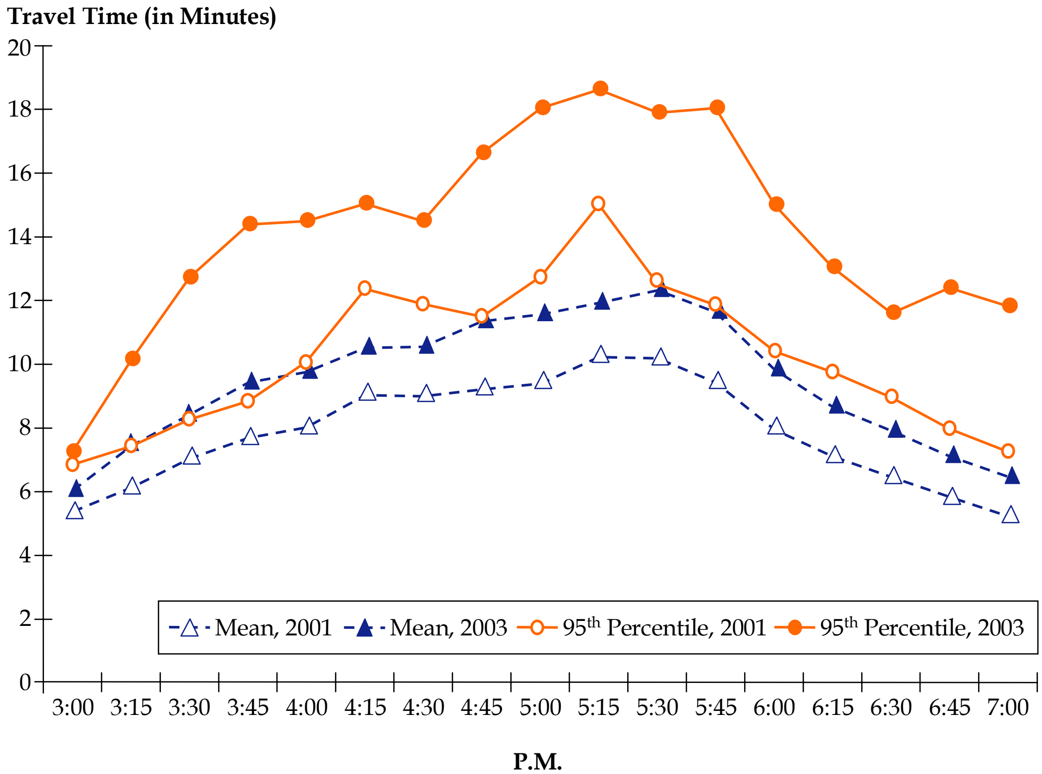
I-75 Southbound Central Atlanta, Thursdays, 2003



Note: Comparing what is happening on the highway system right now to "typical" (average) and "extreme" (95th percentile) conditions provides both operators and travelers with information that can lead to actions. For example, the afternoon of September 4, travelers could see that congestion was lighter than usual and could schedule additional activities. January 16 on the other hand was a heavy congestion day and as it unfolded, operators could post diversion messages to try to control it.

Planners are most interested in how things change over a longer period of time, though the question of "are things getting better or worse" is of general interest as well. In the I-75 corridor in central Atlanta, travel times in the afternoon peak period have increased and reliability has decreased between 2001 and 2003 (Figure 5.7).

Figure 5.7 Congestion and Unreliable Travel Have Increased on I-75 Southbound in Central Atlanta, Georgia
Thursdays, 2001 and 2003

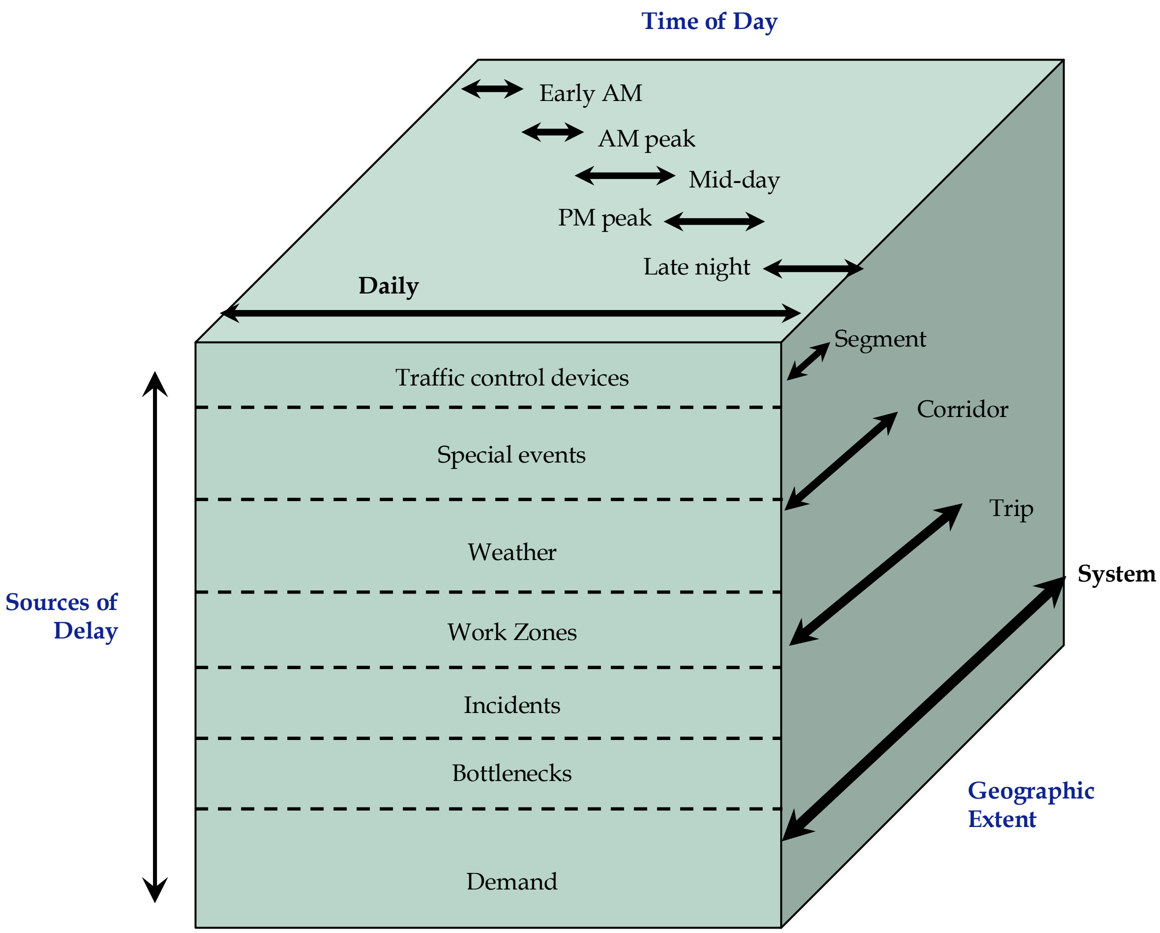


Note: By comparing the average travel times in 2001 and 2003 (the blue lines), it can be seen that average congestion levels have increased in this corridor. At the same time, travel time reliability has decreased, as shown by the increase in the 95th percentile travel times.

5.2.10 Principle 10: Three Dimensions of Freeway Mobility/Congestion Should Be Tracked with Mobility Performance Measures: Source of Congestion, Temporal Aspects, and Spatial Detail

As we have seen, congestion and travel time reliability are determined by multiple factors, or sources. In addition, congestion has temporal and spatial aspects that need to be considered; in other words, measures for both the duration and extent of congestion be developed. By allowing different geographic views of the system, the measures are also scalable; they are capable of depicting parts of or the whole system. Figure 5.8 shows how these three dimensions can be represented. Each of the dimensions is discussed below.

Figure 5.8 Performance Measures for Congestion Should Encompass Multiple Dimensions – Space, Time, and Source Congestion



Sources of Congestion: The F-SHRP Reliability Research Program[8] identified "seven sources" that contribute to overall congestion.

1. **Traffic Incidents** – Events that disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents. In addition to blocking travel lanes physically, events that occur on the shoulder or roadside also can influence traffic flow by distracting drivers, leading to changes in driver behavior and ultimately to the quality of traffic flow.

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[8] *Providing a Highway System with Reliable Travel Times*, report for NCHRP Project 20-58(3), September 2003, http://trb.org/publications/f-shrp/f-shrp_webdoc_3.pdf.

2. **Work Zones** – Construction activities on the roadway that result in physical changes to the highway environment. These changes include a reduction in the number or width of travel lanes, lane "shifts," lane diversions, reduction, or elimination of shoulders, and even temporary roadway closures. Delays caused by work zones have been cited by travelers as one of the most frustrating conditions they encounter on trips.

3. **Weather** – Environmental conditions can lead to changes in driver behavior that affect traffic flow. Due to reduced visibility, drivers will usually lower their speeds and increase their headways when precipitation, bright sunlight on the horizon, fog, or smoke are present. Wet, snowy, or icy roadway surface conditions also will lead to the same effect even after precipitation has ended.

4. **Fluctuations in Demand –** Day-to-day variability in demand leads to some days with higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity results in variable in travel times.

5. **Special Events –** Special case of demand fluctuations whereby traffic flow in the vicinity of the event will be radically different from "typical" patterns.

6. **Traffic Control Devices –** Intermittent disruption of traffic flow by control devices such as railroad grade crossings, drawbridges, and poorly timed signals also contribute to congestion, particularly if they are poorly timed.

7. **Inadequate Base Capacity (Physical Bottlenecks) –** Physical restrictions such as lane-drops, steep grades, sharp curves, limited lateral space, and merge areas contribute to what is typically thought of as "recurring congestion."

At the present time, tracking congestion by source is a difficult task because of the interactions of the seven sources. For example, the base capacity of a roadway determines to what degree events such as incidents will affect congestion.[9] Figure 5.9 shows the nature of these complex interactions. For example, bad weather can lead to more incidents, which can lead to even more incidents ("secondary" incidents). Also, increased congestion can lead to changes in demand – travelers may choose to leave at different times or forego trips because of unusually high congestion on a given day.

Only recently has the transportation profession started to think of congestion in these terms. Yet it is critical to do so because strategies must be tailored to address each of the sources of congestion, and they can vary significantly from one highway to another. Nationally, an estimate of how much each of these sources contribute to total congestion is as follows and depicted graphically in Figure 5.10.[10] These estimates are a composite of many past and ongoing research studies and are rough approximations.

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[9] Consider a rear-end crash that blocks a single lane of freeway. If the freeway has two lanes in a direction, the impact will be more severe than if three or more lanes exist.

[10] http://www.ops.fhwa.dot.gov/congestionmitigation/congestionmitigation.htm; estimates of the effects of variable traffic demand are not available.

Figure 5.9 A Model of Congestion and Its Sources

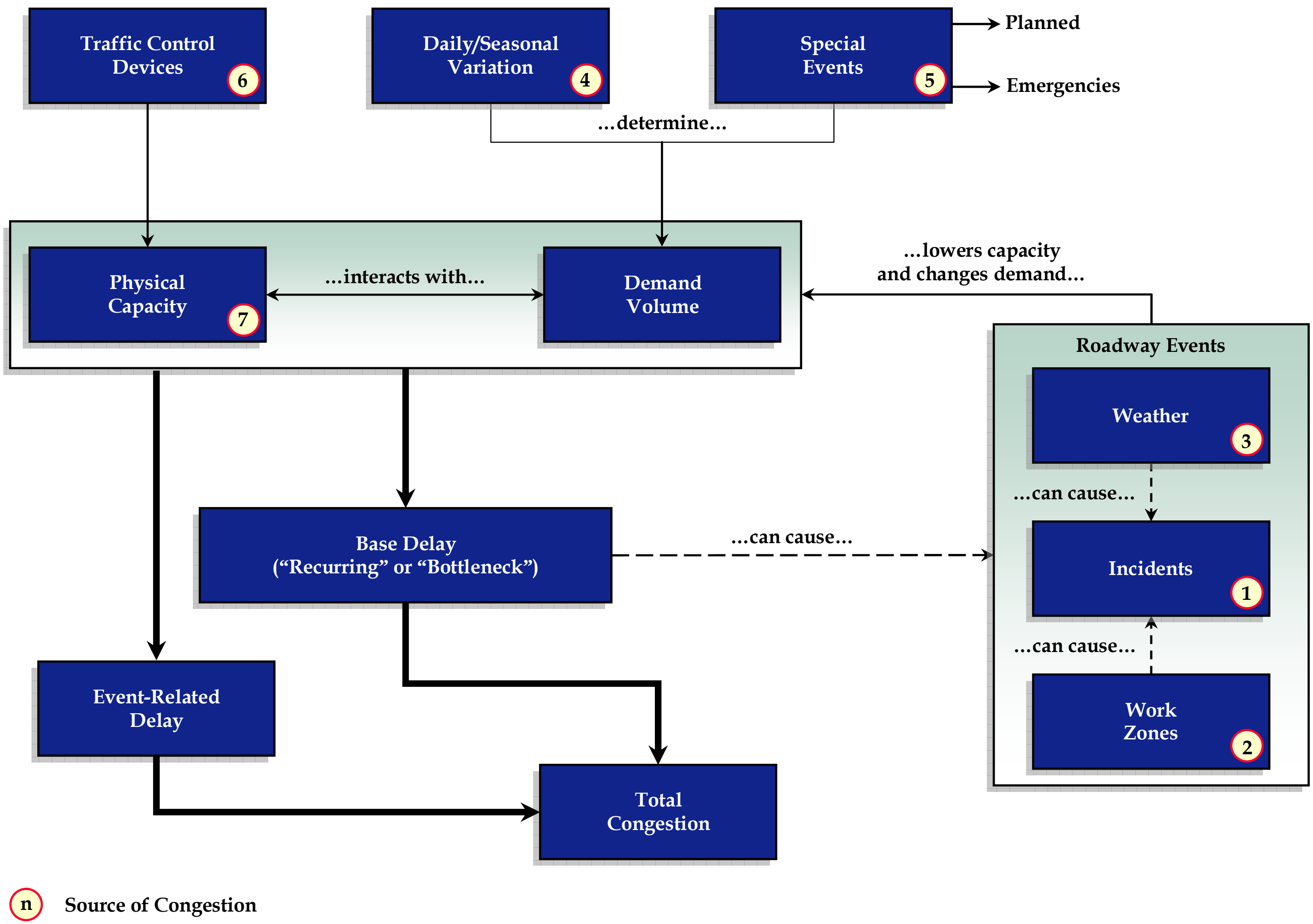
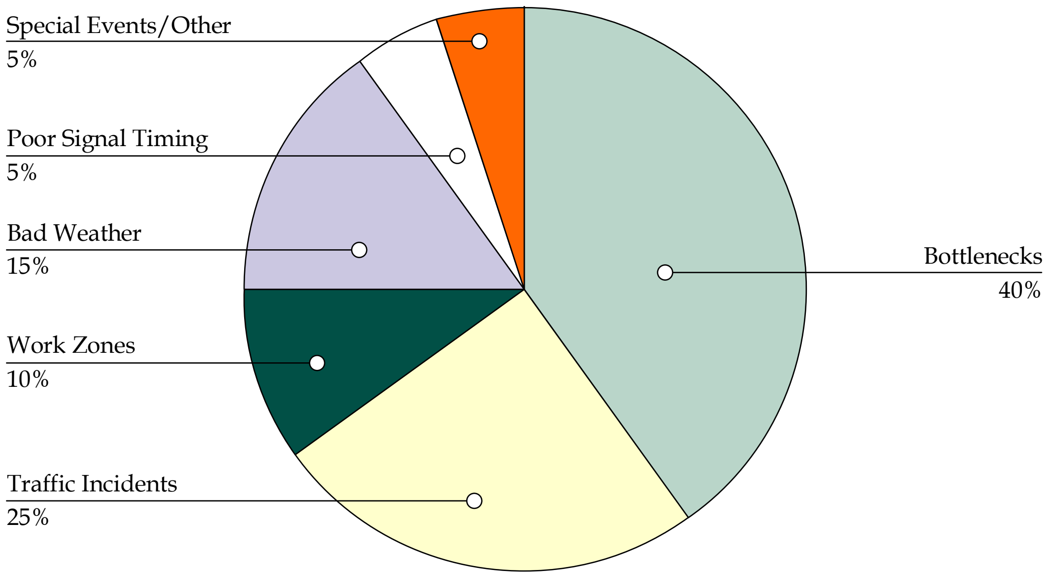


Figure 5.10 The Sources of Congestion
National Summary



Source: Cambridge Systematics, Inc. and Texas Transportation Institute, *Traffic Congestion and Reliability: Trends and Advanced Strategies for Mitigation*, September 1, 2005, http://www.ops.fhwa.dot.gov/congestion_report/index.htm.

It is important to note that these global estimates of congestion sources do not necessarily hold for specific highway corridors. For example, some highways may have high crash rates, leading to a greater proportion of congestion due to traffic incidents. Others may be dominated by a physical bottleneck, such as a narrow bridge, leading to a higher proportion of bottleneck-related congestion. Differences in congestion sources between rural and urban are particularly striking. In rural areas, just about any delay that occurs will be event-related rather than caused by bottlenecks (insufficient capacity). In fact, in rural areas, preliminary estimates suggest that traffic incidents and work zones alone cause 80 to 90 percent of what delay that does occur. Of course, the total amount of delay in rural areas (about 400 *million* vehicle-hours of delay annually) is but a fraction of what occurs in urban areas (about 5.1 *billion* vehicle-hours of delay).[11] These distinctions are extremely important because they indicate what specific strategies should be implemented at any given location.

Controlling for these interactions is problematic and is the subject of current research.[12] This means that for the immediate future, it will be difficult for transportation agencies to

[11] Chin, S.M. et al., *Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2 Report*, ORNL/TM-2004/209, Oak Ridge National Laboratory, November 2004.

[12] NCHRP 7-15, *Cost-Effective Measures and Planning Procedures for Travel Time, Delay, and Reliability*, is currently examining this issue. End date of this project is December 2005.

track congestion by source. However, establishing a framework that does so – including setting up the data programs that are required to support congestion source tracking – is in the best interest of agencies.

Most of the same travel time-based performance measures can be used for each source (e.g., amount of delay attributable to incidents, work zones, etc.). The sources of congestion also require efficiency measures that describe their characteristics (e.g., incident duration, work zone extent). Figure 5.11 shows how travel time reliability, the sources of congestion, and activity-based performance measures are linked together in a cohesive performance measurement package, consistent with Principles 6 and 7 above. In this example, by tracking all three levels (or tiers) of performance, transportation professionals can glean information about system performance:

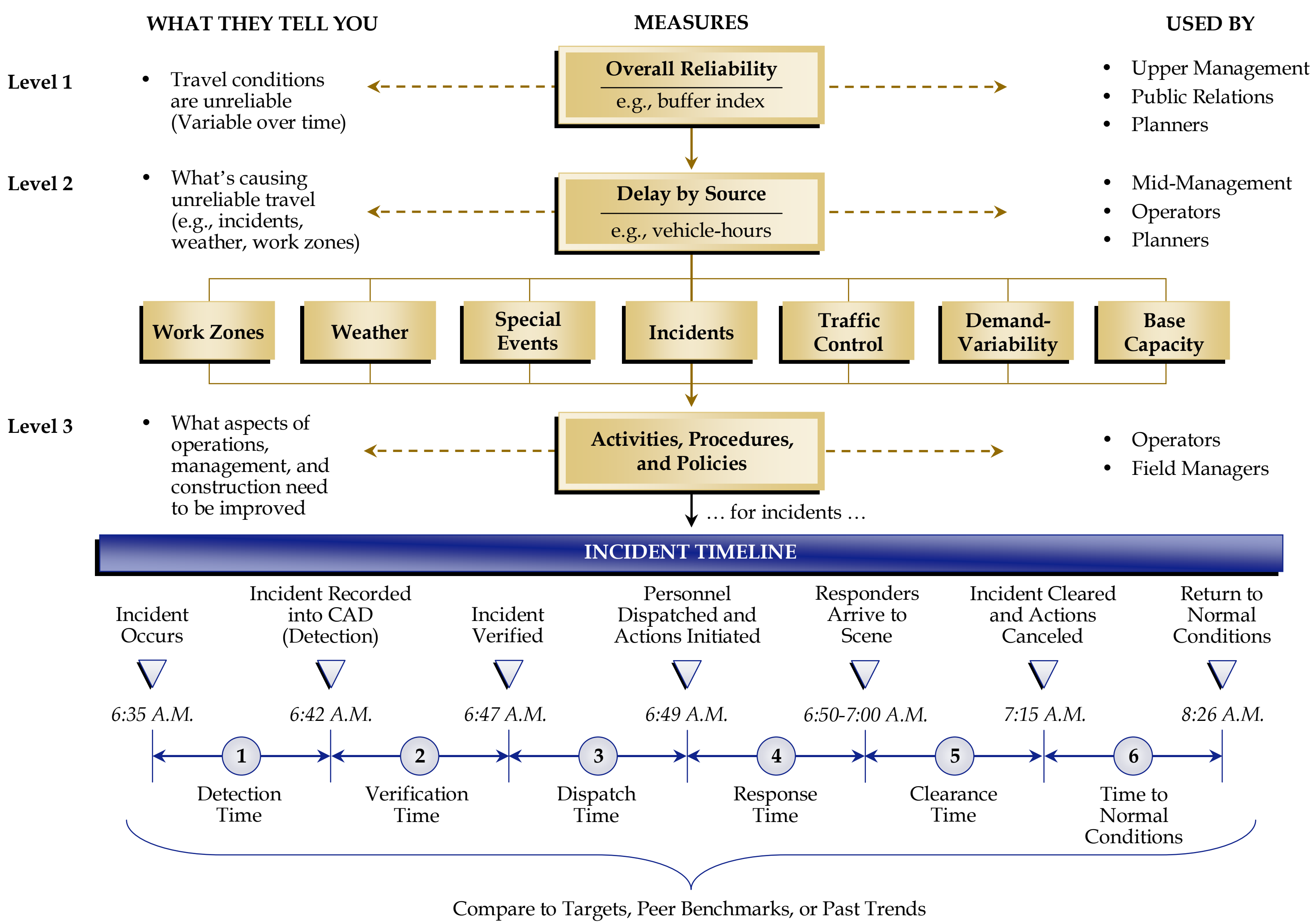
- Overall reliability provides an indication of how consistent travel conditions are for users, i.e., how variable conditions are (but not to what the variability is due);
- Estimating delay by source provides insight into what aspects of congestion are the problems, indicating at the program level what areas should receive focus; and
- Characteristics of each source – and the strategies developed to deal with them – provide a basis for determining what specific activities need to be improved.

Structuring performance measures in the tiered structure shown in Figure 5.11 is important for practitioners to undertake because it ***provides additional explanatory power on why certain trends occurred***. If just overall reliability statistics reported and a change was evident from one year to the next, a logical question is "why did this occur?" Practitioners may not be the ones asking the question – it may come from upper management, elected officials or the public. Being able to explain the change shows those outside the agency that practitioners understand what's happening, but more importantly, this understanding leads to specific actions that should be undertaken (e.g., more investment in one of the congestion source areas that is abnormally high).

Temporal Aspects of Congestion: Measuring congestion by times of the day and day of week has a long history in transportation. A relatively new twist on this is the definition of a weekday "peak period" – multiple hours rather than the traditional peak hour. Definition of peak periods is critical in performing comparisons. For example, consider a three-hour peak period. In smaller cities, congestion may usually only last for one hour – better conditions in the remaining two hours will "dilute" the metrics.

Spatial Aspects of Congestion: Congestion should be monitored at several different levels within a metropolitan area or state. For freeway performance monitoring, the higher levels of aggregation are probably unnecessary: trips (from origin to destination) and areawide. However, it is important to maintain continuity between freeway performance monitoring and these larger views of congestion. The metrics recommended later in this section can be applied at all levels.

Figure 5.11 Example Structure for Linking Quality of Service and Activity-Based Freeway Performance Measures



5.2.11 Principle 11: Communication of Freeway Performance Measurement Should Be Done with Graphics That Resonate with a Variety of Technical and Nontechnical Audiences

Communicating results of performance monitoring is an important element of the entire performance measurement process. Careful consideration of purpose, audience, and use of the measures during the development of the measures also is valuable when determining methods of reporting results. Often the reporting of results occurs as part of the monitoring and feedback and in other instances, reporting is a desired final step.

The several audiences for performance information includes agency managers and staff with specific responsibilities for operating the system or making allocation decisions and delivering system performance, elected officials, customers/users of the system, and other stakeholders. While the content and detail of reports to these groups may differ, collectively they document accomplishments, communicate the benefits of the transportation program, establish management accountability for results, and provide a point of departure for discussion of future revisions to policy goals and objectives, performance targets, or setting performance measures themselves.

Basic principles for freeway performance monitoring multiple metrics, quality of service and activity-based, dimensions (source of congestion, temporal aspects, and spatial detail) lead to the use of a variety of measures reported in a number of different ways. Different graphic presentations are appropriate for different audiences. For example, detailed information using transportation jargon may be appropriate for technical audiences, but not lay communicating with the public or elected officials.

Formats of presentation data include tables, graphs, and succinct statements. Graphs, maps, and exhibits are particularly helpful when conveying results to more sophisticated users. Table 5.3 indicates audiences, potential applications, and characteristics for reporting performance. The final column indicates examples from the Florida performance measurement system. The following describes the process of reporting on performance used by the Florida Department of Transportation. The Florida Transportation Plan (FTP) establishes 20-year goals and objectives and is updated and published every five years while the Short-Range Component of the FTP documents shorter-range (10-year) goals, objectives, and strategies and is published annually. A more detailed Program and Resource Plan sets forth specific operating polices and performance measures that guide the development of each program. The Program and Resource Plan is a 10-year plan containing program funding levels and financial and production targets that are balanced to anticipated revenues. It is produced annually for the legislature. A 5-year listing of projects (called the Work Program) is developed annually based on the Florida Transportation Plan, Program, and Resource Plan, extensive district and public involvement and ultimately decision-making by a strong executive committee at the Department. Finally, a Performance Report which is an annual report, including a summary of the financial operations of the Department and the success in meeting short-term goals is produced.

Table 5.3 Communication of Performance Measurement Example *Florida DOT*

Intended Audience	Application	Characteristics of Reporting Performance	Example from Florida
Public	Traveler information General Information	Use of maps, easy to understand graphics and straightforward statements	*Over the last year the rate of change of person hours of delay on the Florida Intrastate system has remained constant*
Elected Officials	High-level reporting of trends, often called a Dashboard, part of a legislative report	Relate to a specific goal, report in context of targets	*Congestion levels dropped slightly in the seven largest counties* Supported by a graphic showing Density vehicles per lane-mile (percent of vehicles per lane-mile versus year) *What used to be rush hour has now extended well beyond an hour in duration* Supported by a peak-hour congestion graphs showing percent of travel congested versus year
High-Level Management	Management of Programs Resource allocation Project selection		Annual report reports on Quantity (person, truck, and vehicle miles traveled); Quality (Average Speed and delay); Utilization (percent of system congested, vehicles per lane-mile and percent of system heavily congested) These are reported for the peak periods, by state and seven urbanized areas
Mid-Level Management	Resource allocation within office for office business management	Details with graphs, charts	Full range of Mobility measures (see below)
System Operators	Operating decisions	Real time	Total Delay in vehicle miles derived from ITS vehicle detector systems

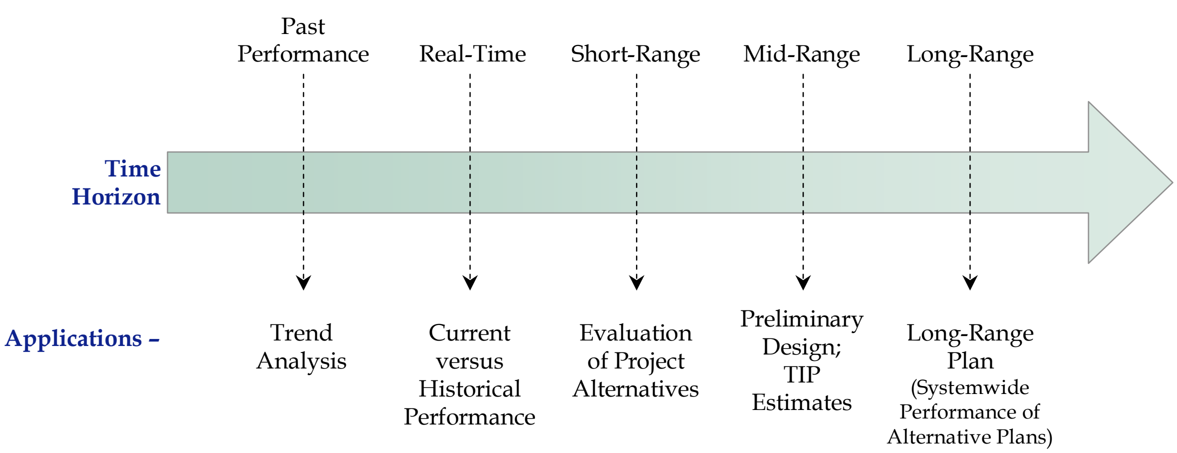
5.2.12 Principle 12: Continuity Should Be Maintained in Performance Measures across Applications and Time Horizons; the Same Performance Measures Should Be Used for Trend Monitoring, Project Design, Forecasting, and Evaluations

In order to establish a comprehensive and integrated performance measurement program, it is important that practitioners apply performance measures (metrics) uniformly across all types of applications. It is desirable to maintain performance measures that are used for specific applications, but a core set of measures should be used across **all** applications.

This is particularly useful for congestion/mobility metrics, and it is not all that difficult to implement. Referring back to Figure 5.1, it is easy to see that if travel time and a few other basic types of data are available, a wide variety of measures can be computed. While this may mean mixing directly measured travel times with model-produced estimates, it nonetheless is feasible to produce these estimates. Figure 5.12 shows the framework for carrying through the same performance measures across the time horizon of project development.

For example, consider a typical travel demand forecasting model used in by transportation planners to make predictions of future traffic on the roadway network. These models also produce link-level estimates of vehicle speeds and or delays by relating them to the volume-to-capacity ratio. Since these are simple variants of travel time, once these are obtained, any number of travel time-based measures can be computed. There are additional refinements (e.g., accurate link-level capacity values) and caveats (uncertainty in future volume estimates) that must be applied, but at least a common set of values allow the possibility of comparisons to current conditions and the experience of peer agencies.[13]

Figure 5.12 The Same Performance Measures Should be Carried Across Applications Spanning the Entire Time Horizon



[13] Section 6.0 presents a more thorough discussion of modeling versus measurement and their compatibility.

6.0 Development of Freeway Performance Measures

6.1 Introduction

6.1.1 Purpose of Section

As the primary output of this section, the *Guidebook* provides a recommended set of freeway performance measures to be used by a variety of agencies. These are broken down into two sets: 1) a core set of a few measures that should be implemented by all agencies, and 2) a supplemental set which will be applied selectively depending on agency activities and the nature of the local setting. In addition, this section also discusses several related issues, including the following:

- Modifications and additions to the recommended set of performance measures, including measures related to cost-effectiveness;
- How to set performance "targets"; and
- A general discussion of data and methods that can be used to develop freeway performance measures (Section 9.0 provides the detail).

6.1.2 Background and Overview

Key Considerations

A specific process was followed by the Research Team in identifying the measures that should be used for freeway performance measurement.

1. Develop a set of principles to be followed in developing the measures.
2. Review the literature and our own experiences; develop a list of potential measures for each of the applications listed in the original objective.
3. Compile results from the benchmarking interviews to see what practitioners are using. Develop a first recommended minimum set.
4. Revise the recommended set based on Panel comments and new information, particularly from the NTOC effort.
5. Get feedback from the Panel on the revised list.

6. Get feedback from practitioners during the field visits.

7. Develop final set.

A key consideration for the recommended performance measures is how to develop them: what data and methods should be used? It is the contention of the authors of the *Guidebook* that the lack of complete data should not be a hindrance to analysis, but should rather be accepted as a fact and understood as a necessary part of the examination of several different analyses and different time horizons. In other words, "do not let the perfect be the enemy of the good" when developing a performance measurement program.

Relationships to Other Freeway Performance Activities

This section forms the basis for subsequent sections of the *Guidebook* by identifying the specific measures to be used by agencies in monitoring freeway performance. It is based on the basic principles given in Section 5.0.

6.1.3 A Note on Threshold-Based versus Continuous Measures

Performance measures can be defined by the way in which they measure a phenomenon: either a threshold or boundary can be established and the phenomenon is counted on one side of it (e.g., total VMT that occurs on roads with a given pavement rating), or the measure is continuous or statistical-based (e.g., average travel time). Threshold-based measures have the advantage of being easily explained but since they are binary (either a measurement is in the range or it isn't), they can be insensitive to subtle changes in the underlying phenomenon. Also, because the threshold implies a value judgment about what is "good" or "acceptable," it may not be useful for all applications. Therefore, where threshold-based measures are recommended, the *Guidebook* usually defines two separate measures with different threshold values.

■ 6.2 Recommended Performance Measures

6.2.1 Core and Supplemental Measures

Tables 6.1 and 6.2 present the recommended Core and Supplemental freeway performance measures, respectively. The Core measures represent those that should be developed by all agencies involved with freeway performance that have sufficient data available to them to undertake their development. In cases where data currently do not exist, agencies should strongly consider developing the data necessary to compute the Core measures. (Section 7.0 discusses data collection activities.) Note also that the tables identify whether a particular performance measure has been identified in the recent NTOC effort.

Table 6.1 Recommended Core Freeway Performance Measures

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average (Typical) Congestion Conditions (Quality of Service)					
Travel Time	The average time consumed by vehicles traversing a fixed distance of freeway	Minutes	Specific points on a section or a representative trip only; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	Direct correspondence to NTOC measure, but distinction between "link" and "trip" travel time is not used
Travel Time Index	The ratio of the actual travel rate to the ideal travel rate[a]	None; minimum value = 1.000	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Total Delay, Vehicles	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions[b]	Vehicle-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC distinguishes between recurring and nonrecurring delay; delay by source recommended by *Guidebook* as supplements
Total Delay, Persons	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions[c]	Person-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC distinguishes between recurring and nonrecurring delay; delay by source recommended by *Guidebook* as supplements
Delay per Vehicle	Total freeway delay divided by the number of vehicles using the freeway	Hours (vehicle-hours per vehicle)	Section and areawide	Peak hour, a.m./p.m. peak periods; daily	Not recommended by NTOC

[a] Travel rate is the inverse of speed, measured in minutes per mile. The "ideal travel rate" is the rate that occurs at the free-flow speed of a facility, or a fixed value set for all facilities that is meant to indicate ideal conditions or "unconstrained" (see text for discussion of the ideal/unconstrained/free-flow speed).

[b] See text above for definition of "ideal."

[c] See text above for definition of "ideal."

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average (Typical) Congestion Conditions (Quality of Service) (continued)					
Spatial Extent of Congestion No. 1	Percent of Freeway VMT with Average Section Speeds < 50 mph[d]	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Spatial Extent of Congestion No. 2	Percent of Freeway VMT with Average Section Speeds < 30 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Temporal Extent of Congestion No. 1	Percent of Day with Average Freeway Section Speeds < 50 mph	Percent	Section and areawide	Daily	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Temporal Extent of Congestion No. 2	Percent of Day with Average Freeway Section Speeds < 30 mph	Percent	Section and areawide	Daily	NTOC uses a single measure with different thresholds, but the concept is fundamentally the same
Density	Number of vehicles occupying a length of freeway	Vehicles per lane-mile	Section	Peak hour/periods for weekday/ weekend	Not recommended by NTOC
Reliability (Quality of Service)					
Buffer Index	The difference between the 95^{th} percentile travel time and the average travel time, normalized by the average travel time	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods, mid-day, daily	NTOC recommends a "buffer time" which is the difference between the 95^{th} percentile travel time and the average; conceptually the same as the *Guidebook*
Planning Time Index	The 95^{th} Percentile Travel Time Index	None; minimum value = 1.000	Section and areawide	Peak hour, a.m./p.m. peak periods, mid-day, daily	NTOC recommends a "buffer time" which is the difference between the 95^{th} percentile travel time and the average; conceptually the same as the *Guidebook*

[d] A freeway "section" is length of freeway that represents a relatively homogenous trip by users. Logical breakpoints are major interchanges (especially freeway-to-freeway) and destinations (e.g., Central Business District). The term "section" is sometimes used to describe this, but it usually implies additional parallel freeways and/or transit routes.

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Capacity Bottlenecks (Activity-Based)					
Geometric Deficiencies Related to Traffic Flow (Potential Bottlenecks)	Count of potential bottleneck locations by type[e]	Number	Section and areawide	N/A	Not recommended by NTOC
Major Traffic-Influencing Bottlenecks	Count of locations that are the primary cause of traffic flow breakdown on a highway section, by type	Number	Section and areawide	N/A	Not recommended by NTOC
Throughput (Quality of Service)					
Throughput – Vehicle	Number of vehicles traversing a freeway in vehicles	Vehicles per unit time	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Direct correspondence to NTOC measure
Throughout – Persons	Number of persons traversing a freeway	Persons per unit time	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Direct correspondence to NTOC measure
Vehicle-Miles of Travel	The product of the number of vehicles traveling over a length of freeway, times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Truck Vehicle-Miles of Travel	The product of the number of trucks traveling over a length of freeway,[f] times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC

[e] Bottleneck types are: Types A-C weaving areas (see HCM and Section 7.0); left exits; freeway-to-freeway merge areas; surface street on-ramp merge areas; acceleration lanes at merge areas < 300 feet; lane drops; lane width drops >= 1 foot; directional miles with left shoulders < 6 feet; directional miles with right shoulders < 6 feet; steep grades; substandard horizontal curves. The shoulder categories are included because of the ability of more than 6-foot shoulders to shelter vehicles during traffic incidents.

[f] Trucks are defined as vehicles with at least six tires, i.e., FHWA Classes 5-13 plus any larger vehicles as defined by a state.

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Throughput (Quality of Service) (continued)					
Lost Highway Productivity	Lost capacity due to flow breakdown – the difference between measured volumes on a freeway segment under congested flow versus the maximum capacity for that segment	Vehicles per hour	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Customer Satisfaction (Quality of Service)					
Worst Aspect of Freeway Congestion	(Defined by question)	1) happens every work day, 2) incidents that are not cleared in time, 3) encountering work zones	Areawide or statewide	Annually; tied to survey frequency	Not recommended by NTOC
Satisfaction with Time to Make Long-Distance Trips Using Freeways	(Defined by question)	1) very satisfied, 2) somewhat satisfied, 3) neutral, 4) somewhat dissatisfied, 5) very dissatisfied, 6) do not know	Areawide or statewide	Annually; tied to survey frequency	Direct correspondence to NTOC measure
Safety (Quality of Service)					
Total Crashes	Freeway crashes as defined by the state, i.e., those for which a police accident report form is generated	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	Not recommended by NTOC

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Safety (Quality of Service)					
Fatal Crashes	Freeway crashes as defined by the state, i.e., those for which a police accident report form is generated, where at least one fatality occurred	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	Not recommended by NTOC
Overall Crash Rate	Total freeway crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	Not recommended by NTOC
Fatality Crash Rate	Total freeway fatal crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles			Not recommended by NTOC
Secondary Crashes	A police-reported crash that occurs in the presence of an earlier crash[g]	Number			Not recommended by NTOC
Ride Quality (Quality of Service)					
Present Serviceability Rating (PSR)	The general indicator of ride quality on pavement surfaces[h]	(Internal scale)	Section and areawide	Annually	Not recommended by NTOC
International Roughness Index (IRI)	Cumulative deviation from a smooth surface	Inches per mile	Section and areawide	Annually	Not recommended by NTOC

[g] See text for discussion.

[h] See: http://www.fhwa.dot.gov/policy/1999cpr/ch_03/cpg03_2.htm.

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Environment (Quality of Service)					
Nitrous Oxides (NOx) Emission Rate	Modeled NOx attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Volatile Organic Compound (VOC) Emission Rate	Modeled VOC attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Carbon Monoxide (CO) Emission Rate	Modeled CO attributable to freeways divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Fuel Consumption per VMT	Modeled gallons of fuel consumed on a freeway divided by freeway VMT	Number	Section and areawide	Annually	Not recommended by NTOC
Incident Characteristics (Activity-Based)					
No. of Incidents by Type and Extent of Blockage	Self-explanatory	Type: 1) crash, 2) vehicle breakdown, 3) spill, 4) other. Blockage: actual number of lanes blocked; separate code for shoulder blockage	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Incident Duration[i]	The time elapsed from the notification of an incident to when the last responder has left the incident scene	Minutes (median)	Section and areawide	a.m./p.m. peak periods, daily	Direct correspondence to NTOC measure
Blockage Duration	The time elapsed from the notification of an incident to when all evidence of the incident (including responders' vehicles) has been removed from the travel lanes	Minutes (median)	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC

[i] Since in many cases the actual time the incident occurred is unknown, the notification time is used to indicate the official "start" of the incident. On most urban freeways, through the use of cell phones by the public, the time between when the incident occurs and when it is first reported is very small.

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Incident Characteristics (Activity-Based) (continued)					
Lane-Hours Loss Due to Incidents	The number of whole or partial freeway lanes blocked by the incident and its responders, multiplied by the number of hours the lanes are blocked	Lane-hours	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Work Zones (Activity-Based)					
No. of Work Zones by Type of Activity	The underlying reason why the work zone was initiated: 1) resurfacing only, 2) RRR, 3) lane addition w/o interchanges, 4) lane additions w/interchanges, 5) minor cross-section, 6) grade flattening, 7) curve flattening 8) bridge deck, 9) bridge superstructure, 10) bridge replacement, 11) sign-related	Number	Section and areawide	Daily	Not recommended by NTOC
Lane-Hours Lost Due to Work Zones	The number of whole or partial freeway lanes blocked by the work zone, multiplied by the number of hours the lanes are blocked	Lane-hours	Section and areawide	a.m./p.m. peak periods; midday; night; daily	Not recommended by NTOC
Average Work Zone Duration by Type of Activity	The elapsed time that work zone activities are in effect	Hours	Section and areawide	Daily	Not recommended by NTOC
Lane-Miles Lost Due to Work Zones	The number of whole or partial freeway lanes blocked by the work zone, multiplied by the length of the work zone	Lane-miles	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Weather (Activity-Based)					
Percent of hours influenced by weather	"Weather Influence" = Measurable precipitation during, fog, snow/ice cover on roadway	Percent	Section only	Daily	Not recommended by NTOC
Extent of highways affected by snow or ice	Highway centerline mileage under the influence of uncleared snow or ice multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC

Table 6.1 Recommended Core Freeway Performance Measures (continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Weather (Activity-Based) (continued)					
Extent of highways affected by rain	Highway centerline mileage under the influence of rain multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Extent of highways affected by fog	Highway centerline mileage under the influence of fog multiplied by the length of time of the influence	Centerline-Mile-Hours	Section and areawide	Daily	Not recommended by NTOC
Operational Efficiency (Activity-Based)					
Percent Freeway Directional Miles with (traffic sensors, surveillance cameras, DMS, service patrol coverage)	One measure for each type of equipment deployed in an area	Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Percent of Equipment (DMS, surveillance cameras, traffic sensors, ramp meters, RWIS) in "Good" or Better Condition	One measure for each type of equipment deployed in an area	Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Percent of total device-days out-of-service (by type of device)	One measure for each type of equipment deployed in an area	Percentage (xxx.x%)	Section and areawide	Annually	Not recommended by NTOC
Service patrol assists	Self-explanatory	Number	Section and areawide	Annually	Not recommended by NTOC

Table 6.2 Supplemental Freeway Performance Measures

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average Congestion Conditions (Quality of Service)					
Bottleneck ("Recurring") Delay	Delay that is attributable to bottlenecks[a]	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC defines two categories: recurring and nonrecurring; see text for discussion
Incident Delay	Delay that is attributable to traffic incidents	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC defines two categories: recurring and nonrecurring; see text for discussion
Work Zone Delay	Delay that is attributable to work zones	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC defines two categories: recurring and nonrecurring; see text for discussion
Weather Delay	Delay that is attributable to inclement weather	Vehicle-hours	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	NTOC defines two categories: recurring and nonrecurring; see text for discussion
Maximum Freeway Queue Length	The longest continuous queue (vehicle speeds < 30 mph over a 5-minute period) resulting from a physical or event-related bottleneck	Miles	Section	N/A	Not recommended by NTOC
Ramp delay (where ramp metering exists)	Delay that occurs at ramp meters	Vehicle-hours	Individual ramps and section as a minimum	Peak hour, a.m./p.m. peak periods	Not recommended by NTOC
Abnormal Volume-Related Delay	Delay caused by abnormal high volumes[b]	Vehicle-hours	Section and areawide	Peak hour, a.m./ p.m. peak periods, midday, daily	Not recommended by NTOC

[a] Delay is the excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions; see text for a discussion of "ideal" conditions.

[b] May be due to either special events or normal variation due to daily/seasonal fluctuations in demand.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Average Congestion Conditions (Quality of Service) (continued)					
Volume-to-capacity ratio	The ratio of the demand volume attempting to use a short segment of freeway divided by the freeway's capacity, as defined by the *HCM*	None	Bottleneck locations only (freeway interchanges, lane-drops, bridges)	Peak-hour volume/ peak-hour capacity Peak-period volume/ peak-period capacity	Not recommended by NTOC
Traffic Demand Indicator	Ratio of actual traffic demand (volume) to average traffic demand[c]	None	Section and areawide	Peak+Shoulder Periods	Not recommended by NTOC
Delay per Capita	Total freeway delay divided by the population of the area being studied	Vehicle-hours per person	Areawide and statewide	Peak hour, a.m./p.m. peak periods; daily	Not recommended by NTOC
Average speeds by hour of the day (used primarily as an indicator of air quality)	The miles traveled by vehicles over a distance divided by the time it took to travel that distance (space mean speed)[d]	Miles per hour	Section and areawide	Peak hour, a.m./p.m. peak periods; daily	NTOC defines "speed" as the time mean speed
Reliability (Quality of Service)					
Reliability: Failure Measure No. 1	Percent of trips (section or O/D) with space mean speeds <= 50 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC

[c] See text for a more complete explanation.

[d] Although the *Guidebook* calls this space mean speed, depending on how the measurements are taken, it may be a "synthesized" space mean speed. That is, if the basic measurements are from point detectors, theoretically speaking, it is closer to being a time mean speed. See Section 9.0 for more discussion.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Reliability (Quality of Service) (continued)					
Reliability: Failure Measure No. 2	Percent of trips (section or O/D) with space mean speeds <= 30 mph	Percent	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Planning Time Index	95th percentile travel time divided by the free-flow travel time	N/A	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Throughput (Quality of Service)					
VMT per capita	Freeway VMT divided by the population of the study area	N/A	Section and areawide	Peak hour, a.m./p.m. peak periods, midday, daily	Not recommended by NTOC
Customer Satisfaction (Quality of Service)[e]	All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1-3 years				
Biggest concern about transportation[f]	Defined by survey question	Percent			Not recommended by NTOC
Most important thing the Department could do to improve congestion[g]	Defined by survey question	Percent			Not recommended by NTOC

[e] Usually included in statewide surveys of public's attitudes towards transportation and service provided; may also be done at the local level.

[f] 1) Congestion, 2) poor road and bridge condition, 3) highway crashes, 4) transit not available.

[g] 1) Build more roads, 2) clear incidents faster, 3) reduce time that work zones are needed, 4) more effective snow removal, 5) better inform travelers about congestion they will encounter on their trips.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)*[h] *(continued)		All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1 to 3 years			
Usage rates and percent of favorable response to broadcast video images	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to traveler information about 1) congestion, 2) work zones	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to DMS messages	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percent of favorable response to service patrols	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response to work zone management	Defined by survey question				Not recommended by NTOC
Percent of favorable response to freeway planning process	Defined by survey question	Percent			Not recommended by NTOC

[h] Usually included in statewide surveys of public's attitudes towards transportation and service provided; may also be done at the local level.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Customer Satisfaction (Quality of Service)*[i] *(continued)		All customer satisfaction measures apply areawide or statewide All customer satisfaction measures developed every 1 to 3 years			
Percent of favorable response with completed projects	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with air quality	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with long-distance travel	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with pavement condition	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with highway safety (how safe it is to travel?)	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with amount of salt used on main rural highways	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with environmental aspects of road planning and design	Defined by survey question	Percent			Not recommended by NTOC
Percent of favorable response with environmental aspects of road construction	Defined by survey question	Percent			Not recommended by NTOC

[i] Usually included in statewide surveys of public's attitudes towards transportation and service provided; may also be done at the local level.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Safety (Quality of Service)					
Number of fatal, injury, and PDO crashes – total and by: 1) type of collision, 2) time of day, 3) relation to ramps, 4) "first harmful event" (fixed object, rollover, etc.)	All safety data defined by state police accident report (PAR)	Number; distribution percents within each category	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
High-crash locations[j]	All safety data defined by state police accident report (PAR)		All safety measures computed areawide; section level may be computed if multiple years are used. Specific locations or short segments of freeway	All safety measures computed annually	No safety measures recommended by NTOC
Alcohol-involved crashes (fatal, injury, total)	All safety data defined by state police accident report (PAR)	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Commercial vehicle crashes (total and hazmat involved)	All safety data defined by state police accident report (PAR)	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC

[j] Most states have procedures for identifying high crash locations. Additional guidance may be available through software packages such as FHWA's *SafetyAnalyst*.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Safety (Quality of Service) (continued)					
Commercial vehicle crash rate	Total number of commercial vehicle crashes divided by commercial vehicle VMT	Rate	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Crashes where speed was a contributing factor	All safety data defined by state police accident report (PAR)	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Total Work Zone Crashes, Injuries, and Fatalities	All safety data defined by state police accident report (PAR)	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Total Weather-Related Crashes, Injuries, and Fatalities	All safety data defined by state police accident report (PAR)	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually	No safety measures recommended by NTOC
Incident Management (Activity-Based)					
First Responder Response Time	Time difference between when the incident was first detected by an agency and the on-scene arrival of the first responder	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Incident Management (Activity-Based) (continued)					
Notification Time	Time difference between when the incident was first detected to when the last agency needed to respond to the incident was notified	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Total Response Time	Time difference between when the incident was first detected by an agency and the on-scene arrival of the last responder	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Clearance time	Time difference between when the first responder arrived on the scene and blockage of a travel lane is removed	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
On-Scene Time	Time difference between when the first responder arrives and the last responder leaves an incident scene; may also be computed for individual responders	Minutes	Section and areawide		Not recommended by NTOC
Linger Time	Time difference between when the blockage of a travel lane is removed and the last responder leaves the incident scene	Minutes	Section and areawide		Not recommended by NTOC
Traffic Influence Time	Time between when an incident was first detected and the last responder leaves the incident scene	Minutes	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Detection Method (citizens, police, other agencies) per month	The method which incidents are detected or reported	Locally defined	Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC
Service patrol assists (total and by incident type)			Section and areawide	a.m./p.m. peak periods, daily	Not recommended by NTOC

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Work Zones (Activity-Based)					
Traffic volume passing through work zones	Self-explanatory; AADT estimates may be used in place of actual counts	Vehicles	Section and areawide	Daily	No work measures recommended by NTOC
Average Time Between Rehabilitation Activities by Type of Activity	Type of activity: 1) resurfacing only, 2) RRR, 3) lane addition w/o interchanges, 4) lane additions w/interchanges, 5) minor cross-section, 6) grade flattening, 7) curve flattening, 8) bridge deck, 9) bridge superstructure, 10) bridge replacement, 11) sign-related	Months	Areawide	N/A	No work measures recommended by NTOC
Average Number of Days Projects Completed Late	"Late" is any time after the scheduled completion	Days	Areawide	N/A	No work measures recommended by NTOC
Ratio of Inactive Days to Active Days	"Active" is when some work zone activity was performed during a day	N/A	Areawide	Annually	No work measures recommended by NTOC
Crashes per lane-mile lost	Work zone crashes divided by the number of lanes lost	N/A	Section, Areawide, and Statewide	Annually	No work measures recommended by NTOC
Average Work Zone Duration by Work Zone Type by Lanes Lost	Time length of work zone activities by their severity in terms of traffic impact; Lanes lost = 0, 1, 2, 3, 4+	Hours	Areawide	Annually	No work measures recommended by NTOC
Average Number of Days That a Contract Work Zone is Active	"Active" is when some work zone activity was performed during a day	Days	Areawide	Annually	No work measures recommended by NTOC
Weather (Activity-Based)					
Number of incident responses during weather-related events	Self-explanatory	Number	Areawide	Monthly and Annually	No weather measures recommended by NTOC
Lane-miles and freeway miles officially closed due to weather or flooding	Self-explanatory	Lane-miles	Areawide	Monthly and Annually	No weather measures recommended by NTOC

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Weather (Activity-Based) (continued)					
Number of freeways with reduced speed limits by MP3 reductions	Self-explanatory	Number	Areawide	Monthly and Annually	No weather measures recommended by NTOC
Number of freeway ramps closed due to weather by weather event	Self-explanatory	Number	Areawide	Annually	No weather measures recommended by NTOC
Time between 2 inches of snow accumulation and plowing (clearance)	Self-explanatory	Minutes	Areawide (lane-mile weighted)	Annually	No weather measures recommended by NTOC
Lane-miles pretreated with chemical snow/ice control	Self-explanatory	Lane-miles	Areawide	Annually	No weather measures recommended by NTOC
Lane-miles pretreated with chemical snow/ice control that experienced snow or ice conditions	Self-explanatory	Lane-miles	Areawide	Annually	No weather measures recommended by NTOC
Weather event VMT ratio	VMT during event: VMT for recent same DOW	N/A	Areawide	Annually	No weather measures recommended by NTOC
Weather event delay ratio	Delay during event: delay for recent same DOW)	N/A	Areawide	Annually	No weather measures recommended by NTOC
Delay per lane-mile affected by major weather events	Self-explanatory	Rate	Areawide	Annually	No weather measures recommended by NTOC
Crashes per lane-mile affected by major weather events	Self-explanatory	Rate	Areawide	Annually	No weather measures recommended by NTOC

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Operational Efficiency (Activity-Based)[k]					
Service patrol vehicles in operation per shift	Self-explanatory	Number	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
Percent freeway miles with (electronic data collection, surveillance cameras, DMS, service patrol coverage)	Self-explanatory	Percent	Areawide	User-specified	No operational efficiency measures recommended by NTOC
Number of messages placed on DMSs	Self-explanatory	Number	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
Individuals receiving traveler information by source (511, other direct means)	Self-explanatory	Number	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
Percent of equipment (DMS, surveillance cameras, sensors, ramp meters, RWIS) in "good" or better condition	Self-explanatory	Percent	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
Percent of total device-days out-of-service (by type of device)	Self-explanatory	Percent	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
Incident detection method	Self-explanatory	Number	Areawide	User-specified	No operational efficiency measures recommended by NTOC

[k] A multitude of other operational efficiency measures resides in asset management information and performance measurement systems.

Table 6.2 Supplemental Freeway Performance Measures (continued)

Performance Measure	Definition	Units	Geographic Scale	Time Scale	Relationship to NTOC Measures
Operational Efficiency (Activity-Based)[1] *(continued)*					
No. devices exceeding design life	Self-explanatory	Number	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
MTBF for field equipment (by type of device)	Self-explanatory	Days	Section and areawide	User-specified	No operational efficiency measures recommended by NTOC
Number of freeway miles instrumented with traffic data collection devices	Self-explanatory; directional miles	Miles	Areawide	User-specified	No operational efficiency measures recommended by NTOC
Freeway construction projects completed within 30 days of scheduled completion	Self-explanatory	Number	Areawide	User-specified	No operational efficiency measures recommended by NTOC

[1] A multitude of other operational efficiency measures resides in asset management information and performance measurement systems.

The recommended performance measures were developed by pulling information from several recent efforts, the interviews conducted with state DOTs and MPOs, and the research teams own experience. The recent efforts that served as a basis for the recommendations are: FHWA's Mobility Monitoring Program,[1] the NTOC performance measures effort,[2] and FHWA sponsored efforts on incident management,[3] and work zone management.[4]

The Supplemental measures are those that round out a comprehensive freeway performance monitoring program, but are not "mission critical." Moreover, there is a wide range of additional performance measures beyond the Core and Supplemental sets that can be constructed and used by transportation agencies – the ones presented in Tables 6.1 and 6.2 are by no means exhaustive.

Because there are multiple agencies, particularly in urban areas, with an interest in freeway performance, the details of who actually develops the measures needs to be worked out locally. With the exception of the Operational Efficiency category of measures – which are chiefly the concern of agencies actively engaged in operations – there is no single way to determine which type of agencies are best suited for performance measure development. One way to help to decide may be that agencies with the underlying data may be in the best position to develop measures, but this is not strictly necessary. What is necessary, however, is that all agencies with an interest in freeway performance measurement be involved at some level in developing the measurement programs.

6.2.2 Congestion/Mobility Measures

As mentioned in Section 1.0, the emphasis of the *Guidebook* is on performance measurements related to congestion and mobility for two reasons: 1) congestion is such a highly visible factor and strong influence on travelers on urban freeways, and 2) lack of previous work in this area by the profession. To begin, some kind of definition for congestion would be useful. Unfortunately, congestion is one of those elusive and relative events that we intuitively "know it when they see it," but is difficult to bound exactly. One of the Federal Highway Administration (FHWA) source defines congestion as:

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1 http://mobility.tamu.edu/mmp.

2 National Transportation Coalition: Performance Measurement Initiative (Final Report), July 2005.

3 Balke, Kevin, *Measuring the Effectiveness and Performance of Multi-Agency Traffic Incident Management Programs*, http://ops.fhwa.dot.gov/incidentmgmt/inst_coordination/perf_measure_study.htm.

4 Ullman, Gerald R., Holic, Andrew J., and Scriba, Tracy A., *Estimates of Work Zone Exposure on the National Highway System in 2001,* Paper Presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., January 2004.

> *Simply, highway congestion results when traffic demand approaches or exceeds the available capacity of the highway system. While this is a simple concept, it is not constant. Traffic demands vary significantly depending on the season of the year, the day of the week, and even the time of day. Also, the capacity, often mistaken as constant, can change because of weather, work zones, traffic incidents, or other nonrecurring events.*[5]

Another recent FHWA document defines congestion more colloquially:

> *Congestion is relatively easy to recognize – roads filled with cars, trucks, and buses, sidewalks filled with pedestrians. The definitions of the term congestion mention such words as "clog," "impede," and "excessive fullness." For anyone who has ever sat in congested traffic, those words should sound familiar. In the transportation realm, congestion usually relates to an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower – sometimes much slower – than normal or "free-flow" speeds. Congestion often means stopped or stop-and-go traffic.*[6]

Other definitions of congestion include:

> *Utilization of highways that results in degradation in travel ability and intended throughput.*

> *Inability to travel at expected conditions.*

As can be seen, congestion definitions are imprecise and often involve value judgments, yet determining the bounds of congestion is important because the public and elected officials often want to know how much congestion is occurring. For tracking purposes – where we are interested mainly in changes in congestion level – it almost does not matter; any reasonable measure of congestion will pick up changes over time. However, policies on project selection and design are often keyed to threshold levels of congestion.

Complicating the matter even further is that, just as "we know it when we see it," congestion also is "in the eye of the beholder." That is, user perceptions of congestion are tempered with their experience and expectations. Whereas, in small towns waiting through a complete traffic signal cycle would be considered major congestion, large city dwellers might be pleased if they were only delayed by that much.

What is the way out of this for practitioners grappling with congestion performance measures? There are no easy answers, but the *Guidebook's* principles are useful here, namely, that travel time is the basis for measuring congestion and multiple measures should be applied. The use of multiple metrics is especially significant when using measures that incorporate a threshold – this makes the measure binary – either congestion

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[5] http://www.fhwa.dot.gov/congestion/congest2.htm.

[6] Cambridge Systematics and Texas Transportation Institute, *Traffic Congestion and Reliability: Trends and Advanced Strategies for Mitigation*, September 1, 2005, http://www.ops.fhwa.dot.gov/congestion_report/index.htm.

occurs or it does not. At the local level, some experimentation and expansion is certainly warranted to determine what the thresholds should be. This may involve a consensus-building exercise based on local perceptions to arrive at the most appropriate thresholds. One strategy is to set different thresholds for congestion based on the size of the area in which the freeway is located or by traffic level. No attempt to set variable congestion thresholds is attempted in this *Guidebook*, because its recommendations are thought to be universal. This does not preclude local adaptation of the measures, but ideally would lead to additional locally defined measures to supplement those in recommended in this *Guidebook*.

The Core measures recommended for basic congestion levels are comprised of continuous measures (travel time, travel time index, total delay, and density), a unit-based measure (delay per vehicle), and threshold-based measures (spatial and temporal aspects). The unit-based measure is an extremely important one because it describes conditions from the individual user's perspective and partially accounts for growth in traffic that may be influencing congestion a freeway section or network. Density is a commonly used measure of driving convenience on rural freeways where flow breakdown may not routinely occur but traffic levels limit maneuverability. Densities associated with oversaturation (forced flow) may also be used, especially since some agencies use aerial photography to capture congestion. In such cases, densities may be used directly or can be related back to the recommended performance measures that are based on speed.

The spatial and temporal extent measures are both defined with thresholds of 50 mph and 30 mph. 50 mph was chosen because that is generally the boundary between free and congested flow, i.e., the speed at freeway capacity. 30 mph was chosen to capture flow that is truly in the saturated regime – speeds between 30 mph and 50 mph are likely to be "transitional in nature" (i.e., queue formation and recovery).

Delay by source is recommended in the Supplemental measure category. As discussed later in this section and in Section 8.0, the ability either to measure these directly or to model them is currently limited. Therefore, for the time being, they are really placeholders awaiting more mature methods to measure them. In the interim, two options exist to get at the issue of event-related congestion:

1. Practitioners can use the recurring/nonrecurring dichotomy (see Section 8.0 for a calculation method); and

2. The Core reliability metrics can be used as an indicator of event-related delay. These measures relate to the underlying variability in travel conditions, and this variability is mostly due to events. Therefore, high values for the reliability metrics indicate a large amount of nonrecurring congestion. Some experimentation is in order using local data to identify what a "high value" for a reliability metric is. Practitioners may use the data in Tables 6.3 and 6.4 as a basis for comparison.

Table 6.3 Corridor Congestion Statistics
Seattle, Washington, 2000-2003

Corridor	Travel Time Index			
	2000	2001	2002	2003
I-5A, NB (I-405 to I-90 11.13 miles)	1.20	1.32	1.22	1.22
I-5A, SB (I-90 to I-405 11.13 miles)	1.13	1.25	1.17	1.17
I-5B, NB (I-90 to SR 520 2.69 miles)	1.25	1.74	1.53	1.54
I-5B, SB (SR 520 to I-90 2.69 miles)	1.22	1.31	1.24	1.23
I-5C, NB (SR 520 to SR 526 21.39 miles)	1.17	1.33	1.29	1.31
I-5C, SB (SR 526 to SR 520 21.39 miles)	1.22	1.27	1.30	1.36
I-90, EB (S Norman Street (I-5) to Front Street 14.06 miles)	1.08	1.17	1.13	1.12
I-90, WB (Front Street to 12th Avenue (I-5) 14.32 miles)	1.18	1.15	1.16	1.13
I-405A, NB (I-5 S to I-90 9.01 miles)	1.32	1.36	1.30	1.26
I-405A, SB (I-90 to I-5 S 9.01 miles)	1.20	1.30	1.31	1.23
I-405B, NB (I-90 to I-5 N 15.44 miles)	1.23	1.27	1.25	1.17
I-405B, SB (I-5 N to I-90 15.44 miles)	1.26	1.27	1.28	1.22

	Buffer Index			
	2000	2001	2002	2003
I-5A, NB (I-405 to I-90 11.13 miles)	30%	51%	29%	30%
I-5A, SB (I-90 to I-405 11.13 miles)	21%	30%	32%	35%
I-5B, NB (I-90 to SR 520 2.69 miles)	32%	62%	63%	78%
I-5B, SB (SR 520 to I-90 2.69 miles)	36%	37%	29%	25%
I-5C, NB (SR 520 to SR 526 21.39 miles)	21%	35%	32%	33%
I-5C, SB (SR 526 to SR 520 21.39 miles)	38%	33%	43%	43%
I-90, EB (S Norman Street (I-5) to Front Street 14.06 miles)	19%	71%	29%	31%
I-90, WB (Front Street to 12th Avenue (I-5) 14.32 miles)	31%	27%	38%	30%
I-405A, NB (I-5 S to I-90 9.01 miles)	26%	35%	24%	24%
I-405A, SB (I-90 to I-5 S 9.01 miles)	25%	26%	25%	21%
I-405B, NB (I-90 to I-5 N 15.44 miles)	18%	31%	19%	16%
I-405B, SB (I-5 N to I-90 15.44 miles)	24%	22%	31%	24%

Table 6.4 Corridor Congestion Statistics
Atlanta, Georgia, 2000-2003

Corridor	Travel Time Index 2000	2001	2002	2003
I-75A, NB (I-285 to I-20 7.72 miles)	1.09	1.13	1.11	1.14
I-75A, SB (I-20 to I-285 7.36 miles)	1.05	1.10	1.08	1.15
I-75B, NB (I-20 to I-85 Split 3.73 miles)	1.21	1.32	1.30	1.58
I-75B, SB (I-85 Split to I-20 4.04 miles)	1.38	1.66	1.56	1.88
I-75C, NB (I-85 Split to I-285 8.95 miles)	1.11	1.17	1.09	1.11
I-75C, SB (I-285 to I-85 Split 9.63 miles)	1.05	1.09	1.12	1.19
I-85A, NB (Camp Creek Parkway to I-75 4.18 miles)	1.02	1.01	1.01	1.02
I-85A, SB (I-75 to Camp Creek Parkway 4.05 miles)	1.02	1.01	1.01	1.01
I-85B, NB (I-75 to Jimmy Carter Boulevard 14 miles)	1.07	1.16	1.49	1.13
I-85B, SB (Jimmy Carter Boulevard to I-75 13.6 miles)	1.10	1.12	1.09	1.14

	Buffer Index 2000	2001	2002	2003
I-75A, NB (I-285 to I-20 7.72 miles)	21%	29%	33%	35%
I-75A, SB (I-20 to I-285 7.36 miles)	12%	22%	25%	33%
I-75B, NB (I-20 to I-85 Split 3.73 miles)	48%	59%	58%	100%
I-75B, SB (I-85 Split to I-20 4.04 miles)	24%	36%	32%	56%
I-75C, NB (I-85 Split to I-285 8.95 miles)	30%	39%	32%	35%
I-75C, SB (I-285 to I-85 Split 9.63 miles)	13%	29%	42%	50%
I-85A, NB (Camp Creek Parkway to I-75 4.18 miles)	6%	1%	1%	3%
I-85A, SB (I-75 to Camp Creek Parkway 4.05 miles)	7%	8%	5%	8%
I-85B, NB (I-75 to Jimmy Carter Boulevard 14 miles)	22%	49%	19%	23%
I-85B, SB (Jimmy Carter Boulevard to I-75 13.6 miles)	41%	37%	31%	34%

6.2.3 Travel Time Reliability Measures

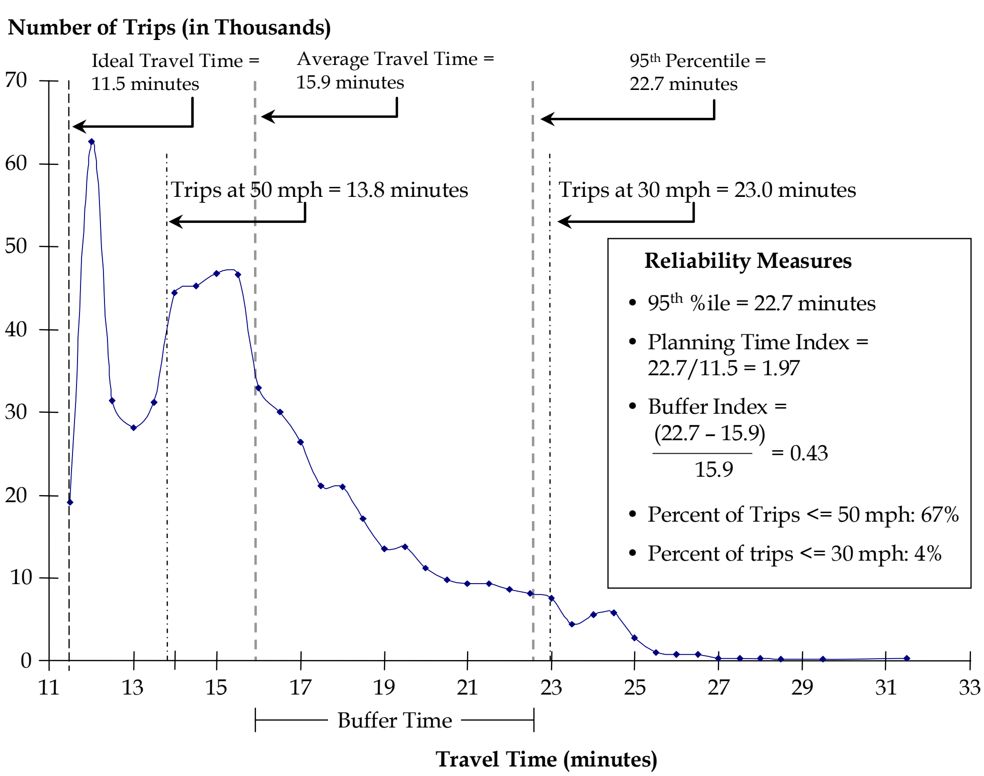
Travel time reliability – how consistent travel conditions are from day-to-day – is now understood as a separate component of the public's and business sector's frustration with congestion problems. (See Section 5.0 for a discussion.) Average travel times and other statistics only tell part of the story. The day-to-day variations in travel conditions pose their own challenges and the problem requires a different set of solution strategies, namely, operations strategies that are keyed to event types (e.g., incident management).

For the two failure-based Supplemental reliability measures, the thresholds are set as the same as for the Core spatial and temporal measures (i.e., 50 mph and 30 mph). Instead of fixing the thresholds, practitioners may choose variable thresholds for additional performance measures. These are particularly useful when used in conjunction with non-freeways measures where the 50 mph and 30 mph speed thresholds are inappropriate. Good examples of this type of measure would be:

Percent of trips (section or O/D) with travel times > ({1.5, 2.0} * average travel time)

The relationship between the variability-based and failure-based measures can be seen in Figure 6.1. Essentially, both types describe the underlying distribution of travel times (what travelers' experiences are over a history) on a section. One way to look at the similarity is that the failure-based measures are another form of percentile describing the distribution. Whereas a percentile fixes the amount of observations on either side of it (e.g., 95 and 5 percent for the 95th percentile) and then selects the travel time for this boundary, a failure-based measure fixes the boundary (travel time, based on a speed threshold) and then determines the percent of observations on either side of it.

Figure 6.1 Distribution of Travel Times and Related Reliability Measures, SR 520 Seattle, Eastbound, 4:00-7:00 P.M. Weekdays (11.5 Miles Long), January–April 2004



Why Multiple Measures Are Needed: The Case of Travel Time Reliability

One of the guiding principles for performance measurement established in Section 5.0 is that multiple metrics should be used to describe each aspect of performance, especially congestion/mobility. Examination of trends in congestion data for a section of I-75 in central Atlanta reveals why. This freeway section (4.05 miles in length) in one of the most heavily traveled (at one point AADT is in excess of 330,000 vehicles per day) and congested in the county. p.m. peak-period data from, 2000, 2002, and 2004 show that both the average congestion level (mean Travel Time Index) and congestion on "bad" travel days (95th percentile Travel Time Index) increased over the period (Figure 6.1). Note that a Travel Time Index of 2.0 indicates that it takes twice as long to travel this section during the peak than it does under free-flow conditions. The increasing 95th percentile provides a general indication that reliability decreased over the period.

Figure 6.2 shows what happens with several other reliability metrics over the period. The Buffer Index initially increases in 2002, then decreases slightly in 2004. Why? Because it is measured relative to the mean travel time, and that increased over the period. This tells us something valuable though, namely, that the extreme days are not increasing as quickly as the base level of congestion. In theory, this would indicate that the events that cause extreme travel times (e.g., incidents, bad weather, work zones) are being controlled better but at the same time increasing traffic volume is causing growth in the base congestion level. In fact, operations strategies did grow more aggressive over the period (based on subjective conversations with NaviGAtor personnel) and traffic did grow.

Two failure-based reliability measures are also shown: percent of trips that occur at speeds less than 30 mph and 50 mph. The percent of trips at speeds less than 50 mph was stable over the period, but the percent of trips less than 30 mph grew. These metrics indicate a problem with using threshold-based measures: what they show is largely dependent on what the threshold is. The percent of trips less than 30 mph tells us the same thing as the 95th percentile: that the extreme days are getting worse. However, even this measure supplies a limited amount of information; another problem with failure-based metrics is that they are binary: either a trip; is reliable or it is not. They tell you how badly a trip failed. For example, trips at 29 mph and 3 mph both "fail" but one is clearly a lot worse than the other.

So, did reliability improve or worsen over the period? The 95th percentile and the failure-based metrics are "pure" (not normalized) and show that reliability from the traveler's perspective did indeed worsen. The Buffer Index indicates that part of this worsening reliability is due to the increase in base level congestion, and this increase was more pronounced than the increase in the extremes. Given the need to understand reliability patterns in depth – and the fact that all of these metrics are computed from the same data – it is clear that multiple metrics for reliability are the desired path.

Why Multiple Measures Are Needed: The Case of Travel Time Reliability (continued)

Figure 6.2 I-75 Southbound
Central Atlanta – Congestion Trends

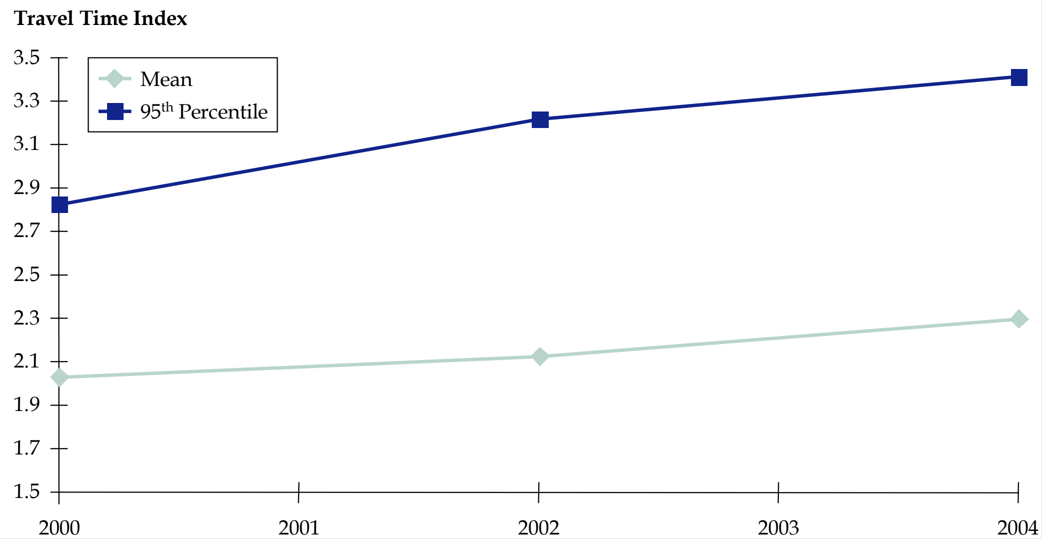
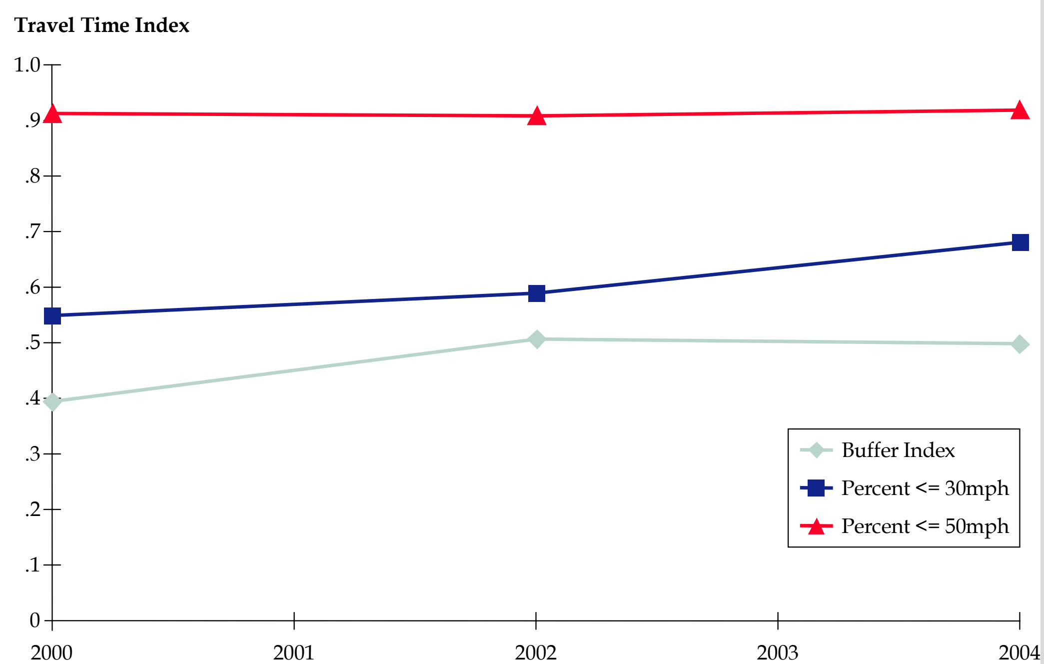


Figure 6.3 I-75 Southbound
Central Atlanta – Reliability Metric Comparison



6.2.4 Congestion: Contributing Factors Measures

In addition to measuring congestion itself, the contributing factors to congestion also should be measured. These are the features and characteristics related to the sources of congestion as presented Section 5.0.

- **Capacity-Related Bottlenecks –** Two categories are identified for ongoing monitoring.

    1. Geometric Deficiencies Related to Traffic Flow (Potential Bottlenecks). These are areas of geometric constraint that have the potential to be bottlenecks if demand volumes are high enough. Bottleneck types are:

        – Types A-C weaving areas (see HCM and Section 7.0);

        – Left-hand exits;

        – Freeway-to-freeway merge areas;

        – Surface street on-ramp merge areas;

        – Acceleration lanes at merge areas < 300 feet;

        – Lane drops;

        – Lane width drops >= 1 foot;

        – Directional miles with left shoulders < 6 feet[7];

        – Directional miles with right shoulders < 6 feet;

        – Steep grades; and

        – Substandard horizontal curves.

    2. Major Traffic-Influencing Bottlenecks. Locations along a freeway section that control traffic flow during peak periods and are the major source of recurring congestion on the section. Most freeway sections (typically 2 to 10 miles in length) will have a single "controlling" bottleneck – these are the ones that should be noted for this category. (The "Geometric Deficiencies" category will capture other potential or secondary bottlenecks.) In urban areas, these are usually freeway-to-freeway interchanges and areas where a lane is loss ("lane-drop"). Occasionally the major bottleneck that dominates traffic flow will be an interchange with a surface street or a series of closely spaced surface street interchanges.

- **Traffic Incident Characteristics –** The number, type, and duration of traffic incidents.

[7] The shoulder categories are included because of the ability of more than six-foot shoulders to shelter vehicles during traffic incidents.

- **Work Zone Characteristics –** The number, type, and duration of work zones.

- **Weather Characteristics –** The duration, extent, and severity of weather events.

6.2.5 Throughput Measures: Vehicles and Persons

One of the most fundamental measures of freeway performance is throughput, or the amount of users being "served" by the system per unit of time (e.g., per hour, per day). Consistent with the principles laid out in Section 5.0, the throughput of both vehicles and persons on the freeway should be measured. While throughput measures alone do not indicate the quality of the service being provided, they are highly useful as supplemental and explanatory measures. For instance, congestion may grow on facility as a result of increased demand; throughput measures capture the increase in demand.

Vehicle-miles of travel (VMT) has a very long history of use in the transportation field and is widely used as a throughput measure. It is also the basis for constructing crash rates. It is the single most important measure of throughput.

6.2.6 Safety Measures

Safety is an extremely important aspect of freeway performance. Crashes, type of crashes, and their consequences (severity) should all be measured. Secondary crashes – crashes that occur in the presence of, or are influenced by, a previous crash – also should be measured.

With the SAFETEA-LU requirement for Strategic Highway Safety Plans (SHSPs), safety is becoming a major emphasis for transportation agencies. The SHSP is intended to:

- Establish safety-related goals, objectives, and performance measures relevant to a list of high priority emphasis areas;

- Address issues at all levels of jurisdiction;

- Identify both current and future candidate safety actions and evaluate their potential benefits, costs, and ability to attain defined performance objectives;

- Establish a mechanism for interagency coordination with respect to safety issues and develop the necessary partnership agreements;

- Carry out a program of public outreach and education in support of the SHSP; and

- Establish a process for evaluating progress towards the SHSP's goals and objectives and updating the plan to reflect progress or changing needs.

Performance measures play a key role in the SHSP process. High level outcome (quality of service) measures can be applied both statewide and on individual facilities and facility types (e.g., total crashes, total fatalities, fatal crash rate). Safety performance measures that "drill down" further will be dependent on what the most significant problems are in a state or on a facility. For example, a state might decide that their run-off-road (ROR) crashes are excessively high, so it may construct performance measures to monitor trends in this type of crash. Note that run-off-road crashes may not be a problem on freeways but perhaps on rural two-lane highways (depending on the local circumstances). Likewise, commercial vehicle crashes (recommended here) may primarily be a problem on freeways. Ever case is different, and agencies are encouraged to use some experimentation in establishing safety performance measures.

Some example of lower level safety performance measures include:

- Ratio of alcohol-related fatalities to all fatalities;
- Number of citations and convictions for impaired driving;
- Safety belt use rate;
- Proportion of unbelted fatal and serious injury victims;
- Percentage of fatal and serious injury crashes that are related to young drivers, pedestrians, bicyclists, motorcyclists, distracted and aggressive drivers, and trucks;
- Number of fatal and serious injury crashes related to roadway departure;
- Ratio of fatal and serious injury crashes related to roadway departure as a percentage of all such crashes;
- Number of fatal and serious injury crashes related to intersections; and
- Ratio of fatal and serious injury crashes related to intersections as a percentage of all ROR crashes.

6.2.7 Operational Efficiency Measures

Operations is becoming a major thrust of transportation programs in the area of operations, and a large share of operations strategies is geared to freeways. Monitoring the activities and equipment used in operations is, therefore, a major feature of freeway performance measurement. The operational efficiency measures recommended here are but a fraction of those that can be developed – agencies are encouraged to expand beyond these depending on the type of equipment deployed and their operating policies. Additional operational efficiency performance measures for consideration by agencies include such metrics as:

- Device/software module uptime percentage (uptime divided by total time);
- Calls sent to Information Technology Helpdesk;
- Helpdesk calls outstanding;

- Helpdesk calls closed;
- Number of TMC Web Site Visitors;
- DMS message duration; and
- DMS Message posting time.

6.2.8 Ride Quality Measures

Highway users frequently cite ride quality, as determined by the physical condition of pavement and bridge surfaces, as an important aspect of traveling. Further, poor surface quality can lead to congestion (lower speeds and higher densities lead to lower base capacities) and crashes (poor skid resistance). Pavement and bridge management systems have a long history with ride quality measures, both outcome (quality of service) and output (activity-based).

6.2.9 Environmental Measures

Many environmental consequences result from freeway usage. However, the *Guidebook* only touches on air quality and fuel use aspects. The recommended environmental performance measures are all model-derived rather than measured quantities. They are focused at the level of the highway system rather than their ultimate consequence (e.g., number of premature respiratory deaths) because of the difficulty in separating out highway-related emissions from other emission sources.

6.2.10 Customer Satisfaction Measures

The private sector relies heavily on customer satisfaction as a major indicator of company performance. As transportation agencies adopt more of a customer focus, they too need to obtain feedback from travelers on how well travelers perceive freeway performance. One potential problem is that narrowing customer satisfaction to just freeways is difficult; travelers usually think in terms of entire trips – which encompass many roadway types, not just freeways.

Customer satisfaction is a measure of the perception of users of a service or product. Customer satisfaction is most commonly measured by surveys that ask users to describe the usefulness or adequacy of a product or service.

In the case of operations services provided, customer satisfaction should measure the usefulness of and knowledge of services such as traveler information and roadway service patrols. In specific geographic locations, other services or activities like ramp metering or electronic toll collection also could be measured. In other state DOT operations programs (i.e., Georgia, Washington State and Minnesota) customer satisfaction surveys have been conducted to ask the traveling public about such program elements as service patrols, ramp metering, DMS messages, HAR messages, 511 telephone service and traveler information web sites. The survey will often ask participants a series of questions such as:

- Are they familiar with the service;
- Have they used the service;
- Are they satisfied with the service;
- Did they find the service useful;
- Did they know certain services were available;
- Did they find messages to be understandable;
- Would they likely use a new service that is to provided in the future; and
- How do they typically obtain traveler information?

6.3 Basic Parameters for the Performance Measures

6.3.1 Defining Sections

Under the "Geographic Scale" heading, the reader will note that the term "section" is used. This term is defined more explicitly in Section 9.0, but in summary, a freeway section is a continuous stretch of freeway where travel patterns are relatively unbroken by major access and egress points. The endpoints of a section may be defined by major landmarks; destinations (e.g., the CBD or regional mall); and major interchanges, especially freeway-to-freeway interchanges. Experience has shown that typical section lengths are in the order of three to six miles, but substantial variation exists.[8]

6.3.2 Selecting Peak Hour and Peak Periods

Many of the recommended congestion measures require fixing the time periods of which congestion is monitored. Determining the peak hour is the least difficult of these, since we already have determined its length. The traditional definition of "peak hour" is the hour for which demand (volumes) for use of a facility is the highest. However, on congested freeways, it is difficult to base this decision on volumes, since observed volumes will be lower than capacity during times of congested flow. Therefore, it is recommended that the peak be defined in terms of the worst congestion, as measured by the highest travel times or one of its variant measures.

[8] http://mobility.tamu.edu/mmp.

In some cases, traditional peak hours have been selected from hourly volume data that begins on the hour and ends on the hour (e.g., 5:00 p.m. to 6:00 p.m.). Yet, there is no reason why this should be the case, and with the availability of freeway surveillance data with a high degree of temporal detail, it is easy to ***construct the peak hour as the continuous 60-minute period with the worst average travel time performance over the course of a year in both directions of travel***. In fact, identifying that the peak is "off the hour" is valuable piece of information to communicate to the public and demonstrates that professionals are aware of congestion patterns. If detailed data are not available to make this determination, then professions should use their judgment as to when the peak begins and ends. In addition, other recommendations are made:

- Peak hours should be computed for each freeway section individually. This allows for the fact that the peak is different on some freeways. For example, a freeway section adjacent to a CBD may peak earlier in the afternoon than one in the exurbs – it takes a while for CBD employees to get to the exurbs.

- Peak hour definitions should be revisited by analysts every three years to account for changes in travel patterns.

The same rules apply for defining the morning and afternoon weekday peak periods (referred to as a.m. and p.m. peaks in Tables 6.1 and 6.2). However, there is a complication – how long should the peak period be? It makes a difference. Set it to long and uncongested flow will dilute the congestion statistics. Set it too short and congested flow on the fringes will not be captured. However, since the recommendations in Tables 6.1 and 6.2 call for multiple congestion measures, this problem is not a large problem since information from the other measures can help explain the congestion picture, especially when used side-by-side with measures for the peak hour. Final selection of the length of the peak period is subject to local knowledge, but ***in general, three-hour periods in both the morning and afternoon should be defined as the peak periods for most freeways***. In smaller urban areas or areas with light congestion, two-hour periods may be more appropriate. In larger urban areas, four-hour periods might be considered.

6.3.3 Determining Ideal Travel Conditions (Free-Flow Speed)

Congestion is a relative term – it must be measured against a benchmark. The amount of congestion is then the size of deviation from the benchmark. Traditionally, the benchmark is chosen to represent ideal travel conditions; in engineering terms, this is the "free-flow speed": the speed at which vehicles would travel under very light volumes (only a few vehicles on the road, traveling unimpeded by other vehicles). This *Guidebook* also uses this basic definition.

However, determining what the free-flow speed should be for monitoring congestion and selecting projects is tricky. With direct speed measurements,[9] it is not difficult to determine free-flow speed; Figure 6.4 shows some of these data for a section of I-75 in Atlanta. Free-flow speed is obtained by considering a subset of the continuously collected speed data that has been summarized to the hourly level and is confined to a region defined by:

- Speeds greater than 50 mph (this eliminates speeds during forced or transitional flow);
- Volumes less than 1,000 vehicles per hour per lane (vphpl); and
- Daylight hours only.

For this section, the data indicates that free-flow speed is roughly 68 mph, the 85th percentile speed for low-volume conditions. Technically, that is correct. But should we consider that congestion begins when speeds drop below 68 mph, say, to 60 mph? Further, the speed limit on this section happens to be 55 mph, so the free-flow speed is noticeably higher, raising the question of whether the free-flow speed (the ideal) should be something that is illegal! On the other hand, if the actual free-flow speed is higher than the speed limit, do we consider speed enforcement to be a source of delay?

One way around this problem is to establish a uniform free-flow speed that represents uncongested flow across all freeways, for example, 55 or 60 mph for urban conditions and 65 or 70 mph for rural conditions. Free-flow speed may also be determined analytically. The Highway Capacity Manual recommends direct measurements if available. If not, it computes freeway free-flow speed from a base (70 mph for urban and 75 mph for rural), and reduces the base for the influencing factors of lane width, right-shoulder lateral clearance, number of lanes, and interchange density. NCHRP Report 387 recommends a regression equation developed by the FHWA based on speed limit alone:[10]

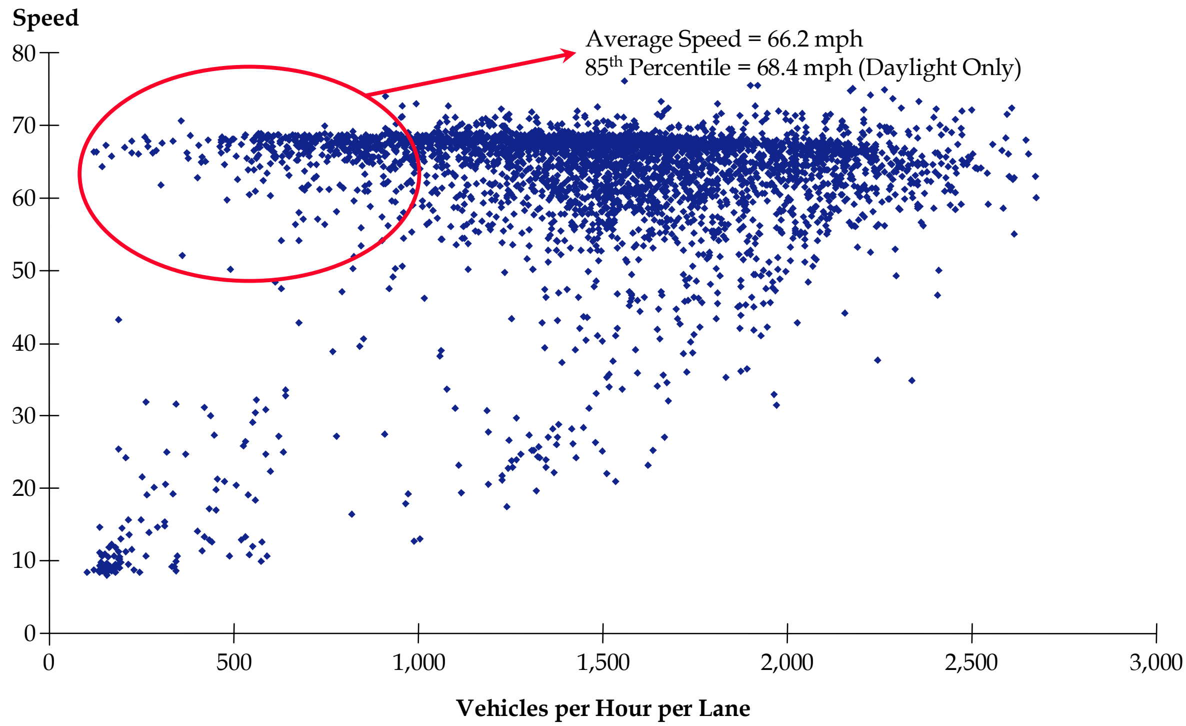
$$FreeFlowSpeed = (0.88 * SpeedLimit) + 14 \quad (1)$$

Note that free-flow speed is always higher than the speed limit: for a speed limit of 55 mph, the free-flow speed is 62.4 mph; and for a speed limit of 65 mph, it is 71.2 mph.

[9] Many older freeway surveillance systems use single-loop in-pavement detectors. These only provide direct measurements of volume and lane occupancy; speed is then computed with locally derived equations which include an assumption on vehicle length and a calibration factor. Depending on how these equations are implemented, it may not be possible to estimate free-flow speeds from such data.

[10] Dowling, R., et al., *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, NCHRP Report 387, Transportation Research Board, 1997.

Figure 6.4 Using Freeway Detector Data to Estimate Free-Flow Speed
I-75 Northbound, Atlanta



Despite the difficulty in establishing the free-flow speed, the previous discussion indicates that it lies in narrow range relatively close to the speed limit. The problem with using speed limit to establish free-flow speed, in conjunction with measured data, is that it provides very inconsistent and arbitrary results. Consider a vehicle traveling on a freeway with uniform design and congestion characteristics at 60 mph with a posted speed limit of 55 mph. Technically, it is speeding, but this is reality in most urban areas. As it approaches the urban fringe, the speed limit changes to 65 mph. Under the speed limit definition of free-flow speed, on the 55 mph posted section, this vehicle incurs no delay, yet on the 65 mph section, it does. Note that this is a problem only when using direct measurements – if congestion is estimated with models, then free-flow speed is always considered the maximum speed for a section, so it does not matter what its value is.

The debate over establishing free-flow speed is obviously not purely a technical matter, but a political one as well. As a compromise, the following recommendation is made: ***the free-flow speed should be set at the lower of 1) the 85th percentile speed that occurs under low-volume conditions, or 2) the speed limit***. Using this approach will most probably miss counting a small amount of extra travel time that would be perceived as a penalty even though the freeway lanes are not operating at slow speeds. For example, if the speed limit is 55 mph, but the 85th percentile speed is 63 mph, then vehicles traveling at speeds in the interval between them would not be counted as being delayed; whereas, in a traditional engineering approach, they would be considered delayed. However, since most delay on freeways occurs during saturated conditions characterized by queuing, this small amount of delay is not considered to be significant.

Note that this recommendation is convenient for freeways when measuring congestion. Other freeway applications may require alternative definitions for freeway free-flow speed. Free-flow speeds on nonfreeways should not be established with this procedure, even for the purpose of congestion measurement.

6.3.4 Recurring/Nonrecurring Delay versus Delay by Source of Congestion

Traditionally, transportation engineers have broken delay into two components: 1) recurring delay (delay that happens in roughly the same place and time with roughly the same magnitude every weekday) and 2) nonrecurring delay (delay that happens in unexpected places and times). As discussed in Section 5.0, this *Guidebook* takes this a step further by defining specific sources of delay. The reason for this is that the recurring/ nonrecurring model is too simplistic – congestion never happens in the same way every day because of the complex interaction of the sources (e.g., physical capacity, incidents, and variable traffic demand). Section 5.0 presents a complete justification for going the extra step in defining congestion by source. Section 8.0 provides methods to estimate delay by source of congestion.

Under the NTOC definition, recurring delay is defined as the delay that occurs under "normal" traffic conditions in the absence of events. This is equivalent to this *Guidebook's* identification of bottleneck delay. NTOC defines nonrecurring delay as the difference between total delay and recurring delay, and is equivalent to the sum of weather, incident, work zone, and demand-related delay used in this *Guidebook*.

6.4 Incorporating Costs into the Recommended Freeway Performance Measures

Costs for freeway programs and improvements have not been incorporated into the recommended sets of performance measures. However, consideration of costs is extremely important in making investment decisions, especially at the project level (i.e., deciding among alternatives). The *Guidebook* did not develop cost-based performance measures as part of the formal recommendations, because performing economic analyses of transportation projects is complex and the subject of many other documents.[11] Further, developing cost-based performance measures (other than just actual expenditures) for ongoing monitoring purposes can be misleading because of year-to-year variations in investments and the fact that the benefit stream continues into the future.

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[11] For example: http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer05.htm and *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (Second Edition)*, AASHTO, 2004.

If an agency wishes to develop cost-based freeway performance measures, the most useful measures for ongoing performance monitoring are probably those related to ***cost-effectiveness***. Simply put, these are ratios of dollars expended divided by impact/ outcome. For example, consider a set of alternatives aimed at improving safety on a freeway. Estimates (based on models rather than measurements) of both the cost of the improvement (both initial capital and maintenance/operating costs) and the expected reductions in crashes over a time horizon (20 years is typical) can be made, so that the performance measure (or, measure of effectiveness) is "dollars per crash reduced." This provides a basis for comparing project-level alternatives. A similar approach can be taken for congestion mitigation strategies, except the measure might be "dollars per hour of delay reduced." In fact, nearly all of the measures presented in Tables 6.1 and 6.2 can be recast as cost-effectiveness measures in a similar way; this is particularly true for operation efficiency measures. Some further examples would include:

- Service patrol annual cost per incident response; and
- Pavement rehabilitation cost per percent increase in PSR.

Using the same measures for evaluations of completed projects becomes more problematic. Usually we are interested in what actually occurs, rather than relying on model estimates. In one sense, this is what we really need to know, yet in another sense, using direct measurements means that other factors become an influence beyond the idealized world of models. For example, in examining the before and after improvement time periods, background conditions, most notably travel demand (e.g., VMT) will change. In the case of safety improvements, year-to-year fluctuations in crashes can be quite large, leading to the well-documented "regression-to-the-mean" phenomenon.[12] In all these cases, controlling for changes in background conditions is required. This means that rather complex forms of analysis are required, and simply computing cost-effectiveness measures from direct measurements is highly misleading. Extending this concept to the system or network level for ongoing performance monitoring suffers the same problems of trying to control for the influence of external factors.

6.5 Setting Performance Targets

Once performance measures are selected, the next step is to set performance targets – values for specific measures that an agency was to achieve in a certain timeframe. There are several approaches to setting these targets that agencies may wish to follow.

1. **Do not set targets.** A simple approach is not to set performance targets for ongoing performance monitoring, alternatives analysis, or project evaluations. Rather, the changes from time period to time period (for ongoing monitoring and evaluations) and

[12] Hauer, E., *Observational Before-After Studies in Road Safety*, Pergamon Press, 1997, ISBN 0-08-043 053 8.

among alternatives are used to indicate performance: "are things better or worse?" This is clearly a good starting point for agencies even if they want to set targets later; it allows them to get use to the process, data development, and communication.

2. **Set "hard" targets or "percent change" targets that are considered to be achievable in the short term.** Fixing target numbers or specifying annual changes is a more complex situation for agencies. This is chiefly a consensus building process with input being provided from a number of sources, including professionals and elected officials, and in some cases the public. In doing so, agencies will want to follow a multi-step process:

    a. Examine recent trends in the performance measure being considered for a target. Look at the rate of change and any unusual circumstances that might have influenced the change. This analysis alone will go a long way toward telling an agency what is achievable, and more importantly, what might be acceptable to the public and elected officials. For congestion/mobility performance, the data in Tables 6.1 and 6.2 provide recent performance characteristics for freeway sections in Seattle and Atlanta. Many more cities also have had their performance quantified as part of FHWA's Mobility Monitoring Program; these can also guide practitioners in this area.[13]

    b. Extrapolate recent trends in the future. Using models or expert judgment, forecast what the performance measures would be under several scenarios: "do nothing," "business as usual," "maintain current conditions," and "aggressive action" are four such scenarios that can bound the possible outcomes. Along with examining the recent past, this provides additional information to be used in the consensus building process.

    c. Look at the performance of peers. If information is available nationally or from other agencies individually, it can be used to help determine targets. Even within an area with varying conditions, this is a useful approach. If congestion is light on one freeway, and it is agreed that this condition is desirable, then its performance standard could be used on other freeways in the area. In either case, having a tangible example that professionals, the public, and elected officials can relate to provides a common basis for consensus on what a target should be. It should be pointed out that peer data for most of the recommended performance measures is highly lacking. On a national scale, the Texas Transportation Institute's annual *Urban Mobility Study* provides areawide statistics for urban areas using the travel time index and delay measures.[14] FHWA's Mobility Monitoring Program Annual Report provides congestion and reliability statistics for individual freeway sections in many urban areas.[15] For crash statistics, data from the National Highway Traffic Safety Administration may be used (including the Fatality Analysis Reporting System {FARS} and General Estimates System) may be used, but published

[13] http:/mobility.tamu.edu/mmp; see the "city reports."

[14] http:/mobility.tamu.edu.

[15] http:/mobility.tamu.edu/mmp.

summaries do not include freeway breakdowns by state.[16] The FHWA publication series *Highway Statistics* does present such a summary, derived from FARS.[17] However, finding data on other categories of performance – and determining what is a "good" or "acceptable" level of performance is nearly impossible. Some data do exist within individual agencies, but up to now there has been no standard definition of performance measures, how they are calculated, and what data are used to support them. This is clearly a gap that should be filled in by future research.

d. Look at the performance of nonpeers with bigger problems. Consider the case of a small city undergoing rapid growth and the resulting growth in congestion. Examination of the current condition of a larger city in the State or region whose conditions are familiar could reveal an upper bound for a target: "in 10 years, we do not want to be any worse than our larger cousin is today."

e. Drill down into your output (activity-based) measures and estimate what the effect of changes in these low-level performance measures will have on the outcome-based targets. (This is an important use for the performance measure structure recommended in Chapter 5, under Principle 7). For example, consider a congestion target that states that congestion level will be held constant over the next 10 years in the face of 2 percent annual traffic growth. Models and examining past performance can be used to make estimates of the overall congestion effect of improving certain activities, for example:

- Reducing average incident duration by 10 percent over the period;
- Reducing the number of required work zones by 5 percent by using thicker pavement overlays (thereby reducing the number of times a highway section must be rehabilitated); and
- Elongating an on-ramp at a known bottleneck.

f. Iterate under closure. Because performance targets will be arrived at by consensus, several passes through the process will be necessary.

3. **Set "stretch goal" targets.** Considered by some to be unrealistic, stretch goals nonetheless provide vision, direction, and motivation for agencies. An example of a stretch goal is eliminating all roadway fatalities, as proposed by some European nations. Stretch goals require a level of commitment and funding not widely available for most U.S. public agencies and must be instituted with caution.

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[16] http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/.

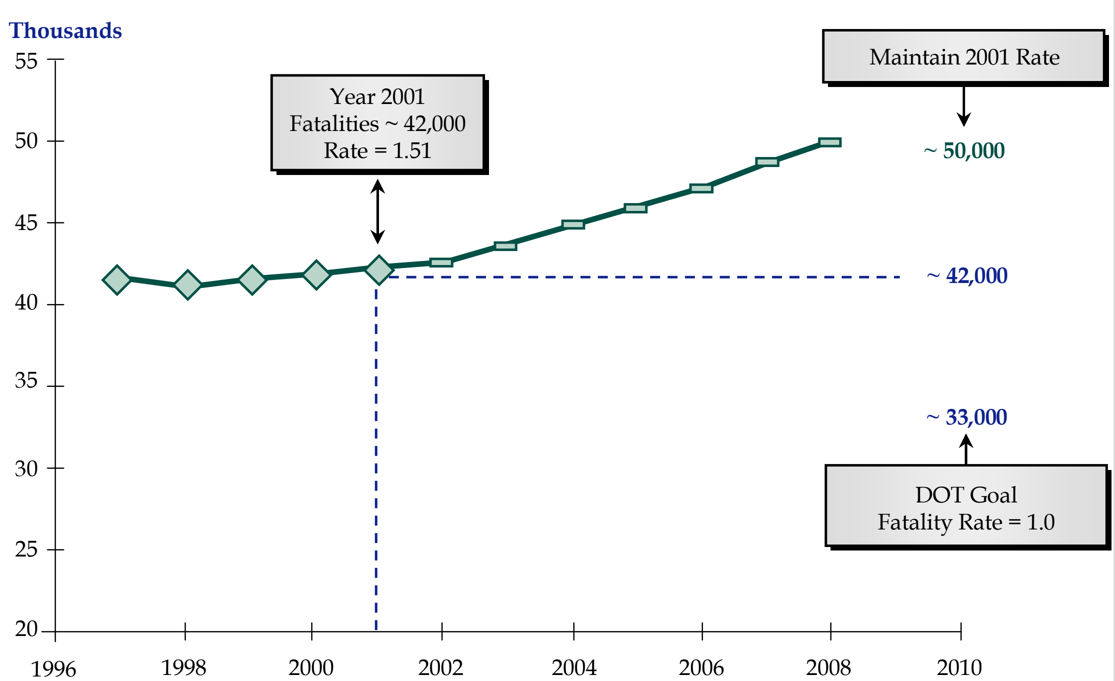
[17] http://www.fhwa.dot.gov/policy/ohim/hs03/re.htm.

Examples of Using Data to Help Set Performance Targets

U.S. DOT 2003 Performance Plan: Highway Safety

Beginning around 2000, Federal agencies have been required to develop performance measures and plans in accordance with the Government Performance and Results Act (1993). Highway safety is a major initiative for both NHTSA and FHWA, and a single performance target related to reduction in highway fatalities was desired for the country. At the time of development, data were available through 2001: about 42,000 fatalities and a fatality rate of 1.51 per MVMT (Figure 6.5). Because VMT was expected to grow by roughly 2 percent per year, if the current fatality rate stayed constant, by 2008, 50,000 fatalities could be expected. Several analyses were conducted to determine what would result if the fatality rate were lowered by different amounts. Figure 6.5 shows the final one chosen: 1.0 fatality per MVMT. Because of the growth in VMT, this translates into a ***target of a 20 percent reduction in highway fatalities between 2001 and 2008***. Note that in order to achieve this target, the fatality rate has to be dropped by 34 percent because of the growth in background VMT.

Figure 6.5 U.S. DOT Performance Target Setting for Highway Fatalities



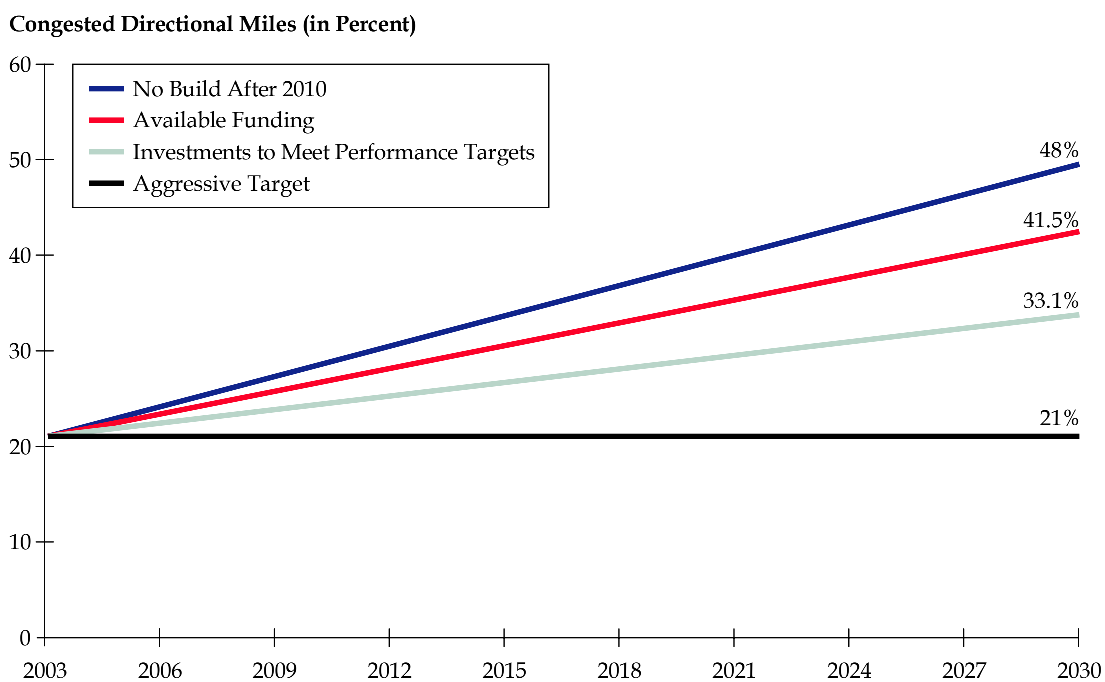
Source: Federal Highway Administration, *Fiscal Year 2003 Performance Plan*, September 2002.

Examples of Using Data to Help Set Performance Targets (continued)

Minnesota DOT (Mn/DOT) Transportation System Plan

Mn/DOT also used to data and analysis to develop performance targets for many categories, including pavements, bridges, safety, and mobility. Because there is little precedent within the department (or in any DOT for that matter) for developing performance targets, Mn/DOT's efforts to date must be viewed as a "work in progress" that is likely to change as more is learned. For freeway mobility, Mn/DOT extrapolated its primary mobility performance measures (percent of congested directional miles) out to 2030 (Figure 6.6) under several different investment scenarios. Two targets were initially set: an aggressive and moderate target. The aggressive target would maintain current congestion levels at 21 percent of the system, but would require resources beyond any reasonable funding scenario. The moderate target was ultimately selected which limits the increase in congestion to 33.1 percent by 2030.

Figure 6.6 Mn/DOT Use of Extrapolation as an Aid in Setting Mobility Performance Targets



Mn/DOT also provides specific guidance for setting performance targets across the whole time horizon. Mn/DOT has found that performance targets are most easily developed and agreed upon when the time horizon is in the medium or long-range frames. These have proven to be helpful in calculating resource gaps and stimulating new strategies. Given the time required to undertake many transportation projects, annual or quarterly targets are subject to too much uncertainty.[18]

DEFINITIONS

Statewide Transportation Plan Target (long-range: 20-, 10-, 6-year)

The level of service (performance on the measure) that Mn/DOT aims to achieve based on a balance of policy and customer expectations. Unconstrained target may be based on a reasonably achievable funding scenario. May require substantial new resources or changes in strategies and business practices.

Highway System Operations Plan Target (4-year horizon)

The level of service (performance on the measure) that Mn/DOT aims to provide in specific years of the Operations Plan – FY 2006, 2007, 2008, 2009. Two scenarios – performance-based unconstrained and fiscally constrained. Defines the gap we would seek to close if adequate resources or strategies become available.

Business Plan Target (2 years)

The level of service (performance) that Mn/DOT intends to deliver in specific years of two-year budget, such as FY 2006 and FY 2007. Defines how much of the gap between the long-range customer-based target and current performance we will fill in the next biennium with a given level of resources

Statewide Transportation Plan or District Plan Target (20+ years)

The level of service that Mn/DOT aims to achieve based on a balance of policy and customer expectations. Unconstrained target may be based on a reasonably achievable funding scenario. May require substantial new resources or changes in strategies and business practices.

STEPS IN ESTABLISHING A TARGET FOR A MEASURE

1. Collect baseline performance data (current and recent periods) and project it out to over your planning period.

2. Draft a target for what we should aim to deliver over the four-year planning period of the Highway Systems Operations Plan. Base the target on a balance of customer expectations and sound engineering and life-cycle costing considerations.

[18] Conversation with Mark C. Larson, Office of Investment Management, Mn/DOT.

6.6 Considering Off-Freeway Impacts

While the focus of this *Guidebook* is on the performance of freeways, freeways cannot be viewed in isolation: they are part of a larger highway system which, in turn, is part of the environment in which the public interacts. For instance, improvement in freeway performance, particularly congestion, will be one of the many factors influencing development patterns and economic growth of an area. The interactions here are complex, but several models have been developed to quantify the larger impacts of congestion improvement (i.e., travel time or delay savings) on the larger land use and economic environments.[19] Guidance on how to use these models is provided elsewhere and not repeated in this *Guidebook*, but the basic inputs to these models (i.e., the performance measures specified here) are the starting point for using these models.

Still, there are situations that those engaged in freeway performance measurement need to be aware of in constructing their programs:

- **Queues from freeway on-ramps.** Queues may form on both metered and nonmetered ramps from vehicles trying to enter a congested freeway. The queues may spill back beyond the ramp onto adjacent local streets. One of the Supplemental performance measures (ramp delay) is meant to capture this effect, but estimating it is problematic. If the metering rate is known, then delay for the vehicles entering the freeway can be computed over a length of time. What is difficult is estimating the delay these vehicles cause to other (nonfreeway-destined) vehicles on adjacent local streets. Direct measurement of this delay is impossible – the only recourse is to use an analytic method (e.g., highway capacity analysis or simulation model) to derive it, if in fact it is large enough to be warranted. A crude approach would be to:
  - Estimate the number of vehicles trying to enter the freeway per time period (e.g., vehicles per hour);
  - Subtract out the amount that would be stored on the ramp to derive spillback volume; and
  - Perform analysis on the adjacent street with and without the spillback volume.
- **Delay at ramp termini.** Signals are extremely common at intersections of urban freeway off-ramps and local streets. While backups onto the mainline will be reflected by measurements taken on the mainline (except for the small number of vehicles stored on the ramp itself), the demand for approach capacity (“green-time”) by exiting traffic may cause congestion on the local street (which is usually an arterial).

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[19]For example: The *UrbanSim* simulation model for integrated planning and analysis of urban development, which incorporates the interactions between land use, transportation, and public policy (http://www.urbansim.org/) and the *REMI TranSight* model for estimating total economic effects of transportation improvements (http://www.remi.com/).

- **Traffic diversions due to abnormally high congestion.** When freeway congestion is unusually high (usually due to an extreme event like a major incident or work zone), some traffic may divert off of the freeway. In some cases, operations strategies may encourage this by alerting travelers through dynamic message signs or other forms of traveler information. Diversion causes two problems from a measurement perspective. First, it removes demand for the freeway causing congestion measures to indicate less severe congestion than if no diversion occurred. Second, since urban networks have little spare capacity during peak hours and rural networks are sparse (causing circuitous trips), the "missing" freeway delay will show up on nonfreeways. Research has not been done on this topic, but one approach explored by the research team for this *Guidebook* is the development of a Traffic Demand Indicator for freeways with continuous surveillance data available. The Traffic Demand Indicator provides a measurement of how much higher or lower traffic is than "normal." It may be included as one of the formal performance measures that agencies track and report, but it is more useful as one of the background statistics used to explain changes in the formal measures. (It is very useful in helping understand congestion by source; see Section 8.0 for details. It also can be used in conjunction with the NTOC "recurring delay" measure.) It can be computed as follows.

  – Define a.m. and p.m. time periods for nonholiday weekdays, then add an hour to the beginning and ending of each peak period. Call these the "peak+shoulder time period." (If the a.m. peak is from 7:00 to 9:00, then the a.m. time period for analysis is from 6:00 to 10:00.) The reason for this is to be able to measure traffic demand that may have been queued in and around the peaks.

  – For the past 365 days (more or less), compute the average traffic volume in each peak+shoulder time period for two cases: 1) all nonholiday weekdays, and 2) each day of week individually for nonholiday weekdays.

  – For a given day, compute two Traffic Demand Indicators using the previous averages as denominators and the actual traffic for that day and peak+shoulder time period as the numerator.

  – In the case where the surveillance system has a lot of missing data, it is likely that the overall weekday indicator will be more reliable.

Figures 6.7 and 6.8 shows examples of the Traffic Demand Indicator (all weekdays as the denominator) for the p.m. peak+shoulder time period for sections of I-405 in Seattle and I-75 in Atlanta. The p.m. peak period in both of these cities is typically defined as the three hours from 4:00 p.m. to 7:00 p.m., so the peak+shoulder period is from 3:00 p.m. to 8:00 p.m. A value of 1.0 means that traffic volume for that day equals the average weekday volume.

Figure 6.7 Traffic Demand Variability
I-405, Seattle, Northbound, Weekdays, January 2-April 30, 2003

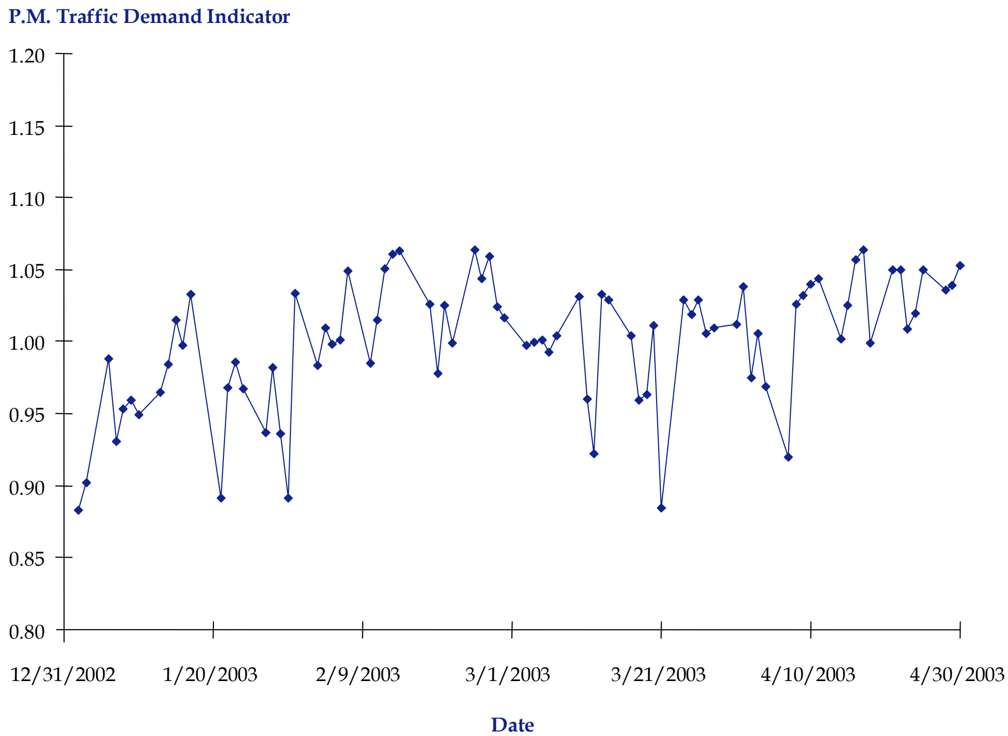
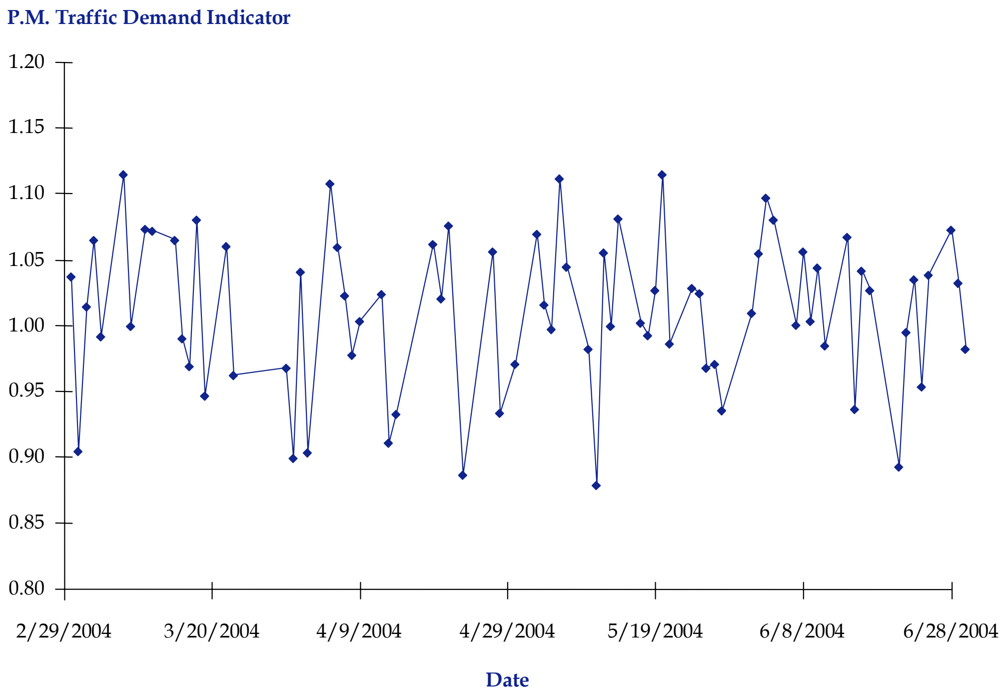


Figure 6.8 Traffic Demand Variability
I-75, Atlanta, Northbound, Weekdays, March 1-June 30, 2004



6.7 Modeling versus Measurement for Developing Performance Measures

6.7.1 Overview

This section provides an overview of modeling techniques that can be used to estimate congestion-related performance measures; Section 8.0 provides more details. Modeling tools can be classified into four major categories:[20] sketch-planning tools; travel demand models, analytical deterministic techniques (e.g., Highway Capacity Manual); and simulation models. The choice of the particular tool[21] depends on the several criteria, including analysis context, size of the study area, facility types to be modeled, travel modes to be included in the analysis, types of management strategies to be evaluated, performance measures to be estimated, traveler responses to be analyzed, and overall tool cost-effectiveness.

6.7.2 Sketch-Planning Methods

Sketch-planning methodologies produce approximate estimates of travel demand and transportation performance measures for preliminary analysis of transportation improvements. Sketch-planning methods use simplified analytical relationships and aggregated data. For example, average speeds are calculated based on the volume-to-capacity (v/c) ratio of the segment under study. Sketch-planning techniques are the simplest and least costly of the modeling tools.

6.7.3 Travel Demand Models

Travel demand models (often called four-step models) simulate the trip making behavior into four sequential steps: 1) trip generation, 2) trip distribution, 3) mode choice, and 4) traffic assignment. Travel demand models were originally developed to determine the impact of highway improvements in metropolitan areas.

Travel demand models produce estimates for link volumes and average speeds for each link of the network. The estimated speeds, however, are not accurate for traffic operations analysis or evaluation of traffic management strategies (in terms of speed, delay, and queues), because the traffic assignment step in the four-step models does not take account queuing on the network links. Planning models do not model the presence of bottlenecks and the queue formation and dissipation. A number of post-processing routines has been

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[20]Cambridge Systematics, Inc., *Traffic Analysis Tools Primer*, prepared for the FHWA, Publication No. FHWA-HRT-04-038, July 2004.

[21]Cambridge Systematics, Inc., *Decision Support Methodology for Selecting Traffic Analysis Tools*, prepared for FHWA, Publication No. FHWA-HRT-04-039, July 2004.

developed to address the inherent limitations of the planning models and to permit the analysis of intelligent transportation system (ITS) measures (e.g., the IDAS software[22]).

6.7.4 Analytical/Deterministic Tools (e.g., HCM)

Analytical deterministic tools consist of analytical relationships between traffic demand and network characteristics (supply). These techniques are suited for analyzing impacts at an isolated location (e.g., the queuing diagram[23] to estimate delay and queue length at a freeway bottleneck or delay at a signalized intersection approach). The Highway Capacity Manual (HCM2000)[24] includes the most widely used analytical and deterministic methodologies. The HCM2000 analysis procedures estimate the capacity and level of service (LOS) based on performance measures for each facility type (e.g., density for basic freeway segments).

The HCM2000 procedures are macroscopic (consider average traffic stream characteristics), deterministic (ignore stochastic variability), and static (analyze operating conditions for a fixed-time analysis period and ignore transitions in traffic conditions). The HCM procedures are ideal for analyzing the performance of isolated facilities with relatively moderate congestion problems, but they cannot generally evaluate system effects (e.g., it is assumed that the performance of the segment under study is not adversely affected by conditions on the adjacent roadway). Furthermore, they are not well suited in analyzing freeway management strategies (e.g., ramp metering, traveler information systems).

6.7.5 Simulation Models

Simulation tools model the traffic stream movements and interactions in time and space. Existing simulation models can be classified in the following categories:

- **Macroscopic models** are based on the conservation of flow and deterministic relationships of the flow, speed, and density of the traffic stream. They consider flow rates or platoons of vehicles and simulate traffic flow in small time increments on each section of the network.

- **Microscopic models** simulate the movement of individual vehicles based on car-following, lane-changing, and queue discharge algorithms every one second (or a fraction of a second). Microscopic models can model in detail the effect of design, control, and management scenarios, but require additional input data and significantly higher

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[22] Federal Highway Administration, *ITS Deployment Analysis System*, 2004.

[23] Urbanek, G. L., and R. W. Rodgers, *Alternative Surveillance Concepts and Methods for Freeway Incident Management*, Federal Highway Administration Report RD 77-58/63, Washington D.C., 1978.

[24] Transportation Research Board, *Highway Capacity Manual 2000*, National Research Council, Washington D.C., 2000.

computer time and storage requirements compared to macroscopic models. Thus, they are mostly suited for analyzing small networks.

- **Mesoscopic models** simulate individual vehicles, but their movements and interactions are modeled based on macroscopic traffic flow relationships, (i.e., they combine the properties of both micro and macro simulation models).

Simulation tools provide several performance measures per vehicle trip (travel time, delay), network link (throughput, queue length), and the total system. They can model the build up, propagation, and dissipation of traffic congestion and systemwide effects and transitions in traffic states. However, they require a large amount of input data and several parameters that must be calibrated to local conditions.

The choice of the model to estimate the performance measure depends on several factors:

- **Data requirements.** If good data is not available, the users should consider a less effort-intensive tool category, such as using sketch-planning tools, instead of microsimulation. The results of the simpler tool categories are usually more generalized, and the users should carefully balance the needs of an accurate analysis with the amount of data required, staffing, and the budget available.

- **Limitations in funding** to purchase tools and train the users. Traffic analysis tools require a significant capital investment. Software licensing and training fees can make up a large portion of the budget. When faced with limited funding, focus on the project's goals and objectives, and prevent "scope creep."

- **Limitations in resources** (staff, capabilities, and funding) to build the network and conduct the analysis. Most traffic analysis tools are very resource intensive to implement, especially the model construction and calibration (front-end) phases. On the other hand, keep in mind that there is no perfect tool. At some point, users must consider moving forward if the effort required to perfect the model will yield few results.

- **Data entry, and the diversity and inconsistency of the data** needed to run each of the different tools. Each tool uses unique analysis methodologies that do not necessarily overlap, so the data requirements for analysis can vary greatly. In most cases, data from past projects contribute little to a particular analysis effort. Users must be ready to budget enough resources for data collection.

- **Lack of understanding** of analysis tools limitations and assumptions. Often times, limitations and "bugs" would not be discovered until the project has moved halfway or beyond. It is important to glean experiences from past projects or communicate with fellow users of a particular tool or tool category, and find out how the tool fit into their projects. By finding out others' experiences, the users would get a better understanding of what they would be up against as the project progresses.

- **Lack of features.** Some analysis tools are not designed to evaluate specific strategies that the users would like to implement. This is particularly more prevalent in modeling ITS strategies or other advanced traffic components. Often times "tricking" the tool into mimicking a certain strategy is a short-term solution, but there needs to be a degree of flexibility for the advanced users to customize the tools accordingly.

Table 6.5 summarizes the performance measures that can be obtained from the application of the above described analytical methods.

Table 6.5 Use of Analytic Techniques to Estimate Performance Measures

	Analysis Tools/Methodologies			
Performance Measures	**Sketch Planning**	**Travel Demand Models**	**Analytical/ Deterministic Tools (HCM)**	**Simulation Models**
Trip-Based				
Travel Time	–	+	–	+
Travel Time Reliability[a]	–	–	–	–
Corridor/Segment-Based				
Average Speed	+	+	+	+
Travel time (VHT/PHT)	+	+	+	+
Throughput (VMT/PMT)	–	+	+	+
Total Congestion Delay[b]	–	–	+	+
Incident Delay	+	-	-	+
Bottleneck-Based				
Volume[c]	+	–	+	+
v/c Ratio[d]	+	+	+	+
Queue Length[e]	–	–	+	+
Incident Delay	–	–	–	+

+ The model does generally provide estimates of the measure.

– The model does not generally provide estimates of the measure.

[a] **Travel Time Reliability:** Estimate of the uncertainty in travel times because of traffic volume variations, incidents, weather, or special events. It is usually quantified using *the buffer time index, coefficient of variation*.

[b] **Congestion Delay:** The additional travel time experienced by travelers at speeds less than a reference speed (e.g., the free-flow speed), expressed in vehicle/hours; includes all sources.

[c] **Volume:** Volume discharged downstream of the bottleneck locations (vehicle/hours).

[d] **Volume-to-Capacity (v/c) ratio:** The ratio of flow rate to capacity of the facility.

[e] **Queue Length:** Length of queued vehicles waiting to be served (miles).

7.0 Data to Support Freeway Performance Measures

7.1 Introduction

7.1.1 Purpose of Section

The purpose of this chapter is to examine the data required to report freeway performance measures and the mechanisms for obtaining those data. This is the first of two chapters that deal with the data needed to perform freeway performance reporting. This chapter will describe the various types of data needed to support the recommended set of freeway performance measures, as well as many alternative performance measures. It will discuss the specific data elements that can be collected (irrespective of the device used to collect them), the definitions of those data items, their potential sources, and how they can be used to create the types of performance measures discussed in the previous chapter.

While this chapter discusses the types of data needed to report the performance measures selected in Chapter 6, the following chapter discusses the data processing steps necessary to convert the statistics actually collected into the performance measures that meet the selected reporting needs, that is, the data manipulation required to convert "data" into "information."

7.1.2 Background and Overview

Key Considerations

In a very large sense, performance measurement is all about data. It does little good to specify a complete and complex set of performance measures if accurate and timely data are not available to actually compute them. As such, the availability of data will directly reflect on what performance measures **can** be computed and reported, as opposed to what performance the agency/region **would like** to compute and report.

As a result, data availability needs to be a major element included in the development of the performance measures. Rarely are the majority of data required to perform performance measurement collected and made available specifically for that purpose. Of course, just because data are not currently available does not mean that desired performance measures should not be adopted. Adopting measures for which data currently cannot be provided simply means that the agency has been put on notice that additional data sources are needed to meet the roadway management and policy information needs of that agency or region.

One frustrating aspect of performance monitoring is that the financial resources for actually performing the performance reporting are inevitably limited, and thus the resources available for data collection are limited. No resource-constrained agency really wants to pay for "data." However, most agencies are willing to pay for "improved system performance and control" or even "answers to key policy questions." Consequently, most data available for performance monitoring purposes are originally collected for purposes other than "monitoring freeway performance." Instead, they are most commonly collected to provide input to traffic management systems, such as toll collection or ramp metering, to provide data feeds for publicly accessible traveler information systems, or to supply key data needed to operate decision support systems.

The fact that the data are collected for purposes other than "performance monitoring" has two significant repercussions:

1. To compute performance measures, the data must first be extracted from the systems which actually collect the data; and

2. The raw data that are obtained must frequently be manipulated fairly extensively to produce the desired statistics.

7.1.3 The Steps Involving Collecting and Using Data

Obtain the Existing Data

Because most of the available performance data are collected for purposes other than reporting performance, obtaining data from existing traffic management and traveler information systems is often far more difficult than logic would indicate. Budgets for the development and deployment of the traffic management and traveler information systems are often smaller than needed, and a very common cost reduction strategy is to remove or significantly curtail the data archiving function that is needed to store, and efficiently retrieve, the data collected as part of that traffic management system. Consequently, creation of a performance monitoring system must often start with the construction of the software needed to efficiently store and retrieve data already "collected" by an existing traffic management system.

Develop Data Manipulation Procedures

Once obtained from the data archives, the data collected in the field can be:

- Used directly as a measure of performance (e.g., vehicle volumes, vehicle speeds);

- Combined with other data from other devices in the field to compute a new performance statistic (e.g., travel times computed from toll tag readers at different locations);

- Mathematically transformed into a different performance measure (e.g., point speeds at consecutive locations can be used to estimate travel times along a corridor);

- Combined with other directly measure data to produce more complex performance measures (e.g., vehicle volume and speed data can be used to compute vehicle hours of travel or vehicle hours of delay); and

- Used as input to various transportation modeling systems to estimate a wide variety of statistics that cannot be measured by the available sensor equipment (e.g., volume data used to feed a simulation model can produce estimates of pollution emissions).

In general, the more directly the collected data can be used for performance reporting, the more accurate the performance measure. (For example, collecting speed data at a point gives an excellent measure of vehicle speed at that point. While that kind of data from multiple consecutive points can be used to estimate travel time along a corridor, the accuracy of the travel time estimates is lower than accuracy of the speed measurement at the point at which it is measured.) However, because most of the data used for performance reporting comes from management systems built for purposes other than performance reporting; manipulation of that data, and the combination of data from multiple sources is necessary to produce the majority of the performance statistics desired.

The good news is that the data collected to run traffic management and traveler information systems are often well suited for computing the performance of freeways. The bad news is that the available data rarely answer all of the policy questions for which performance measures are desired, and thus supplemental data collection is frequently required in order to meet all of the data requirements of a comprehensive performance reporting system.

Understand the Available Data

Once all of the "available" data have been identified, the next step is gaining a clear understanding of exactly how well those data represent the performance of the freeway they are being collected on, and how limitations in those data affect their use as performance measures. Understanding the strength, weaknesses, and holes in the available data helps determine what supplemental data need to be collected specifically for performance monitoring. It also defines the need for many of the data manipulation steps that are required (and discussed in the following chapter), and many of the assumptions that must be made to convert the available data into the required performance statistics.

A good example of the need for understanding the data being collected comes from the collection of vehicle volume and speed data. Many freeway management systems use loop detectors to collect volume and speed data. In many cases, not all loops at a given location are operating. The data system can usually describe how many loops are not functioning correctly. The data analyst needs to be aware of these holes in the data, determine whether the quality of the data remaining is sufficient to meet their needs, and have built data imputation techniques for handling the holes in the data set.

Collect Supplemental Data

Once a clear understanding of the available data exists, it is possible to define the supplemental data collection that is needed to complete the data sets needed for the desired performance monitoring system. Supplemental data will be used to:

- Fill in the gaps in available data; and
- Provide information that help eliminate biases in the previously collected data.

Given the realities of performance monitoring budgets, supplemental data collection programs must often be phased in over time.

One common supplemental data program that may need to be implemented is a vehicle occupancy data collection effort. The number of people in each vehicle is not a commonly collected data item for traveler information or freeway control systems. However, statistics on carpool use are needed if the performance monitoring program needs to describe the effectiveness of policies designed to encourage shared ride travel.

A second supplemental data collection effort that is frequently needed is data on the public's perception of roadway performance. Again, these data are not required to operate or manage traffic control systems or traveler information systems, but they provide substantial insight into what the public views as important, how the public views the different traffic management programs being pursued, and how the public views overall performance of the roadway system. All of these are key inputs to the public decision-making process, and are therefore important performance reporting statistics.

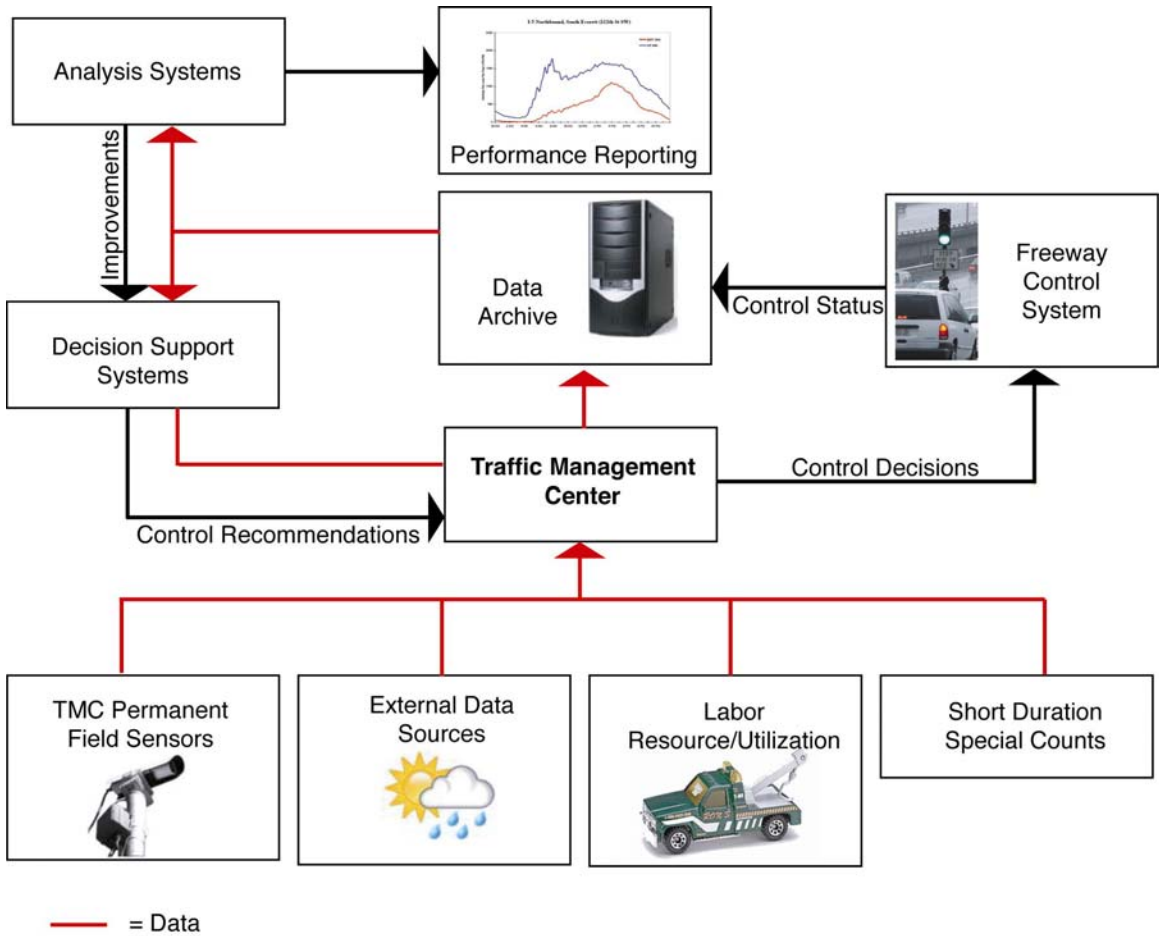
A third supplemental type of data is on the number and/or percentage of trucks that are in the freeway traffic stream. Freight movement is a key policy issue, and the vast majority of freight moves by truck. Understanding how much freight moves on a given freeway is therefore important to the overall performance reporting for that road. Truck volume (by size of truck if possible) is also a key input to geometric, structural, and operational analyses for freeways. Thus, collecting data that describe the size and nature of trucking movements on a freeway is a strategically important supplemental data item.

Lastly, if special events or non-accident incidents are major causes of congestion, supplemental data may need to be collected that describe when, where, and for how long these traffic disruptions occur. (Such data usually already exists for major accidents.) Without such data, it is not possible to determine the impacts these events have on facility performance, nor is it possible to determine how effective the programs are which were implemented specifically to reduce the impacts of these events on freeway performance.

7.1.4 Data Sources and Flow

Figure 7.1 illustrates the flow of data within a model performance monitoring program. Data collected for specific management purposes is combined with data collected from special studies and with data collected from external sources. "External sources" can mean that the data are collected by other agencies (e.g., weather can be obtained from the National Weather Service), or it can simply mean that the data come from agency systems that are not directly tied to the freeway management system (e.g., labor deployment and activity reporting systems).

Figure 7.1 Common Flow of Data for Freeway Performance Monitoring



A data archive system or process then needs to 'fuse' the available data in order to create useful analysis data sets. Finally, analysis software performs the necessary calculations to produce the desired performance reports. Performance reports not only inform operators and decision-makers about how well the freeway system is working; when used properly, they provide feedback to the freeway operators on the effectiveness of the operational strategies being used on that freeway. For proactive freeway operators, this feedback, in turn, leads to the development of newer/better operational control strategies. The performance reporting system can then be used to track the performance of those new control strategies. The end product is a continually improving freeway management capability, along with a reporting process that allows the agency to take credit for those improvements.

7.1.5 Introduction to What Data Are Needed

As noted in Chapter 6, to accurately describe freeway performance, it is necessary to obtain data on a variety of subjects, including the following:

- Usage levels (e.g., vehicles, people, freight);
- Mobility (e.g., travel times, speeds, reliability);
- Geometric data (e.g., number of lanes, cross section widths);
- Safety (e.g., accidents and other incidents);
- Environmental conditions and other traffic disruptions (e.g., special events);
- Customer satisfaction; and
- Any other factor that policy-makers consider important to transportation service delivery on freeways.

The data within these basic categories and their sources are discussed in the subsections of this chapter.

■ 7.2 Sources for Performance Data

Data used for reporting on freeway performance are commonly provided by five different types of data collection mechanisms:

1. Permanent monitoring devices and systems;
2. Short duration monitoring devices or programs;
3. Labor or resource utilization and management systems;
4. Public response surveys; and
5. Data sources external to the freeway agency.

Because limited resources are available for collecting data simply for performance monitoring purposes, the most cost-effective data sources are those that already exist in order to perform specific management functions. For example, the best freeway volume and congestion data tends to come from data sets collected as part of the input data needed to collect tolls, set ramp metering rates, provide incident detection, or meet traveler information system needs. These data are not "collected for performance monitoring"; they are collected to "operate the ramp metering system" or to "detect incidents." However, the data collected in order to operate the ramp metering system or operate the incident detection system also frequently provide excellent data on freeway performance.

Labor and resource management systems are also key sources of data. The most forward looking DOTs have implemented job reporting/labor tracking systems that collect the labor and equipment utilization statistics necessary for managing those resources. These statistics are used to manage the field staff and their equipment. They track what jobs each staff person does during a day, how long those tasks take, and what equipment were used.

Traditionally, these data were written on paper and had to be transcribed in order to be used. This is expensive and time consuming. More modern systems are being put into place that allow field staff to record their actions on PDAs which store the data electronically. The data are then uploaded to a centralized database either wirelessly throughout the day, or in a "batch download" at the end of the day when the staff return from the field. In either case, by using modern electronics and communications, much of the cost of the data entry has been eliminated. This makes it cost effective to operate these systems, and makes available the information needed to both manage the agency's field resources and provide the raw statistics needed to understand the events that require those staff actions. Once again, a single data collection system meets multiple purposes.

Only when management systems do not already collect the desired data should an agency fund special data collection activities to provide performance monitoring information. Typical supplementary data collection efforts include vehicle occupancy counts, public opinion surveys, floating car travel time runs on freeways with no permanent data collection, and short duration traffic volume or vehicle classification counts.

Because of the costs involved, these supplemental data collection efforts almost always require sampling a limited number of locations for limited time periods. As a result, supplemental data collection systems tend to provide good estimates of average conditions, but provide a less robust view of the variability of the attributes which affects freeway performance. For example, if travel times are only collected on a limited number of weekdays during the year (e.g., 10 days, or roughly 5 percent of total work days), it is unlikely that during those 10 days a good description of the worst 10 to 15 percent of days of travel is obtained. Yet the very bad days which make up those 10 to 15 percent of the worst trips taken are exactly where the operational improvements provided by enhanced incident response will have the greatest effect. If the data collection system does not collect data on those days, it is incapable of reporting on some of the largest benefits of the system.

The following sections provide more detail on the specific data items a freeway agency should look to collect, and the mechanisms from which those data can be obtained.

■ 7.3 Roadway Performance Data (Use and Mobility)

Two of the most obvious sets of freeway performance statistics that are needed relate to the number of vehicles using the freeway and the speeds at which those vehicles operate. Both sets of statistics (use and speed of travel) need to be reported, because an operational policy that results in a positive change in one, with no change in the other, would normally be considered an improvement in freeway operational performance. For example, if as a result of some improvement or new service, the road in question:

- Carried more vehicles in a given time period, but saw no decrease in speeds during that time period, or
- Carried the same amount of traffic, but at increased speeds (i.e., less delay).

the agency would conclude that improvement was beneficial. Similarly, a modest increase in use, accompanied by a significant increase in delay (a decrease in speed of travel) might not be considered an improvement in performance. Thus, measuring use without mobility or mobility without use can easily lead to misinterpretation of freeway performance.

The above comparisons also show that data on “speed of travel” is often converted into measures of “delay” or “travel time” in order to express freeway performance in a manner that more effectively informs the decision-maker or the public. This is an excellent example of the fact that the “units” in which data are collected are often not the units in which performance is reported.

In the case of “mobility,” the basic data that must be collected is the speed of vehicles operating on specific segments of freeway. But the specific mechanism for collecting data on the speed at which vehicles travel over a segment of roads can vary from one freeway system to the next. It can be collected at a single point that is assumed to be representative of a larger segment of road. It can be collected at multiple points within one or more segments with the results of those multiple measurements being combined (averaged) in some fashion. It can be collected by directly measuring the time it takes for specific vehicles to traverse that segment of road, with the times for each of those vehicles then being averaged or combined in some fashion to obtain a “roadway average.”

All of these data collection mechanisms work. Each has limitations. For example, travel times computed from point sources are not as accurate as directly measured travel times. But having multiple points at which speed is measured yields a more robust picture of where congestion is occurring than simply having a measure of total travel time along that segment of road.

Understanding the limitations inherent in any data set, and building the analytical and reporting systems so that they account for those limitations (including collecting additional data where necessary) is an integral part of working with the available data. Chapter 8 discusses many of the techniques for handling data, given its limitations and strengths, with the end product of transforming it into more useful performance statistics. The good news is that once the basic data on “vehicle speed” are collected (whether as vehicle speeds or as travel times over defined roadway segment), the data are relatively easily converted into other measures of vehicle mobility for reporting and analysis purposes.

The second major performance statistic is freeway use. Basic vehicle volume data usually available if any permanent freeway monitoring equipment is present on the roadway segments for which data are desired. In addition to **vehicle** volume, it is often necessary to measure **person** volume on freeway segments or corridors. Person volume is particularly important on those freeways where transportation policies have been implemented with the intent of maximizing person throughput and/or minimizing delay per person, and where active efforts are in place to increase the number of people in each vehicle, in lieu of (or in addition to) adding additional vehicle capacity to that roadway. Finally, it is often desired to collect data that describes the amount of truck traffic occurring on that roadway.

As noted earlier, the "best" data collection mechanisms for both vehicle volume and speed are those which are already in place in order to provide input data to traffic control systems. These same data are then available "free" to judge the performance of those control systems. In addition to being "free," these data also have the advantage of being from "permanent" or "continuous" data sources. This means that if these data are routinely stored (and can be analyzed), then data are available to measure the *distribution* of freeway performance. That is, an understanding is gained of not only how the freeway operates on the "average" day, but how the facility operates on "bad" days, and how often those "bad" days occur. Public perception of roadway performance is often driven by "bad" days. Thus,

- Understanding how often "bad" days occur;
- Measuring how "bad" they really are;
- Determining the cause of those bad days;
- Implementing countermeasures to limit the occurrence of those causes and/or to limit the traffic impacts from those events when they do occur; and
- Measuring the performance of those countermeasures.

result in an accountable freeway management program that can use actual facility performance to defend its actions, make the case for increased funding, and take credit for the measurable improvements those actions achieve.

Another caveat to place on the data collection program is the need to be able to create temporal aggregations of the data being collected. For example, "average speed for the day" for a given road segment is a far less useful statistic than "average speed during the peak hour." Thus, data collection needs to be performed in such a way that the changing temporal aspects of freeway performance can be reported. Important temporal timeframes that are commonly used include time of day (peak hour, peak period, midday); day of week (weekday versus weekend, average weekday versus Friday); and performance on specific days (Memorial Day weekend).

7.3.1 Introduction to Roadway Performance Data Collection Devices

Devices that can be used to supply vehicle volume and speed information on a continuous basis are discussed below. Considerable literature exists on this subject. Unfortunately, data collection technology has been changing quickly in recent years due to the influx of new sensors developed as part of various Intelligent Transportation Systems initiatives. Thus, no conventionally printed report can provide an up-to-date description of all of the available sensors, let alone the accuracy achieved using those sensors.

Readers interested in learning more about vehicle monitoring equipment should investigate the current literature. Several Federal and state supported web sites maintain reports on the performance of traffic monitoring devices. The following resources are good places to start when looking for information on traffic devices and their performance:

- The Vehicle Detector Clearinghouse: http://www.nmsu.edu/~traffic;
- The Minnesota DOT tests of non-intrusive detectors: http://www.dot.state.mn.us/guidestar/nitfinal/;
- The FHWA web site, "Summary of Vehicle Detection and Surveillance Technologies": http://www.fhwa.dot.gov/ohim/tvtw/vdstits.htm;
- Middleton, D., and R. Parker, *Vehicle Detector Evaluation*, October 2002, Texas Transportation Institute, FHWA/TX-03/2119-1; and
- The California Center for Innovative Transportation web site on traffic surveillance: http://www.calccit.org/itsdecision/serv_and_tech/Traffic_Surveillance/surveillance_overview.html.

These sources primarily discuss traditional traffic monitoring equipment.

In addition to the traditional traffic monitoring devices, if the freeway in question happens to be a toll facility, it is possible to use electronic toll collection data to obtain both volume and travel time information. Toll revenue statistics (the number of tolls collected, not the total revenue collected) provide one-half of the primary performance information, the number of vehicles being served on each segment of roadway. For toll roads with electronic toll collection, travel time between toll collection locations can be computed by matching the time and locations at which individual toll tags are observed.

While advances in technology, computing power, and communications have increased the technological options for data collection, no single technology has proven to be "better" than the others for collecting the vehicle volume and speed information needed for all traffic management applications. Instead, each technology has strengths and weaknesses that make it the "best" choice under specific conditions and a "less than optimal" choice under other conditions. For example, toll tag data is an excellent technology choice for an all-electronic toll road. That same technology is less than ideal for a freeway which has no toll collection function.

The performance of any given technology is also highly dependent on the quality of the installation of the data collection sensor and the quality of the hardware and software used by each specific vendor. The published literature and informal discussions with data collection staff from around the country provide stories of both successes and failures involving just about every data collection technology and vendor in the market. Consequently, any agency looking to select data collection devices should examine the extensive material available in the references listed above, and conduct a comprehensive product selection and testing program before committing to purchasing specific devices from specific vendors.

7.3.2 Advice for Selecting and Purchasing Data Monitoring Equipment

It is extremely important when purchasing new data collection equipment that the purchasing agency carefully test any selected equipment in *the local conditions under which it is expected to function*, prior to completing the purchase, to make sure the equipment works as described by the vendor under the actual conditions where it will be used. A number of agencies has purchased data collection equipment that could be shown by the vendor to work elsewhere in the country, but that did not meet the required performance specifications when applied at this new location.

In addition, each agency needs to have quality control checks on the installation of that equipment, and calibration testing of the equipment after it is installed. These steps insure that the selected and installed devices will work as desired, at least at the time they are installed. The agencies should also set aside the necessary funding to operate and maintain the equipment they purchase, or the quality of data available for both management decisions and performance reporting will degrade over time.

In order to increase the chance of purchasing reliable, accurate, long lived equipment, the purchasing agency should carefully consider the tradeoffs between a number of key equipment attributes. It is the combination of these attributes, the relative importance of which changes from location to location and implementation to implementation that truly drives the selection of the "best" technology for any given implementation. Key attributes that need to be considered are the following:

- Type of measures that are actually collected by a given device/technology;
- Accuracy of the data collected (given the environment in which the equipment must be operated);
- Environmental limitations for each technology;
- Capital cost of the devices;
- Installation and deployment costs;

- Ongoing operations and maintenance costs; and
- Communications costs.

A proper equipment evaluation effort starts with obtaining a complete understanding of the data needs that the system should meet. This usually means understanding not just the immediate needs of the "system" for which the data will be collected, but also the secondary needs for which those collected data will be used. Decisions must then be made concerning how much funding is available, given those "needs." (There is never enough money to collect everything "needed," so the real question is what is *really needed given the available funding* – where "really needed" may change if additional funding can be brought to the table by groups outside of those funding the purchase and deployment of the data collection equipment.)

Having answers to the questions of "what is really needed?" and "how much funding actually exists?" allows valid decisions to be made based on the relative merits of different devices and technologies. For example, if relatively little maintenance funding will exist, and data reliability is very important, a valid approach would be to give more weight to purchasing technologies that might require a higher initial investment, but that have higher levels of reliability and lower maintenance costs. Conversely, if the primary need is to get the system up and running in order to show its value, a valid decision might be to purchase lower cost sensors which have higher, long-term maintenance costs in order to get the system operating. Once the system demonstrates its value, additional funding can be obtained to upgrade or repair sensors.

The basic technologies to choose from for monitoring traffic and the basic attributes of those technologies are presented in the following subsection.

7.3.3 Sensor Technologies for Volume and Speed Measurement

A wide range of point sensors are used in this country for continuously monitoring freeway performance. Among the more commonly used technologies are inductance loops, video cameras, microwave radar detectors, acoustic sensors, infrared sensors, and RF toll collection beacons. These devices generally provide data that directly measure point specific attributes (vehicle presence and/or speed). In some cases they provide additional vehicle attribute data (class of vehicle, or specific vehicle ID).

These basic measures allow the determination of vehicle volume and average speed of vehicles on a facility, which in turn serve as the building blocks for the majority of the more complex operational performance measures (e.g., VMT, VHT, delay, travel time indices) that provide a more complete understanding of roadway performance. When saved for later use, the continuous streams of volume and speed data provided by permanent sensor networks provide the historical record needed to understand and report freeway system operational performance.

Given the large volume of written material on sensors and sensor performance, as well as the rapidly changing nature of the sensor market, this section provides only basic information on commonly used data collection technologies, including the traditional strengths and weaknesses of those technologies. It does not describe how specific vendors have attempted to surmount known technological limitations, nor does it judge the published levels of success of those efforts. More detail on these technologies can be obtained in the previously cited references.

Traffic volume and speed monitoring devices are generally broken into two basic categories: intrusive detectors and non-intrusive detectors. Intrusive detectors are those sensors that must be placed in, on, or under the roadway surface itself. Non-intrusive detectors are those which operated beside or completely above the roadway.

Intrusive Detectors

Intrusive sensors can be broken into two subcategories: vehicle sensors and axle sensors. Vehicle sensors "observe" entire vehicles. These technologies include inductance loops, and magnetic technologies that "sense" the presence of metal in vehicles. They do not require "contact" with the vehicle, but need to be close enough to the vehicles being sensed that they must be placed in the lane in which vehicles are to be observed.

Sophisticated (and more expensive) versions of these sensors, and the electronics attached to them, cannot only count vehicle volume, but can differentiate among different classes of vehicles, usually based on the overall length of the vehicle itself. In the case of the most sophisticated of these devices, the shape of the electronic signal created by each passing vehicle can be used to determine the number and spacing of axles on that vehicle, which in turn allows the classification of that vehicle based on its axle configuration.

The second subcategory of intrusive sensors directly measures axle passage. The most common of these technologies for permanent data collection is the piezo-electric sensor, although a number of other pressure sensitive technologies are also used.

For axle-based counters, the axle "hits" must then be converted into "vehicle volumes." To do this requires that the electronics attached to the sensor understand when one vehicle ends and the next begins. For simple devices, vehicles are differentiated based on assumptions about the minimum headway at which vehicles are willing to follow. Devices that use these assumptions are commonly used for short duration, portable counters. A more common approach for permanently installed axle sensors is to include an inductance loop as part of the sensor package. The inductance loop signal is used to define when one vehicle ends and the next begins, and the axle sensor(s) are used to count the number and spacing of each vehicle's axles.

For both axle sensor and vehicle sensor technologies, vehicle speed can be estimated using sophisticated signal analysis, but it is more commonly computed by simply placing two sensors at known distance apart, and using that distance and the time difference between sensor activations to compute the speed of the vehicle as it moves from one sensor to the next.

Once vehicle speed is known for individual vehicles, vehicle classification is possible. The exact classification system that can be used will vary considerably from one device to another based on the nature of the data each sensor provides. Most classification schemes are state specific and are based on either overall vehicle length or the number and spacing of axles. The algorithms must be state specific because laws governing truck size and weight differ considerably from state to state, and thus the configurations of trucks vary from state to state.

The major drawback of intrusive sensors is that they are located in, on top of, or under the roadway right-of-way. Thus, their placement normally requires closing that right-of-way while the sensor is placed. Closing lanes can be problematic in areas of high traffic volumes, because the political cost of "creating congestion" is too high to be accepted frequently. This has implications for how quickly a failed sensor can be repaired or replaced, which in turn affects data reliability and integrity.

On lower volume freeways, especially in rural areas, it may be possible to place some portable intrusive sensors without closing the roadway, but even in these cases, a staff person must be in the travel lane at least briefly to place the sensor. This creates a safety concern that limits where intrusive devices can be used.

In addition to the congestion and safety issues, the need to close lanes in order to place and/or maintain sensors has definite cost implications. The traffic control required to close urban freeways lanes is substantial, and the cost of that operation is consequently non-trivial. The result is that the cost of intrusive sensors tends to be far greater than just the cost of the sensor and its associated electronics, as the cost of installation is often larger than the cost of the sensors and electronics.

Lastly, intrusive sensors generally work accurately only when vehicles remain within the lane lines which existed when the sensors were placed, since each sensor tends to measure traffic in one lane. If vehicles do not follow the lane lines, for example because it is snowing and drivers cannot see those lines, these sensors tend to count inaccurately. Thus, if bad weather occurs frequently or if lane discipline is routinely poor for other reasons, intrusive sensors may not be a good choice.

Another instance when intrusive sensors may not be a good choice is when lane geometry is expected to change frequently due to planned construction activities. Each time lane lines are moved during a construction project, intrusive sensors must be replaced by new sensors located properly within the new lane lines if the sensors are expected to produce accurate data during those construction efforts. Since construction activities are a major source of delay, not collecting accurate data during these time periods means that the size, frequency, and duration of those delays are not measured.

Non-Intrusive Detectors

The drawbacks to intrusive sensor technologies have resulted in the development of a number of new sensor technologies that does not have to be placed in, on, or under the roadway surface. These sensors, termed "non-intrusive" sensors, are usually placed high above or besides the roadway. The most common of the non-intrusive technologies are:

- Video;
- Radar (microwave and Doppler);
- Acoustic; and
- Infrared.

Each technology has been marketed by more than one vendor, who frequently uses very different methods for converting the sensor output to measurements of vehicle volume, speed, and other vehicle attributes. The result is that specific vendor implementations of these sensor technologies can have very different performance characteristics.

In general, non-intrusive detection has two basic advantages over intrusive detection. The first advantage is that the sensors are either less sensitive to lane discipline issues. This is either because each sensor "watches" more than one lane, or because the sensor focus can be easily adjusted to "watch" lane lines that have been moved for construction purposes. In some cases, non-intrusive detectors do not collect lane-specific information. Instead, they provide "roadway wide" statistics. These devices are particularly good at measuring vehicle volumes and speeds on road sections with poor lane discipline. It is up to the agency to determine the relative importance of obtaining data for each lane of travel, or whether it is more important to collect accurate statistics during times of poor lane discipline.

A second advantage for non-intrusive detectors is that many of these sensors can be placed and maintained without having to close traffic lanes. This is particularly true for those technologies that can monitor traffic from beside the roadway (for example, side-fired radar). Having sensors that are placed outside of the roadway right-of-way means that installation and repair work on those sensors can occur during the day without closing travel lanes, even on most sections of busy urban freeways. This drastically reduces the cost of sensor placement and repair, and increases the ability of the agency to keep those sensors operating.

Unfortunately, not all non-intrusive equipment operates effectively from beside the right-of-way. Some equipment needs to be placed in an overhead position to count vehicles accurately. Other equipment can operate in both side-fired and overhead configurations, but operates more accurately in an overhead configuration. Alas, lanes of travel must normally be closed when work is going on above those lanes, so overhead mounted, non-intrusive sensors may not have an advantage in lowered installation and repair costs when compared to intrusive sensors.

Understanding Sensor Limitations

Under "normal" conditions, both intrusive and non-intrusive technologies can work accurately if installed and calibrated properly. The Minnesota DOT report on non-intrusive technologies indicated that "the differences in performance from one device (vendor) to another were found to be more significant than the differences from one technology to another."[1] The fact that the same technology could work well or poorly, depending on the specific vendor and/or installation involved, illustrates the need to test equipment supplied by each vendor from whom it will be obtained to ensure that the selected implementation of that technology works, as well as any previously tested implementations.

The fact is that all data collection sensors have limitations, regardless of the technology used or the vendor that provides that equipment. Each vendor attempts to limit the significance of the basic sensor limitations through the signal processing and calibration algorithms built into each traffic detector. The robustness of those algorithms and the quality of the equipment installation has a lot to do with how well each device works in non-ideal conditions. But non-ideal conditions still effect performance. Thus, it is important for any agency looking to purchase equipment to understand the limitations inherent in a given technology. Among the most common "problems" associated with each technology are the following:

- Magnetic inductance loops frequently do not "see" vehicles with low metal content (e.g., motorcycles) and can undercount traffic in very high density traffic conditions where two closely spaced vehicles can be reported as a single large vehicle.

- Video surveillance often has difficulty performing in low visibility conditions (e.g., heavy snowfall, heavy fog), and like inductance loops, can have troubles accurately measuring vehicle volume in high-density, low-speed conditions.

- Many non-intrusive technologies that use side-fired orientations (that is that observe traffic from the side of a road) can undercount traffic volume because of occlusion, which occurs when one vehicle "shields" another from the sensor. (For example, a heavy truck in a lane close to the sensor may obscure a small vehicle traveling beside that truck in the next lane farther away from the roadside detector.)

- Systems that require "vision" (video, infrared) are often affected by long-term degradation of the cleanliness of the lenses through which light passes. Without regular maintenance, dirty lenses decrease the accuracy of the data collected. Thus, these technologies tend to require more maintenance activity than technologies not subject to such degradation.

Understanding how a specific technology works and what its physical limitations are will help an agency select an appropriate device in the first place. While it is often possible for a vendor to overcome many of the limitations of a given technology, selecting a technology that does not have to "overcome" its natural limitations to work in the desired location will increase the probability that the equipment selected will meet the desired performance requirements.

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[1] *Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies*, Executive Summary, FHWA-PL-97-018, by Minnesota Department of Transportation, http://www.dot.state.mn.us/guidestar/nitfinal/execsum.htm.

7.3.4 Short Duration Data Collection

Where data from permanent sensor networks are not available or for data collection tasks where permanent sensors do not work effectively, performance monitoring information must be gathered by manual observation, or by placing temporary monitoring devices.

Manual measures are traditionally used to collect those performance statistics for which automated equipment does not work accurately, or where automated collection is not cost effective. Two common data sets collected manually are vehicle occupancy data and customer satisfaction data (public opinion).

To date, automated data collection equipment has not been able to accurately monitor vehicle occupancy. Research continues to be performed on this subject; and at some point in the future, automated collection is likely, but in the near term, vehicle occupancy will continue to be collected by direct human observation. Similarly, public opinion data tends to be collected as part of specially designed, infrequent surveys. In both cases, modest, well designed, data collection efforts can provide the basic trend data required to measure these key performance statistics.

Modern technology has made it possible to cost effectively perform short duration vehicle volume and speed data collection on freeway segments which do not have permanently mounted sensors. While use of traditional intrusive data collection sensors for short duration counts on high volume freeways tends to be problematic, several of the non-intrusive detector technologies mentioned above can be used in a portable configuration. In most cases, the portable versions of these technologies use a low-powered, side-fired, version of the permanent sensor. The sensors are placed on poles beside the roadway. The poles can either be existing sign or lighting poles, or they are extendable poles mounted on trailers that are towed to the desired roadside location. (Such trailers are often placed behind physical guardrails or other barriers to meet safety needs.) Power is then supplied using solar panels, batteries, or a combination of the two.

Data from these devices are then either transmitted from the site using modern wireless communication systems (e.g., digital cellular, WiFi, etc.), or stored on site, and collected when the equipment is retrieved at the end of the study period. Wireless communications is required if the data are to be used for real-time operational purposes, such as monitoring traffic performance through construction zones; however, if the data are only needed for planning or performance monitoring purposes, on-site storage and retrieved is generally less costly.

Short duration data collection does not provide the long-term data needed to truly understand the variability being experienced on a given freeway performance over the course of a year, but it can provide an excellent picture of average or routine conditions.

Minnesota DOT has tested the accuracy of these portable non-intrusive traffic monitoring devices, and found all of the devices tested to work reasonably well, so long as the equipment was placed in a location that did not violate the basic operating requirements of the technology. For example, the equipment had to be placed at a height sufficient to effectively "see" traffic. It also had to be placed such that the angle of the sensor to the roadway was within the tolerances set by the equipment vendors. More information on portable non-intrusive equipment can be obtained from the Minnesota non-intrusive detector test web site: http://www.dot.state.mn.us/guidestar/projects/pnitds.html.

7.3.5 Private Sector Collection of Vehicle Probe Data

Where traffic data collection is not practical, modern technology is beginning to provide a new option for collecting vehicle speed (but not volume) information. The market for roadway congestion information is large enough that a number of private companies are actively examining ways to collect roadway speed information from vehicle probes.

The following are three basic technologies that are being considered:

1. Tracking of cellular phone locations for use as vehicle speed probes;

2. Collection and fusion of vehicle location information currently in commercial and private vehicle fleets; and

3. Deployment of vehicle location and communication capabilities as part of a vehicle probe network.

Each of those technologies has several technical variations. In theory, each one will work, but none has yet been proven to work with a high level of accuracy and reliability.

Cellular phone tracking has been "just over the horizon" for a number of years. It is based on the fact that Federal Communications Commission (FCC) regulations require that cellular phones be capable of reporting their location with enough accuracy to ensure proper emergency response (the "E-911 requirement"). By tracking the location of individual phones as they move through a geographic region, those phones should be able to provide a picture of roadway performance.

To date, cellular phone tracking has had mixed success. The costs and technical difficulties with meeting the E-911 requirement have delayed deployment of phone tracking capabilities. This may be resolved in the near term by technical improvements in the location algorithms used, and it may also be resolved by placing GPS devices in cell phones, which is a technique being pursued by some cellular phone companies. In addition to resolving the basic issue of "where is the phone located," a number of other technical difficulties have slowed the use of cell phones as vehicle probes. Among the more significant issues are:

- Determining which phones are actually in motor vehicles (as opposed to those in the hands of people walking down the street or in rail cars on tracks beside freeways); and

- Which roads a given phone happens to be traveling on (is it on the freeway or the frontage road?).

A number of tests of cell phone tracking capabilities is currently underway, and the results from those tests should indicate the extent to which cell phone tracking can be used for providing freeway speed information in the near term.

The second technical approach to collecting vehicle probe data relies on the fact that many freight and commercial vehicle operators have placed GPS devices and electronic communications capabilities in their vehicles in order to track the location of those vehicles. Several firms are actively exploring the use of data from these systems for capturing roadway performance information. To make this concept functional, data from multiple vehicle location systems are most likely required. The vehicle tracking data from these multiple systems must then be fused, and unusual attributes of any of the vehicles participating in the system must be removed. (For example, a large number of the tracked vehicles are long-haul, heavy, commercial trucks. These vehicles tend to go very slowly up long hills. If this performance characteristic is not corrected, "congestion" may be frequently reported on most mountain passes, even when no congestion exists.) To date, a full data collection system based on this approach has not reached the market, but several firms are actively working on developing this concept.

A major variation of this probe fleet approach to data collection is based on the concept that vehicles equipped with devices that provide in-vehicle traffic information should themselves become vehicle probes that contribute to the database used by all traveler information system customers. One company demonstrated a functional prototype of such a system at the 2005 ITS World Congress. In that prototype system, individuals would purchase a traffic navigation and congestion reporting system. Vehicles equipped with that device not only receive updates on roadway congestion in the region in which they are traveling, they report any congestion they experience while being driven. The result is that the customers of the traffic information contribute to the traffic information used by other customers.

A current NCHRP study, project number 70-01, *Private Sector Provision of Congestion Data*, is actively reviewing ongoing system tests of privately collected congestion information. Material from that study and the results of specific field operational tests should be reviewed as it is published to learn the status of these various efforts. *However, even if one or more of these efforts turns out to be a cost-effective way to collect freeway speed information, additional data collection that describes the number of people and vehicles using the freeway will still be required, because mobility information without facility use information is of limited utility for freeway performance reporting.*

In addition to the basic cost and accuracy of the technology, a freeway agency also needs to consider the implications of purchasing its performance data from a private source. On the plus side, the freeway agency does not need the staffing or expertise to operate the data collection system. On the negative side, the agency needs a contract mechanism which ensures the continued quality and accuracy of the data that is being given to it. That contract mechanism must also make sure the data are delivered in a timely fashion and in the form specified. Finally, the agency will need a contingency plan in case events outside of the control of the freeway agency disrupt the supply of data. (For example, what happens if the private company providing the data the freeway agency relies on for making decisions goes bankrupt, or the cellular phone company providing phone tracking information decides that it is not in the best interest of the phone company to provide the information used to track cellular phones any more?)

Thus, while considerable benefit might be gained from the private sector provision of congestion information, especially in the ability to quickly and relatively inexpensively expand the geographic coverage of the roadway system for which continuous roadway congestion information is available, that benefit must be traded off against new issues relating to control of that data.

■ 7.4 Freeway Geometric and Operating Data

7.4.1 Introduction

The geometric data specified in this section relates to those elements required to do ongoing freeway performance monitoring. As such, the level of detail is not as great as if analysis of alternative geometric designs using microsimulation models was to be conducted. Therefore, the data specified here is considered to be the minimum required. Freeway geometric data has several uses in a performance measurement program:

- Definition of freeway sections for performance monitoring;
- Capacity analyses;
- Bottleneck identification; and
- Safety analyses.

7.4.2 Required Geometric Data

Defining Freeway Segments and Sections

For performance monitoring, it is necessary to break the freeway up into discrete parts. Freeway segments are the basic building blocks for data collection. These are to be consistent with the HCM definitions. Defining them as the freeway portion between interchanges is an excellent starting point. They may also be defined by the location of traffic monitoring devices, if the traffic being measured can be considered uniform for the segment. *The segment is the basic unit for which all remaining freeway geometric data are collected (e.g., lane width, number, and type of lanes).*

Sections are accumulations of segments. The term "corridor" is sometimes used to denote these, though that term can imply that multiple facilities are included where parallel roadways exist. Sections are meant to represent major travel movements, such as commuter travel or travel to rural recreational destinations. Chapter 9 has more detail on how to define sections.

Cross-Section Data

Basic data on the cross-section should be collected. These data exist in many state roadway inventory files, as well as the Highway Performance Monitoring System (HPMS) Sample maintained by the FHWA. (Note that the HPMS Sample may not be inclusive of all freeway segments, but many states routinely oversample their freeways.) The data should include:

- Number of lanes;
- Lane width;
- Left/right shoulder widths;
- Median width and type; and
- Type of roadway lane (general purpose, HOV, HOT, reversible, etc.).

Vertical and Horizontal Alignment

Details on the nature of grades and curves are generally not required for performance monitoring – only those data items useful for conducting general capacity analyses should be collected. However, extreme grades and curves are exceptions – in these cases, the specific should be collected. The data should include the following:

- "General terrain" is usually adequate for vertical alignment (level, rolling, mountainous);
- Extended grades should have slope and length collected; and
- Only extreme horizontal curves should be noted (usually not a freeway issue).

Lane Configuration Data

Lane configuration data is extremely important for freeway performance monitoring. In particular, designations of auxiliary lanes and special purpose lanes, such as HOV or reversible lanes, need to be understood when conducting performance analyses. For example, in Figure 7.2, AADT calculations would normally consider all the lanes (including auxiliary and HOV). However, for delay or travel time-based analyses, it is usually desirable to separate HOV from general purpose lanes, and to exclude auxiliary lanes (since speeds are naturally lower on these even for uncongested conditions. HOV lanes need to have the hours of operation noted, and if they are reversible, hours need to be keyed to direction.

Weaving sections are of particular concern for freeway performance monitoring because these are areas of vehicular conflicts, which affect both traffic flow and safety. The HCM definitions should be used to define weaving sections (Figures 7.3 through 7.5).

Figure 7.2 Example Lane Configurations

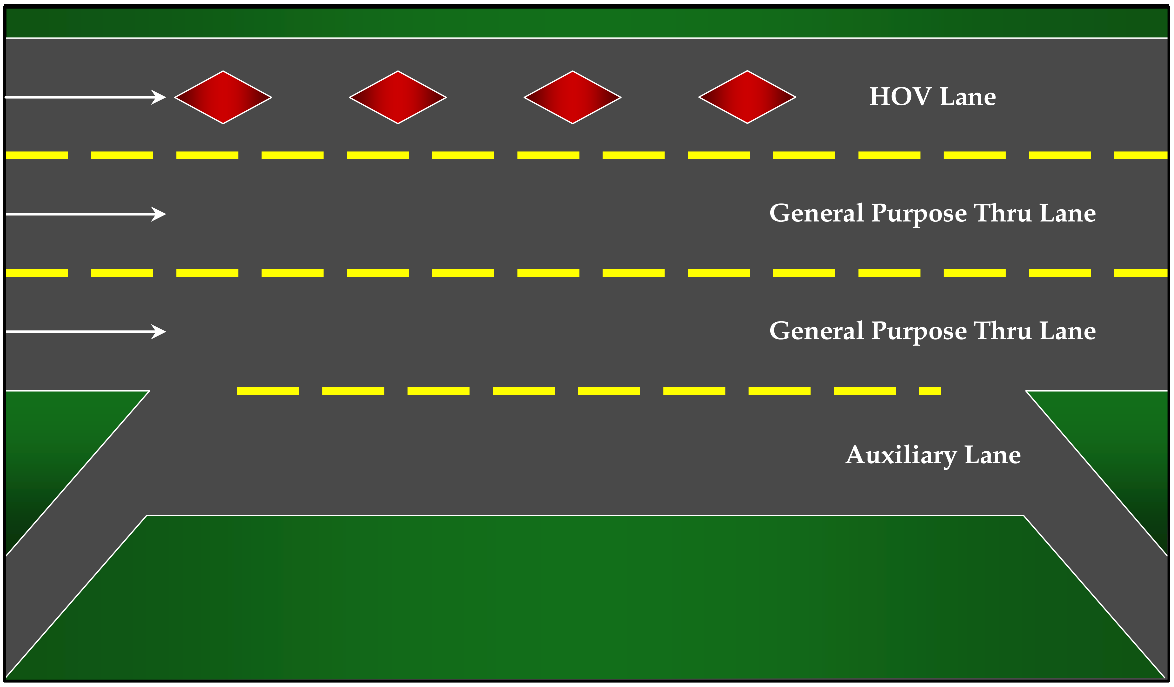
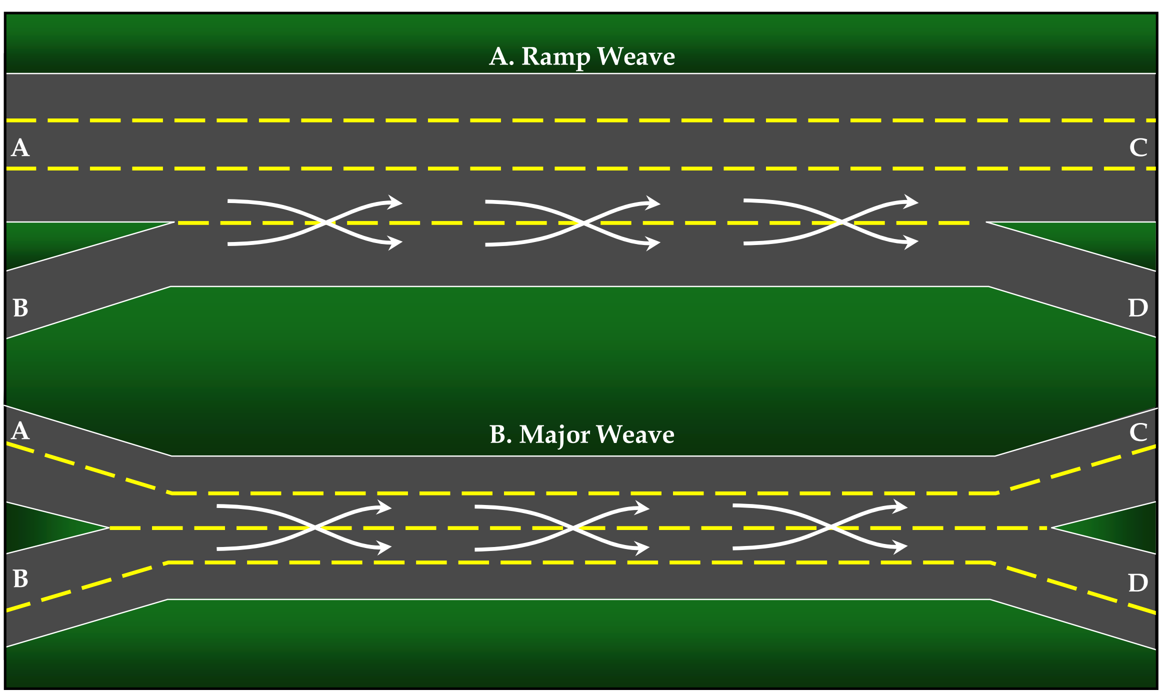
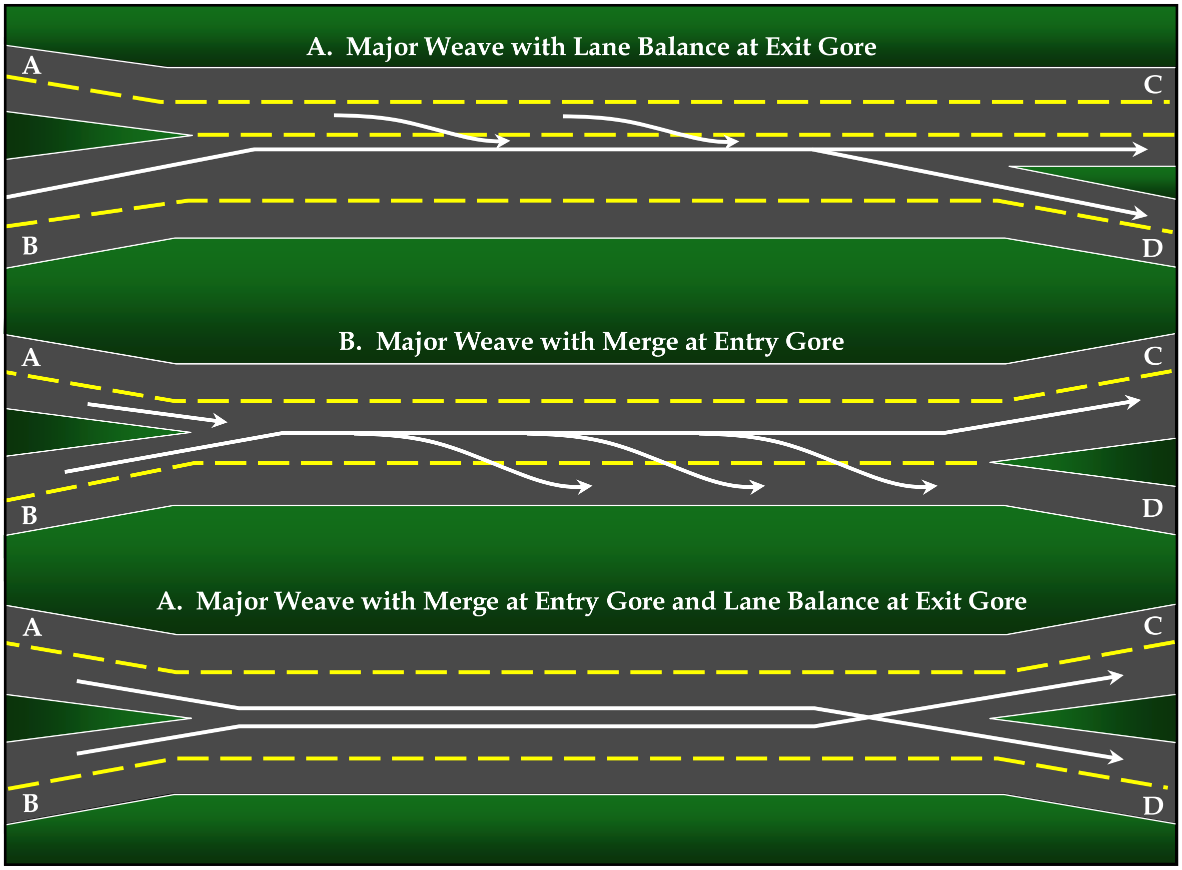


Figure 7.3 Weaving Segments
Type A



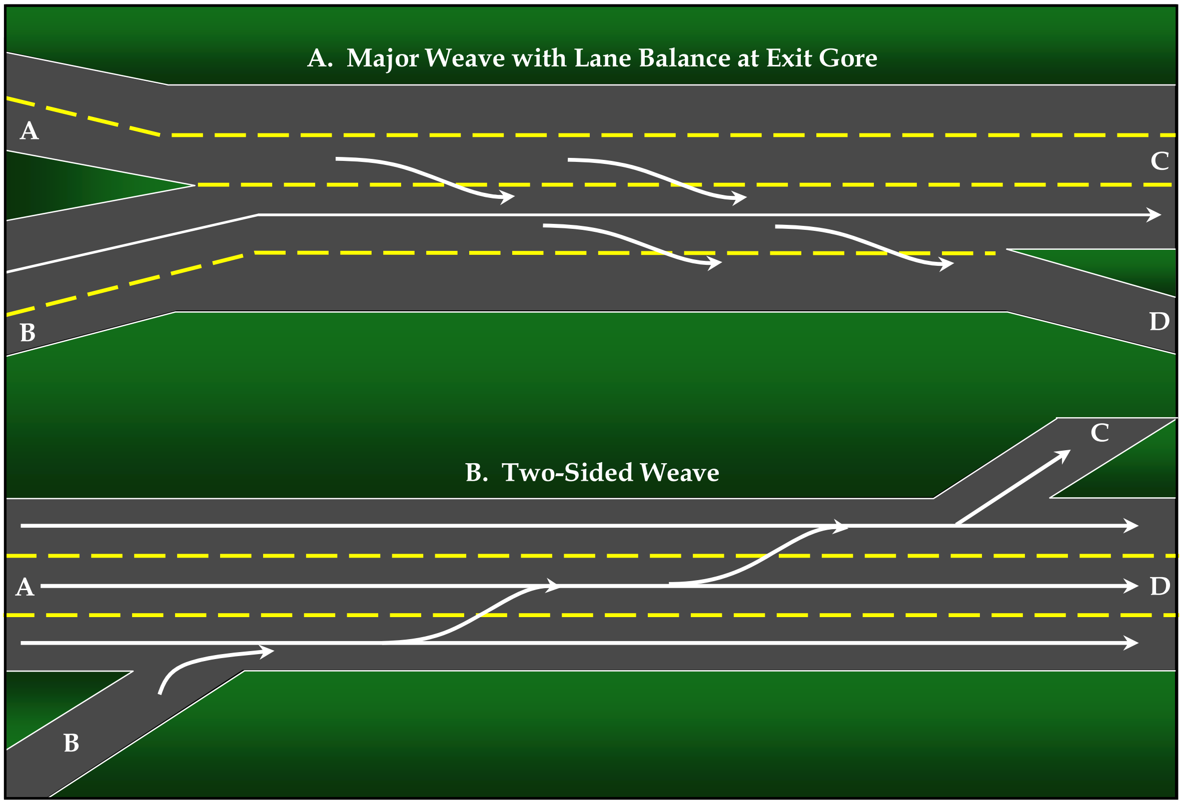
Source: HCM 2000.

Figure 7.4 Weaving Segments
Type B



Source: HCM 2000.

Figure 7.5 Weaving Segments
Type C



Source: HCM 2000.

7.5 Incident Data

7.5.1 Introduction

An extremely important data source for freeway performance monitoring – especially for urban freeways – is one that describes the number, location, characteristics, and duration of incidents. Incidents of all kinds are a significant cause of roadway delay; and the higher the volume a roadway normally carries, the larger the delay (in terms of vehicle-hours lost) that tends to result from any given incident. Reducing that delay is a major part of improving roadway performance.

Having a system that monitors where incidents take place, what types of events take place, and how effective the response is in responding to and clearing those incidents is a key ingredient to a successful incident response program. This is particularly important because to many agencies involved in incident response, keeping the roadways operating as efficiently as possible is NOT a priority. Their priority is public safety and the safety of their response crews. Thus, roadway agencies must be able to present convincing arguments to these agencies for why roadway operations is important, and how the job performance of these other agencies affects the public and their own staff's working conditions. For example, many fire crews routinely close roads at the scene of a vehicle fire, because a closed road is a "safe" working environment for the fire crews. Unfortunately, the back up caused by a road closure can easily create secondary incidents which require the attention of fire crews, thus, making them exposed to danger longer than if a different response (a partial road closure) was used in order to limit the size of the incident-caused congestion back up.

Although incident data are being collected today by transportation and emergency response agencies, there is little uniformity in the data that currently exist. The development of standards (and more importantly, their implementation) has lagged, and the two major standards efforts[2] are more focused on data to improve incident response rather than capturing the impact of incidents on traffic flow. (Both are needed for a comprehensive performance monitoring program.) A recent NCHRP project took a look at this problem and made recommendations for data collection.[3] A current (as of this writing) FHWA project is extending this effort.[4]

7.5.2 Required Incident Data

Figure 7.6 shows the basic categories of data required to support traffic incident-related performance measures. Table 7.1 shows the *minimum* set of data items that should be collected under each of these categories. This more detailed level of data collection makes the data collection function more complex, but it is necessary to analyze differences in incident behavior and/or to manage the response more effectively. For example, we have major problems right now understanding the accident rates associated with different types of HOV lanes, because accident data rarely differentiates between HOV and GP lanes on a given freeway.

[2] *P1512.2 Standard for Public Safety Traffic Incident Management Message Sets for Use by Emergency Management Centers*, developed by the Institute of Electrical and Electronics Engineers, Inc. (IEEE); and *Traffic Management Data Dictionary (TMDD)*, developed by the Institute of Transportation Engineers (ITE).

[3] NCHRP Research Results Digest 289, *Measuring and Communicating the Effects of Traffic Incident Management Improvements*, Transportation Research Board, May 2004.

[4] http://ops.fhwa.dot.gov/incidentmgmt/tim_perfmeasures.htm.

Figure 7.6 Incident Data Model for Performance Monitoring

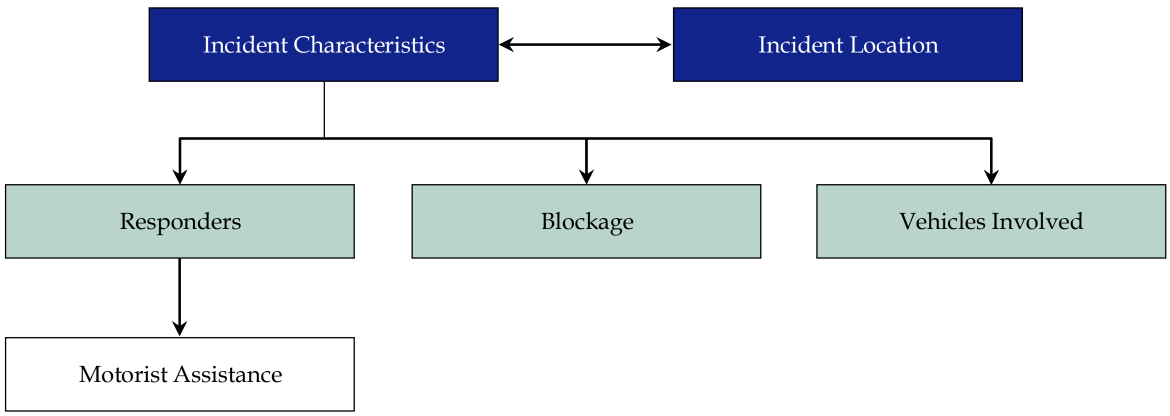


Table 7.1 Basic Incident Data Items for Performance Monitoring

INCIDENT_CHARACTERISTICS	
INCIDENT_IDENTIFIER_identifier	
INCIDENT_IDENTIFICATION_SOURCE_code	
INCIDENT_Type_code	Crash, disabled vehicle, fire, debris, abandoned vehicle
INCIDENT_CollisionType_code	Fixed object, overturn, vehicle/side, vehicle/headon, vehicle/rearend
INCIDENT_BeginDate_date	
INCIDENT_EndDate_date	
INCIDENT_BeginTime_utc	May have to be estimated unless incident is directly observed
INCIDENT_DetectTime_utc	
INCIDENT_VerifyTime_utc	
INCIDENT_FirstResponseDispatchTime_utc	From incident timeline (see Figure 7.7)
INCIDENT_FirstResponderSceneArrivalTime_utc	
INCIDENT_AllClearTime_utc	
INCIDENT_LastResponderSceneDepartureTime_utc	
INCIDENT_Severity_code	KABCO injury scale
INCIDENT_MaximumLanesAffected_quantity	

Table 7.1 Basic Incident Data Items for Performance Monitoring (continued)

INCIDENT_CHARACTERISTICS (continued)	
INCIDENT_TotalDuration_quantity	The time elapsed from the notification of an incident to when the last responder has left the incident scene
INCIDENT_WeatherCondition_code	None, rain, snow, sleet, fog, rain+fog, sleet+fog, smoke/dust
INCIDENT_ResponsePlanEnacted_code	Locally defined
INCIDENT_DmsResponsePlanEnacted_code	
INCIDENT_LOCATION	From local referencing system
INCIDENT_IDENTIFIER_identifier	
INCIDENT_LOCATION_RouteNumber_text	
INCIDENT_LOCATION_RouteSigning_code	
INCIDENT_LOCATION_TrafficDirection_code	
INCIDENT_LOCATION_Latitude_location	
INCIDENT_LOCATION_Longitude_location	
INCIDENT_LOCATION_Xcoordinate_quantity	
INCIDENT_LOCATION_Ycoordinate_quantity	
INCIDENT_LOCATION_Milepoint_quantity	
INCIDENT_RESPONDER (coded for each responding agency)	
INCIDENT_IDENTIFIER_identifier	
INCIDENT_RESPONDER_agency_name_identifier	
INCIDENT_RESPONDER_equipment_type_code	
INCIDENT_RESPONDER_notification_time_utc	From incident timeline
INCIDENT_RESPONDER_dispatch_time_utc	
INCIDENT_RESPONDER_scene_arrival_time_utc	
INCIDENT_RESPONDER_scene_departure_time_utc	

Table 7.1 Basic Incident Data Items for Performance Monitoring (continued)

INCIDENT_MOTORIST_ASSISTANCE	
INCIDENT_IDENTIFIER_identifier	
INCIDENT_MOTORIST_ASSISTANCE_call_number_identifier	
INCIDENT_MOTORIST_ASSISTANCE_vehicle_code	
INCIDENT_MOTORIST_ASSISTANCE_activity_type_code	
INCIDENT_BLOCKAGE (coded for each lane and shoulder blocked)	
INCIDENT_IDENTIFIER_identifier	
INCIDENT_BLOCKAGE_cross_section_feature_affected_code	Lane, partial lane, right shoulder, left shoulder, median, off maintained way
INCIDENT_BLOCKAGE_lane_type_code	Through/GP, through/HOV, auxiliary, on-ramp, off-ramp
INCIDENT_BLOCKAGE_lane_number_code	For lanes, the lane number following either the TMDD[a] or TMG[b] schemes
INCIDENT_BLOCKAGE_begin_time_utc	May have to be estimated if not directly observed
INCIDENT_BLOCKAGE_end_time_utc	
INCIDENT_BLOCKAGE_type_code	Incident-involved vehicle, emergency vehicle, debris
INCIDENT_VEHICLES_INVOLVED (coded for each vehicle involved)	
INCIDENT_IDENTIFIER_identifier	
INCIDENT_VEHICLE_NUMBER_identifier	
INCIDENT_VEHICLE_TYPE_code	Passenger vehicle, single-unit truck, combination truck
INCIDENT_VEHICLE_HAZMAT_PLACARD_code	
INCIDENT_VEHICLE_HAZMAT_RELEASE_code	

[a] Traffic Management Data Dictionary, http://www.ite.org/tmdd/.

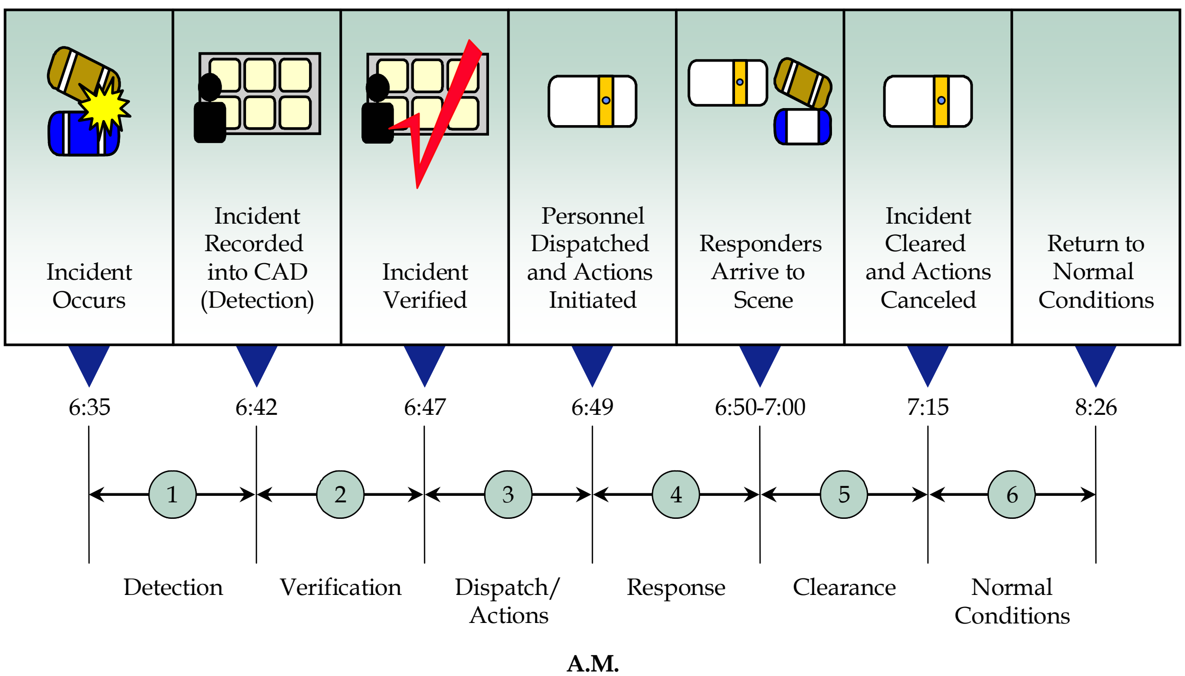
[b] *Traffic Monitoring Guide*, http://www.fhwa.dot.gov/ohim/tmguide/index.htm.

The concept behind this data structure is to capture four basic types of information:

1. **Characteristics of the Incident –** Location, type, severity. These data are more detailed than typically found in existing databases.

2. **The Incident "Timeline" –** Key actions and milestones related to response actions (Figure 7.7). Once these key points are established, many possible combinations are possible.

Figure 7.7 The Incident Timeline



Source: California Department of Transportation.

3. **Details on the Blockage Characteristics –** Whenever lane or shoulder blocking changes, it is noted. In addition to the timeline information, agencies may find it desirable to monitor what happens to the highway cross-section at the incident scene. This accounts for conditions that may change during the course of clearing an incident. For example, a rear-end collision may block a single lane initially. When responders arrive, they may close an additional lane in order to manage the incident. Finally, once cleared, emergency vehicles may remain on the shoulder for some time. All of these discrete events have a widely different impact on traffic flow. These data would allow more refined analyses to be performed, as well as to track how well responders are managing incident scenes (from the perspective of traffic flow). The data required for this task is presented below. The data is structured as the times that

lane or shoulder blocking events begin. Every time the nature of the blockage changes, a new entry is made. This report suggests these data are optional since some agencies may not have the resources to collect them.

4. **Details of Incident Response –** What agencies responded, what equipment was used. The response category has several important attributes. Chief among them is an understanding of how often specific types of response units must be called out, and (when combined with location and time of day information) when and where those responses are needed. This allows agencies to determine what types of arrangements are needed for working with other agencies, which arrangements are most critical to the performance of the roadway system, as well as judge the effectiveness of programs meant to enhance the interaction of the roadway agency and these key partners in the incident response process.

7.5.3 Potential Sources of Incident Data

Thanks to modern technology, it is possible to collect much of the required data through electronic devices used in the field. This reduces the amount of time and money needed to enter data in the office, improves the quality and timeliness of the data, and provides analysts with the management information needed to undertake performance monitoring, and ultimately, to make improvements in the incident management process. The data entry process should be created as part of the routine portion of people's work. It should be as automated to the extent possible. Possible sources of data include the following, and these are not mutually exclusive and multiples may be used in combination to feed data into the system:

- Service Patrol/Incident Response Team Data Entry – PDAs/laptops in the vehicles;
- TMC Operator Data Entry – Automate the conversion of web information to database entries; and
- Police Computer-Aided Dispatch (CAD) files.

Existing data systems may need to be modified to capture the required data. Equally important, procedures for personnel (e.g., TMC operators) may have to be changed in order for data collection to occur.

7.6 Work Zone Data

7.6.1 Introduction

Many DOTs are already facing the need to reconstruct major multilane freeways. These multimillion (billion) dollar projects involve very costly traffic mitigation efforts. These efforts range from working only at night (but resulting in quality control problems, and long project delivery times) to closing entire freeways for entire weekends in order to perform overlay paving for 48 consecutive hours, to "in between" alternatives such as closing two lanes at a time, while construction takes place for two shifts a day.

Understanding which is the best option for a construction management plan involves considerable analysis, for which all of the traditional data (especially volumes by time of day) are required. For very large projects, many state DOTS are doing very sophisticated traffic simulation modeling to determine the effects of alternative traffic management plans. Monitoring of the actual congestion effects is then performed, both to be able to provide data to the public on what has actually happened, and to be able to adjust the traffic management plan in case congestion is worse than expected.

7.6.2 Required Work Zone Data

For the purpose of freeway performance monitoring, the structure specified in Figure 7.8 and the data items specified in Table 7.2 are recommended. These fall into two broad categories:

1. **Work Zone Characteristics –** The actual and planned changes in the roadway environment created by the work zone. These are used to measure the extent of work zones in time (duration) and space (amount of existing highway removed for the work zone), and their impact on safety and mobility. They can also be used in traveler information services to alert motorists to expected work zone conditions. In general, the types of information that should be collected are work zone type, longitudinal characteristics and extent (including details on transition zones and tapers), duration of work zone characteristics, and major cross-section characteristics of the work zone. Separate tracking for both actual and planned changes should be done.

2. **Work Zone Activity –** The activities related to traffic management and construction/ rehabilitation in a work zone. These are used to assess mobility and safety impacts of traffic control plans and motorist guidance, as well as improvements in construction planning and execution. Data include specifications in traffic control plans; times traffic control plans are in effect; traffic control device placement in the field and times used (e.g., pavement markings, DMS and static signage, positive guidance devices, barriers; other new technologies); construction and rehabilitation field activities (e.g., crew size by task, task duration, equipment used on-scene); and time of day and where in the work zone the work occurred.

Figure 7.8 Work Zone Data Model for Performance Monitoring

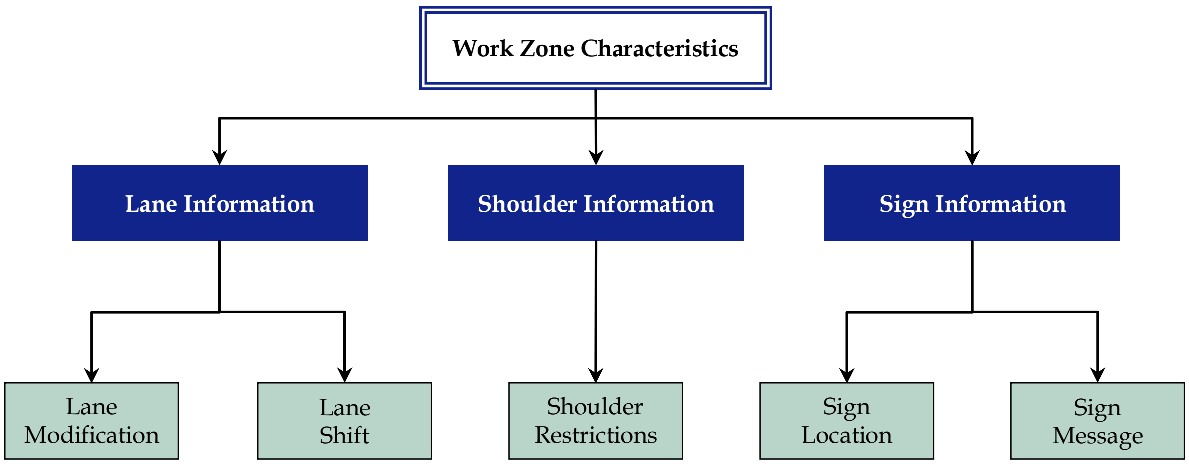


Table 7.2 Data Items for Work Zones

Supporting Data (Used to Support Metrics and for Custom Analysis)

LANE_MODIFICATION_Physical_Restriction_ Type	The type of restriction (closure, narrowing) imposed on the lane
LANE_MODIFICATION_Lane_Narrowing_ Quantity	The measured narrowing of the lane to the nearest 0.5 foot
LANE_MODIFICATION_Physical_Restriction_ Start_ Point	The distance on the link from the upstream end to the beginning of the taper for the lane restriction
LANE_MODIFICATION_Physical_Restriction_ End_ Point	The distance on the link from the upstream end to the end of the taper for the lane restriction
LANE_MODIFICATION_Height_Unevenness	The vertical distance between the height of the measured lane and the lane immediately to its left
LANE_MODIFICATION_Start_Time	Times associated with the lane modification
LANE_MODIFICATION_End_Time	
LANE_SHIFT_Redirection_Description	Text description of any redirection of the lane (shifts, re-routing, etc.)
LANE_SHIFT _Shift_Angle	The degree of angle for the lane shift alignment, measured off the centerline of the lanes approaching the lane shift
LANE_SHIFT _Direction	Which way the lane shift moves traffic (left or right)

Table 7.2 Data Items for Work Zones (continued)
Supporting Data (Used to Support Metrics and for Custom Analysis)

LANE_SHIFT _Start_Point	The distance on the link from the upstream end to the beginning of the lane shift
LANE_SHIFT _End_Point	The distance on the link from the upstream end to the end of the lane shift
SHOULDER_RESTRICTION_Restriction_Type	The type of restriction (closure, narrowing) imposed on the shoulder
SHOULDER_RESTRICTION_Start_Point	The distance on the link from the upstream end to the beginning of the taper for the shoulder restriction
SHOULDER_RESTRICTION_End_Point	The distance on the link from the upstream end to the end of the taper for the shoulder restriction
SHOULDER_Width	Width of the shoulder through the work zone
SIGN_Identifier	A unique alphanumeric code
SIGN_Type	The type of sign
SIGN_LOCATION_Linear_Reference	The location of the sign using the prevailing linear referencing system
SIGN_LOCATION_sition	The location of the sign relative to the roadway
SIGN_MESSAGE_Content	Description of the message on the sign
SIGN_MESSAGE_Begin_Time	For VMSs, the beginning time of the message
SIGN_MESSAGE_End_Time	For VMSs, the ending time of the message
SIGN_MESSAGE_ID_Number	A unique code identifying the message
SIGN_MESSAGE_Type	Type of message displayed
WORK_ZONE_Type	The underlying reason why the work zone was initiated: 1) resurfacing only, 2) RRR, 3) lane addition w/o interchanges, 4) lane additions w/interchanges, 5) minor cross-section, 6) grade flattening, 7) curve flattening, 8) bridge deck, 9) bridge superstructure, 10) bridge replacement, and 11) sign related
WORK_ZONE_Median_Barrier_Type	The type of median barrier used in the work zone treatment, if any
WORK_ZONE_Median_Width	Width of the median during the work zone
WORK_ZONE_Pavement_Type	The type of material from which the pavement is constructed (e.g., concrete, asphalt)
WORK_ZONE_Speed_Limit	Speed limit for automobiles in the work zone

Table 7.2 Data Items for Work Zones (continued)
Supporting Data (Used to Support Metrics and for Custom Analysis)

WORK_ZONE_Number_of_Lanes	The lowest number of lanes at any point in the work zone
WORK_ZONE_IRI	The condition of the pavement as measured by the International Roughness Index
WORK_ZONE_PSR	The condition of the pavement as measured by the Present Serviceability Rating
WORK_ZONE_Pavement Structural Condition	Text description of the physical condition of the pavement
WORK_ZONE_Pavement Type	Type of material from which the pavement is constructed
WORK_ZONE_Weight Restriction	Maximum Vehicle Weight allowable in a work zone
WORK_ZONE_Roadway_Capacity	Reduced roadway capacity due to WZ
WORK_ZONE_LANE_ID_Number	The lane number
WORK_ZONE_LANE_Channelization	Type of channelization present
WORK_ZONE_LANE_Traffic Restrictions	Traffic restrictions for the lane
WORK_ZONE_LANE_Start Point	The distance on the link from the upstream end to the beginning of the lane
WORK_ZONE_LANE_End Point	The distance on the link from the upstream end to the end of the lane
WORK_ZONE_LANE_Type	Lane type
WORK_ZONE_LANE_Width	The width of the lane
WORK_ZONE_LANE_Marking	Text description of how the lanes are marked to provide direction to motorists

■ 7.7 Special Event Data

7.7.1 Introduction

These kinds of events are somewhat different than work zone events, in that, they occur repeatedly (either every year, or more frequently than that). The advantage of this is that an opportunity to collect data on both facility demand and performance exists. This allows you to plan for the next occurrence, judge facility performance relative to previous experiences, and continue to refine operational plans in order to reduce delays.

Because many of these events are keys to either the quality of life in a region, or the economic vitality of a region, reducing the delays experienced in attending these events is key to maintaining the economic health of regions. Traffic delays associated with these events are also highly visible to the public, and thus tend to be a barometer on the performance of the roadway agency.

Consequently, most transportation agencies tend to develop operational plans to effectively handle peak event-related demands. They need performance data to judge the effectiveness of those plans, and to refine them over time. For example, most cities that host major 4th of July fireworks displays install special traffic signal timing plans in order to get patrons to and from these festivities. To do this, traffic volumes are collected each year on roads leading to the events, and serve as inputs to the traffic signal timing plan optimization efforts undertaken to improve access to the area prior to the event, and egress from the area after the event.

7.7.2 Required Special Event Data

Only a minimum amount of data on special events is required, and used primarily to document surges in traffic volumes:

- Event name and location;
- Start/end dates and times;
- Approximate attendance (may be segmented by time periods); and
- Changes in operating policies, including start/end dates and times:
  - HOV restrictions;
  - Contraflow; and
  - Ramp meter timing.

7.8 Crash Data

7.8.1 Introduction

Crash data are collected by police officers at the scene of a crash. Every state has a unique police accident report (PAR) and administrative control of data. Most of the data collected by states are similar in nature, but may differ slightly in the details (e.g., "valid values" for data elements). Crash data from PARs are the most important data resource for safety planning and engineering analyses of safety locations.

Just as every state defines data slightly differently, so too what crashes are subject to data collection also varies, usually by some indicator of the severity of the crash. Common thresholds include:

- Crash with 1+ injuries;
- Crash with 1+ towed-away vehicles; and
- Minimum property damage dollar amount.

Crash data are structured in a hierarchy around individual crashes ("accident level"). Figures 7.9 through 7.11 show this structure and the major data elements in each structure:

- Every crash has one or more vehicles associated with it;
- Every vehicle has either one driver or no driver (parked car);
- Every vehicle can have persons in it (occupants); and
- Non-occupants (pedestrians, bicyclists, etc.) are also included.

Figure 7.9 Hierarchical Structure of Crash Data

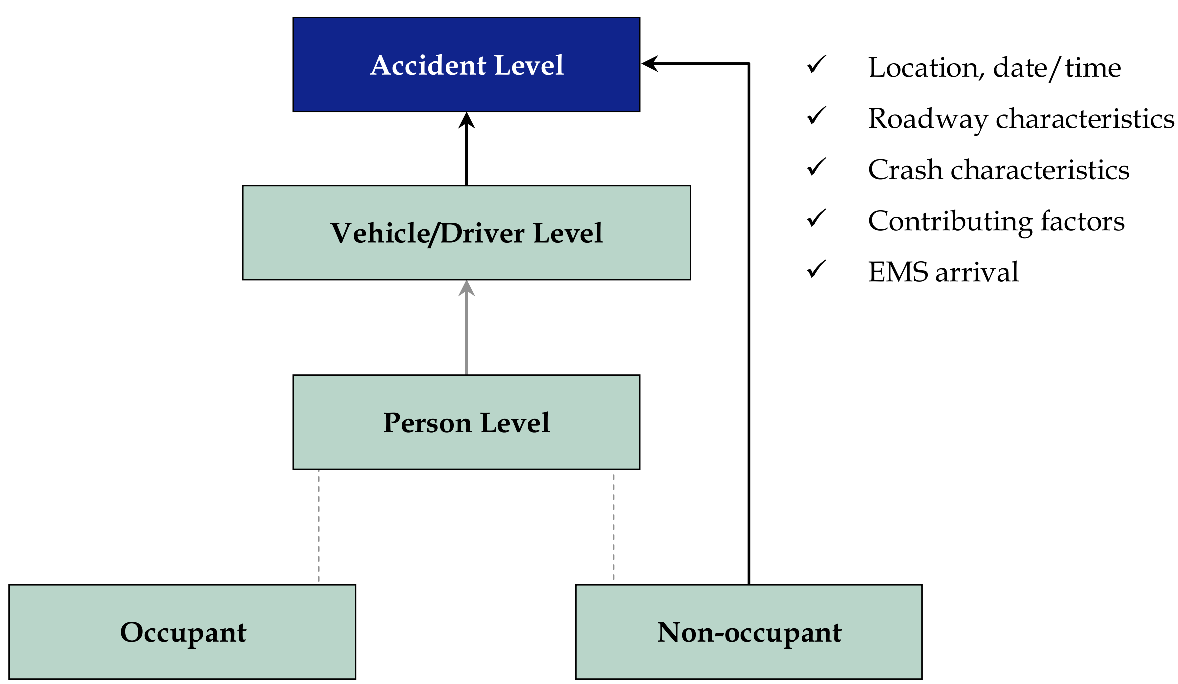


Figure 7.10 Hierarchical Structure of Crash Data

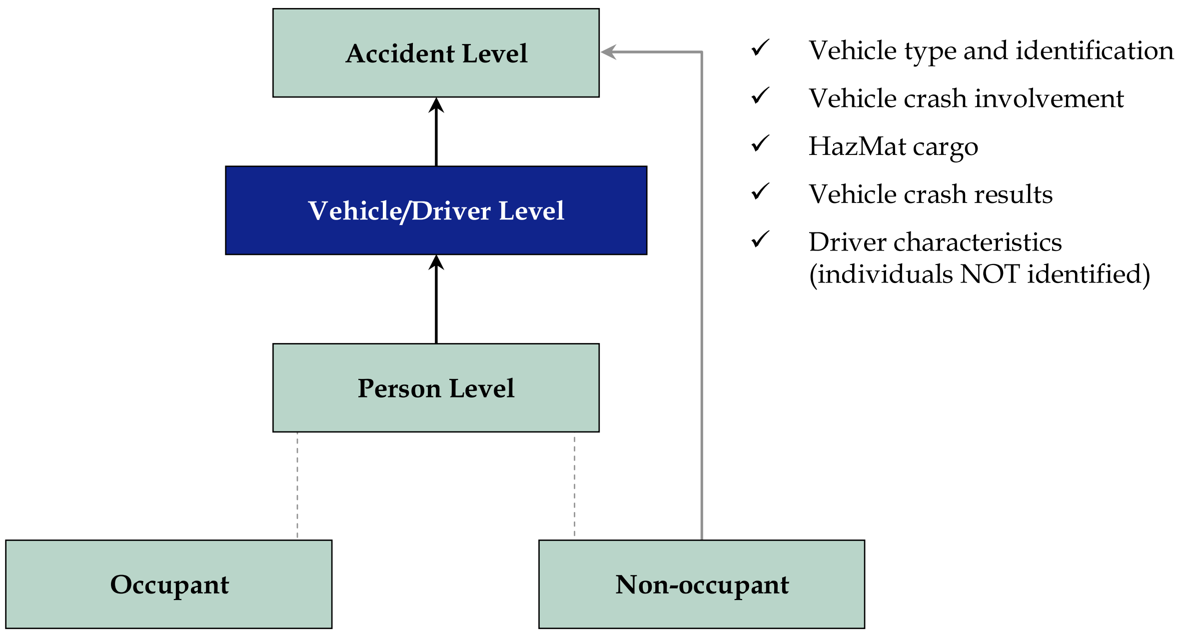
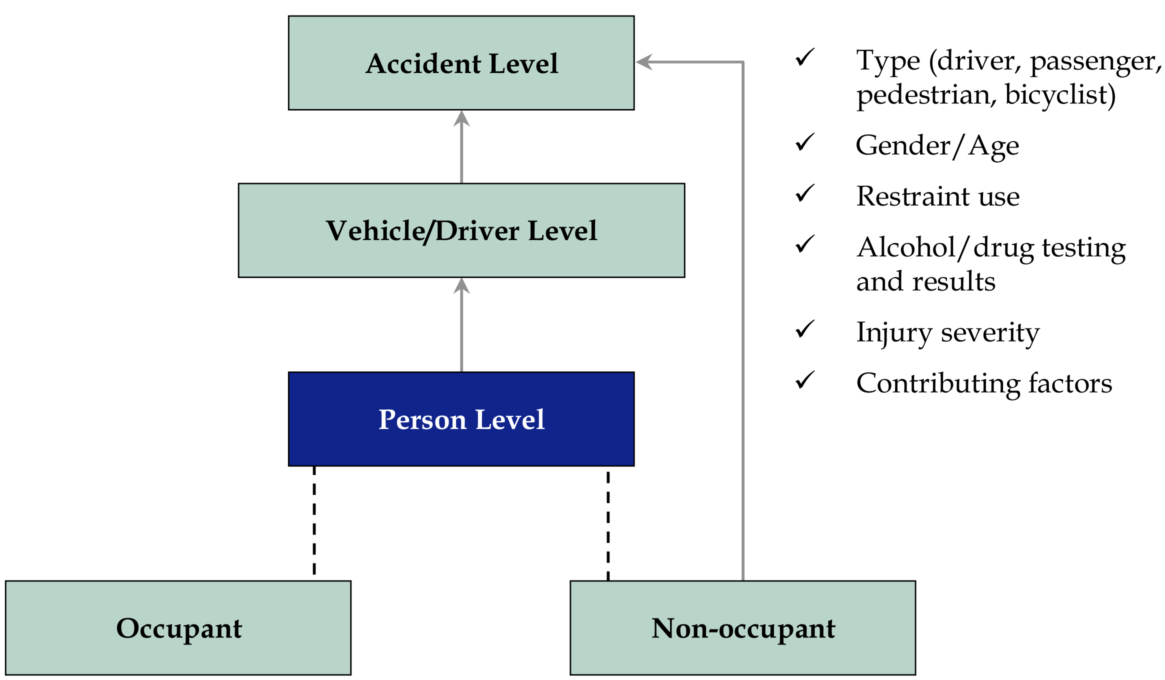


Figure 7.11 Hierarchical Structure of Crash Data



7.8.2 Required Crash Data

All of the data on the state PAR should be available for performance monitoring.

7.9 Weather Data

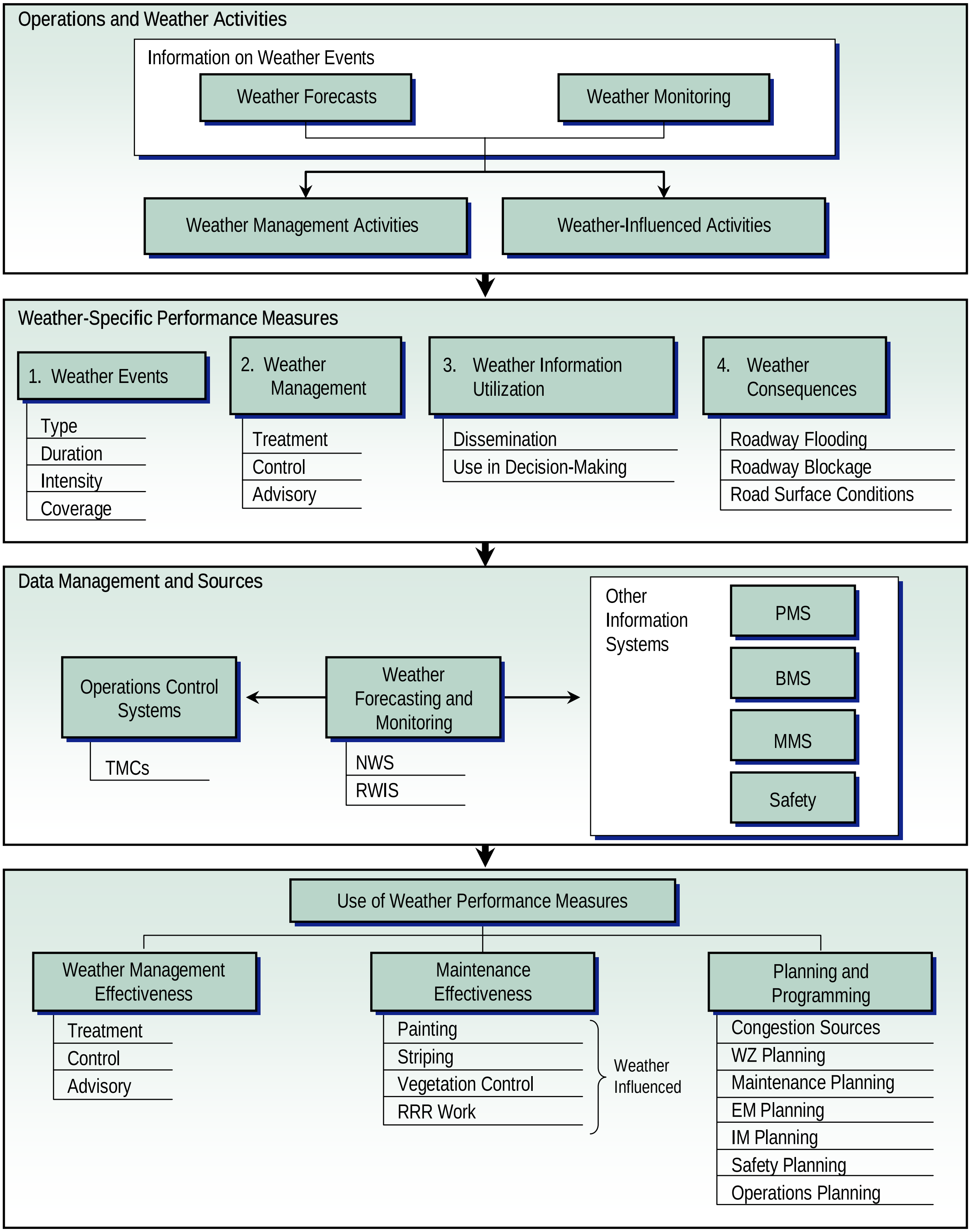
7.9.1 Introduction

Unlike congestion, incidents, and work zones, there has not been much activity in developing performance measures for weather activities. The ones which we are aware of relate to the duration/extent of weather events, weather prediction versus actual weather that materialized, and snow and ice removal activities. However, the influence of weather on traffic flow, safety, and customer satisfaction is substantial. Environmental conditions can lead to changes in driver behavior that affect traffic flow. Due to reduced visibility, drivers will usually lower their speeds and increase their headways when precipitation, bright sunlight on the horizon, fog, or smoke are present. Wet, snowy, or icy roadway surface conditions also will lead to the same effect even after precipitation has ended.

Figure 7.12 outlines an ideal weather performance measures program, which would encompass the core and supplemental measures specified in Chapter 6. Weather performance measures are useful for not only assessing the effectiveness of weather management activities (aimed at mitigating the effect of weather events), but also for assessing how well *weather-influenced activities* (particularly maintenance) are being conducted.

Weather performance measures fall into four broad categories: 1) weather events, 2) weather management, 3) use of weather information in decision-making, and 4) weather consequences. Note that these measures relate only to assessing "after the fact" performance – they do not speak to ***how*** weather information is used in control strategies, which is the domain of control systems. Note also that the top-level outcome measures related to congestion/mobility (i.e., traffic flow quality) and safety are not included here. As previously mentioned, these are universal to all aspects of operations.

Figure 7.12 Framework for a Weather Performance Monitoring Program



7.9.2 Required Weather Data

Because the development and use of weather performance measures have lagged the other performance categories, the *Guidebook* does not specify data elements as was done for incidents and work zones. Rather, a general description of the required data is given.

Weather Events

Definition – Details on the nature of weather events that influence traffic characteristics, travel decisions by users, and activities by agencies.

Features That Should Be Monitored – For each weather event:

- ***Type of Weather –*** Precipitation type, fog, dust, and high winds;
- ***Duration of the Event –*** Self-explanatory;
- ***Intensity of the Event –*** Depends on type of weather: rainfall/snowfall rates, visibility, and wind speed; and
- ***Geographic Coverage of the Event –*** Ideally, roadway segments effects by the weather event.

Weather Management

Definition – Measures on the amount and nature of weather management control strategies applied.

Features That Should Be Monitored:

- ***Treatment Strategies –*** Treatment strategies related to snow and ice control require coordination with maintenance personnel. These include pretreatment of roadway surfaces, as well as removal of snow and ice. Other treatment strategies under more direct control of operations personnel include the support of access for emergency and maintenance vehicles and using RWIS and forecast data to identify areas for pretreatment.
- ***Control Strategies –*** Speed limit control; retiming of ramp meters and traffic signals to accommodate reduced capacity and vehicle speeds; road closures; lane use control; vehicle type restrictions; and aggressive incident management (e.g., more service patrols than normal).
- ***Advisory Strategies –*** HAR and DMS weather messages, 511 weather messages, web site weather messages, and weather messages to private ISPs.
- Costs associated with all the above strategies also should be monitored.

Weather Information Utilization

Definition – Measures related to how effectively weather information is used to implement both direct weather management strategies and in planning and conducting weather-influenced activities.

Features That Should Be Monitored:

- ***Internal Dissemination of Weather Information* –** Weather forecasts and weather monitoring data that were communicated within MoDOT and between MoDOT and other agencies; and
- ***Use in Decision-Making* –** Activities that were planned around or altered by access to weather information.

■ 7.10 Customer Satisfaction Data

There are two types of customer surveys that are employed to assess freeway program performance, usefulness, and awareness: 1) specific service user survey, and 2) general public awareness survey. The user survey is directed at persons who have used a service such as 511, a traveler information web site, or freeway service patrols. The user survey will be more specific and detailed than the general public survey, since it is known that the user is aware of the service and is familiar with how to use it. The participants are contacted through their use of the service. (For example, 511 users can be asked if they are willing to participate in a brief survey during the 511 call. If they are willing to participate they can be asked for a convenient time to receive a call and a phone number.) The user survey can obtain information on whether the information provided was useful, was it understandable, or do they have suggestions for improvement. Two user survey examples are provided in the Appendix D. In both cases, the drivers handed motorists a free mail back postcard after they had helped a motorist.

The general public survey is used to obtain information on awareness of various elements of transportation agency performance, as well as their usefulness and understandability. The questions in the general public survey are usually less detailed than the user survey, since the survey participant may not be aware of the service or be familiar with its use. The general public survey, while less detailed than the user survey, will cover a broader range of the services and topics, mainly not specifically focused on freeways. An example of a general public telephone survey script for operations strategies is included in Appendix D. This survey covers the use of 511, dynamic message signs, service patrols, traveler information web sites, and traveler information from the media.

8.0 Data Processing to Support Freeway Performance Measurement

8.1 Introduction

8.1.1 Purpose of Section

This section of the *Guidebook* presents key data processing topics related to performance monitoring. This section will not provide specific recommendations on database design, software, or programming languages. Instead, the section will focus on providing general principles and guidelines, as well as pointing out issues or common pitfalls in data processing. Data processing may be considered mundane, but this step is a vital part of providing accurate and reliability freeway performance statistics. If not processed correctly, good data can appear to have serious issues or downfalls.

8.1.2 Background and Overview

The data for performance monitoring can be derived from two basic sources: 1) traditional traffic studies (e.g., "special studies") that rely on sampling performance data over time and by location; and 2) archived data that was originally collected for traffic operations purposes. Data processing is important regardless of the data source, but processing data archived from traffic operations systems may have special requirements above and beyond those from a traditional traffic study. For example, archived operations data may require additional computer resources because its detail is typically greater than that of typical traffic studies. Archived operations data may also require additional post-processing to adapt it for use in performance monitoring applications.

Because of the unique requirements and challenges, most of the material in this section of the *Guidebook* will focus on processing archived data from traffic operations systems. Where appropriate, this section will address data processing issues for traditional traffic studies. The section includes sections on quality control procedures, data management and fusion, and data analysis techniques.

8.2 Quality Assurance Procedures for Archived Data from Traffic Operations

Additional quality assurance procedures may be necessary if archived data will be obtained directly from traffic operations systems. To date, the quality of archived data from traffic operations systems has been influenced by two prevailing issues:

1. The difficulty of maintaining extensive electronic field equipment (sensors and communication); and

2. Real-time traffic operations applications that have different data quality requirements than historical uses of archived operations data.

The result has been that some managers and users of data archived from traffic operations have wrestled with data quality problems.

The most important quality assurance strategies when using archived operations data are listed here and discussed in the following sections:

- Improve data quality at the source (if possible) and avoid “scrap and rework”;
- Apply business rules (quality checks) to automate the identification of invalid data; and
- Make data quality results available to data and information consumers.

The FHWA sponsored the development of white papers[1] and two traffic data quality workshops in 2003 to identify key issues, and an action plan for improving the quality of traffic data. A subsequent report in 2004 defined data quality measures and calculation procedures and included several case study examples.[2] Where appropriate, material from these reports has been incorporated into this section; however, readers are referred to these reports for additional information on traffic data quality.

8.2.1 Improve Data Quality at the Source

In the long term, the most cost-effective way to improve data quality is to fix problems at the source. According to data quality professionals, “scrap and rework” (that is, a focus on fixing the low-quality data, instead of fixing the process that is producing low-quality

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[1] The white papers were titled *State of the Practice for Traffic Data Quality*, *Defining and Measuring Traffic Data Quality*, and *Advances in Traffic Data Collection and Management*. These papers are available at http://www.its.dot.gov/library.htm.

[2] *Traffic Data Quality Measurement: Final Report*, September 15, 2004, available at http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/14058_files/.

data) should be avoided at all costs.[3] Fixing problems at the source typically means improving the maintenance and calibration of traffic sensors, which can be difficult if the data consumers (e.g., planners) who want better data are functionally distinct from the data collectors (e.g., operations). Possible strategies for fixing data quality problems at the source include:

- **Resource sharing between functional groups –** Data consumers (outside of the operations function) could contribute funding for additional sensor maintenance. In return, data collectors might agree to a basic set of universal data quality requirements for all data applications. Or, data consumers from a planning group might agree to buy improved field equipment that provides necessary features or capabilities.

- **Focused resources at selected locations –** Many traffic operations centers deploy their freeway traffic sensors in dense patterns (typically every one-half mile); however, this sensor density may not be necessary for some applications like performance monitoring. Thus, a limited but fixed maintenance budget could be used to provide higher quality data at fewer locations. For example, the Maricopa Association of Governments is working with the Arizona DOT to better maintain about 15 percent of the freeway traffic sensors (three-mile spacing) for a regional traffic and performance monitoring system (see Figure 8.1).

- **Multipurpose data collection –** Future deployments of traffic data collection infrastructure could sidestep these data quality issues if they are designed to serve multiple applications, with some applications in real-time and other applications requiring the historical archived data. In this scenario, each application's data quality requirements are determined in advance of deployment, and maintenance and/or calibration standards are put in place to ensure meeting these requirements. The Intelligent Transportation Infrastructure Program (ITIP) was intended to demonstrate this model of multipurpose data, with real-time data being collected by a private-sector company for traveler information, and archived data made available for several designated planning purposes (like the Highway Performance Monitoring System database).

There are several other strategies that can be used to improve data quality when traffic sensors or detectors are being installed.

Better construction specifications can help to ensure that electronic sensors are properly installed with the correct calibration settings. A 2002 report written for the Texas DOT found that having good loop detector construction and installation specifications contributed to minimal detector failures.[4] This report provides numerous examples of loop detector specifications. Similar specifications for various non-intrusive detectors are typically available from the distributor or vendor.

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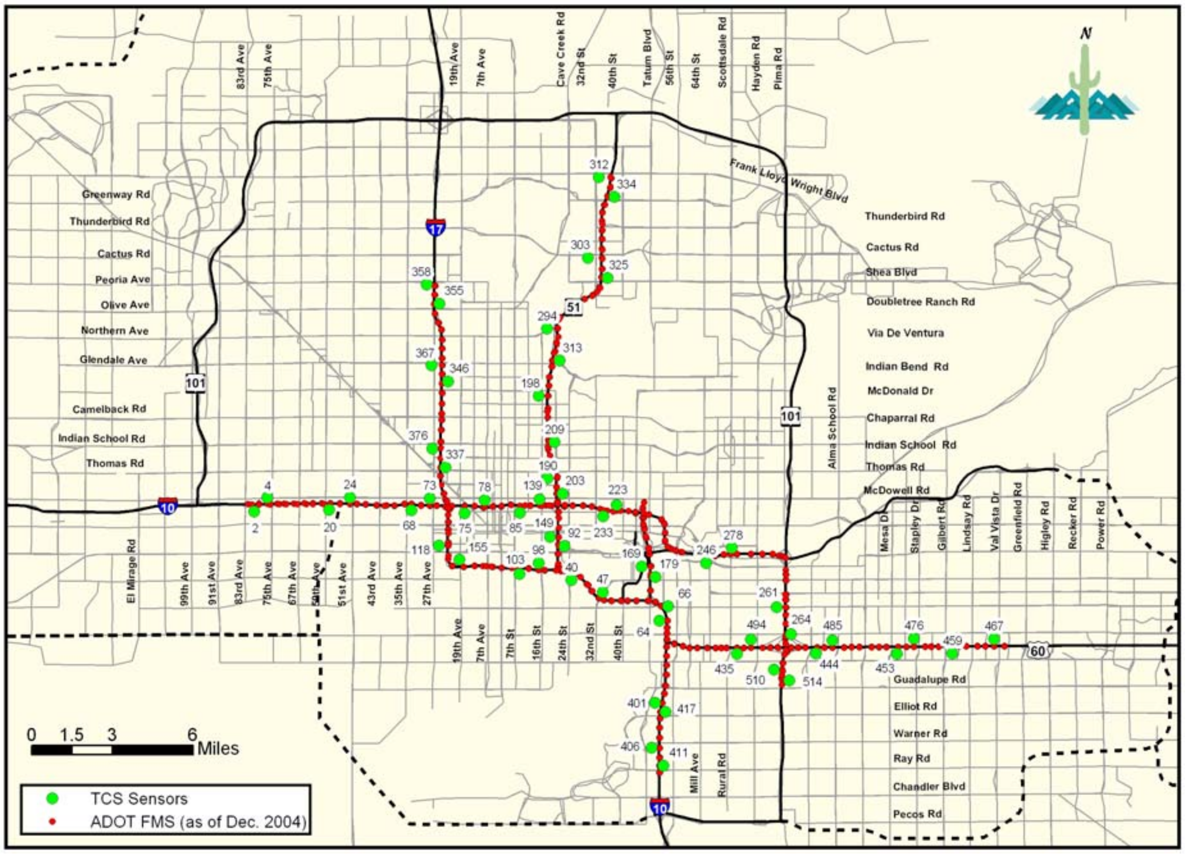
[3] See http://www.infoimpact.com/index.cfm for more information on "scrap and rework" issues related to information and data quality.

[4] See Middleton, D., and R. Parker, *Vehicle Detector Evaluation*, Research Report FHWA/TX-03-2119-1, Texas Transportation Institute, October 2002.

Figure 8.1 Priority Traffic Detectors Designated in Phoenix, Arizona



Source: *Freeway Traffic Conditions and Trends, 2004: Prototype Annual Report* . Prepared by Texas Transportation Institute for Maricopa Association of Governments, June 15, 2005.

An established *construction inspection and acceptance testing process* for field devices will help a great deal, particularly for certain types of sensors like inductance loop detectors. Anecdotal experience has indicated that inductance loop detectors are particularly prone to long-term maintenance issues when they are not installed properly. In these cases, it pays to have a knowledgeable inspector who can verify that field devices have been installed and operate correctly before construction payments are made.

Another strategy involves the use of *performance-based data collection or maintenance contracts*. In these types of contracts, a private company is paid based on the performance of field equipment or the delivery of complete, quality data. For example, the planning division of the Virginia DOT contracts with private companies to count vehicle traffic on certain roads. If the vehicle count data is 100 percent fully complete, then the contractor is paid the full contract amount. If the vehicle count data falls below a certain threshold, then the contractor receives a certain percentage of the full contract amount. VDOT does some extra quality checks to ensure that the contractors are still providing valid data – these checks ensure that the contractors do not estimate or fabricate data.

8.2.2 Apply Business Rules (Quality Control Checks)

The application of business rules (also known as quality control checks or screening rules) can automate the identification of suspect or invalid data values. These business rules describe the range of possible data values that are considered valid. Once suspect or invalid data are identified, they can be "flagged" as suspect or invalid and stored within the database, with the ability to exclude such data from subsequent calculations or analyses. Alternatively, suspect values can be reviewed by data archive managers who will make a final determination about the validity and future use of the "flagged" data.

Business rules can take numerous forms while addressing a variety of issues. In some cases, business rules are based on established theory or concepts, such as highway capacity or traffic flow. In other cases, business rules are based on intuition and "rules-of-thumb." Basic rules may only consider the minimum or maximum values for a single variable. Multivariate rules describe the interrelationships between two or more variables. Spatial or temporal rules address the possible range of values of space and time. For example, a business rule may prescribe the maximum percent difference that is considered valid for sensors in adjacent lanes or upstream/downstream locations. Or, a business rule might describe the maximum percent difference that is considered valid for traffic counts from consecutive years.

Many traffic centers and data archives have developed business rules to address issues in their traffic data collection procedures. Some of the business rules are common among locations, while others are unique by location. Table 8.1 provides an example of quality control checks used in the FHWA's Mobility Monitoring Program for identifying suspect or invalid archived data.[5] Note that this quality control checks are microscopic and are used for fairly detailed data. Other macroscopic quality checks have been defined, but these checks are more appropriate for planning-level data (such as annual average daily traffic volumes) rather than performance monitoring.[6]

[5] See *Monitoring Urban Freeways in 2003: Current Conditions and Trends form Archived Operations Data*, Report FHWA-HOP-05-018, available at http://mobility.tamu.edu/mmp/.

[6] See http://www.fhwa.dot.gov/policy/ohpi/tdep.htm for examples of planning-level traffic data quality checks.

Table 8.1 Quality Control Checks Used in FHWA's Mobility Monitoring Program[a]

Quality Control Test and Description	Sample Code with Threshold Values	Action
Controller error codes Special numeric codes that indicate that controller or system software has detected an error or a function has been disabled.	If VOLUME = {code} or OCC = {code} or SPEED = {code} where {code} typically equals "-1" or "255"	Set values with error codes to missing/null, assign missing value flag/code.
No vehicles present Speed values of zero when no vehicles present. Indicates that no vehicles passed the detection zone during the detection time period.	If SPEED = 0 and VOLUME = 0 (and OCC = 0)	Set SPEED to missing/null, assign missing value code. No vehicles passed the detection zone during the time period.
Consistency of elapsed time between records Polling period length may drift or controllers may accumulate data if polling cycle is missed. Data collection server may not have stable or fixed communication time with field controllers.	Elapsed time between consecutive records exceeds a predefined limit or is not consistent	Action varies. If polling period length is inconsistent, volume-based QC rules should use a volume flow rate, not absolute counts.
Duplicate records Caused by errors in data archiving logic or software process.	Detector and date/time stamp combination are identical	Remove/delete duplicate records.
QC1-QC3: Logical consistency tests Typically used for date, time, and location. Caused by various types of failures.	If DATE = {valid date value} (QC1) If TIME = {valid time value} (QC2) If DET_ID = {valid detector location value} (QC3)	Write to off-line database and/or remove records with invalid date, time, or location values.
QC4: Maximum volume Traffic flow theory suggests a maximum traffic capacity.	If VOLUME > 17 (20 seconds) If VOLUME > 25 (30 seconds) If VOLUME > 250 (5 minutes) If VPHPL > 3,000 (any time period length)	Assign QC flag to VOLUME, write failed record to off-line database, set VOLUME to missing/null.
QC5: Maximum occupancy Empirical evidence suggests that all data values at high-occupancy levels are suspect. Caused by detectors that may be "stuck on."	If OCC > 95% (20 to 30 seconds) If OCC > 80% (1 to 5 minutes)	Assign QC flag to VOLUME, OCCUPANCY, and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY, and SPEED to missing/null.
QC6: Minimum speed Empirical evidence suggests that actual speed values at low-speed levels are inaccurate.	If SPEED < 5 mph	Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null.

Table 8.1 Quality Control Checks Used in FHWA's Mobility Monitoring Program[a] (continued)

Quality Control Test and Description	Sample Code with Threshold Values	Action
QC7: Maximum speed Empirical evidence suggests that actual speed values at high-speed levels are suspect.	If SPEED > 100 mph (20 to 30 seconds) If SPEED > 80 mph (1 to 5 minutes)	Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null.
QC8: Multivariate consistency Zero speed values when volume (and occupancy) are nonzero. Speed trap not functioning properly.	If SPEED = 0 and VOLUME > 0 (and OCC > 0)	Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null.
QC9: Multivariate consistency Zero volume values when speed is nonzero. Unknown cause.	If VOLUME = 0 and SPEED > 0	Assign QC flag to VOLUME, write failed record to off-line database, set VOLUME to missing/null.
QC10: Multivariate consistency Zero speed and volume values when occupancy is nonzero. Unknown cause.	If SPEED = 0 and VOLUME = 0 and OCC > 0	Assign QC flag to VOLUME, OCCUPANCY, and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY, and SPEED to missing/null.
QC11: Truncated occupancy values of zero Caused when software truncates or rounds to integer value. Calculate maximum possible volume (MAXVOL) for an occupancy value of "1."	If OCC = 0 and VOLUME > MAXVOL where: MAXVOL = (2.932 * ELAPTIME * SPEED)/600	Assign QC flag to VOLUME, OCCUPANCY, and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY, and SPEED to missing/null.
QC12: Maximum estimated density Caused by improbable combinations of volume and speed. Traffic flow theory suggests that vehicle density rarely exceeds 220 vehicles per lane per mile.	If ((VOLUME * (3,600/NOM_POLL))/SPEED) > 220 where NOM_POLL is the nominal polling cycle length in seconds.	Assign QC flag to VOLUME, OCCUPANCY, and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY, and SPEED to missing/null.
QC13: Consecutive identical volume-occupancy-speed values Research and statistical probability indicates that consecutive runs of identical data values are suspect. Typically caused by hardware failures.	No more than 8 consecutive identical volume-occupancy-speed values. That is, the volume AND occupancy AND speed values have more than 8 consecutive identical values, respectively. Zero ("0") values are included in this check.	Assign QC flag to VOLUME, OCCUPANCY, and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY, and SPEED to missing/null.

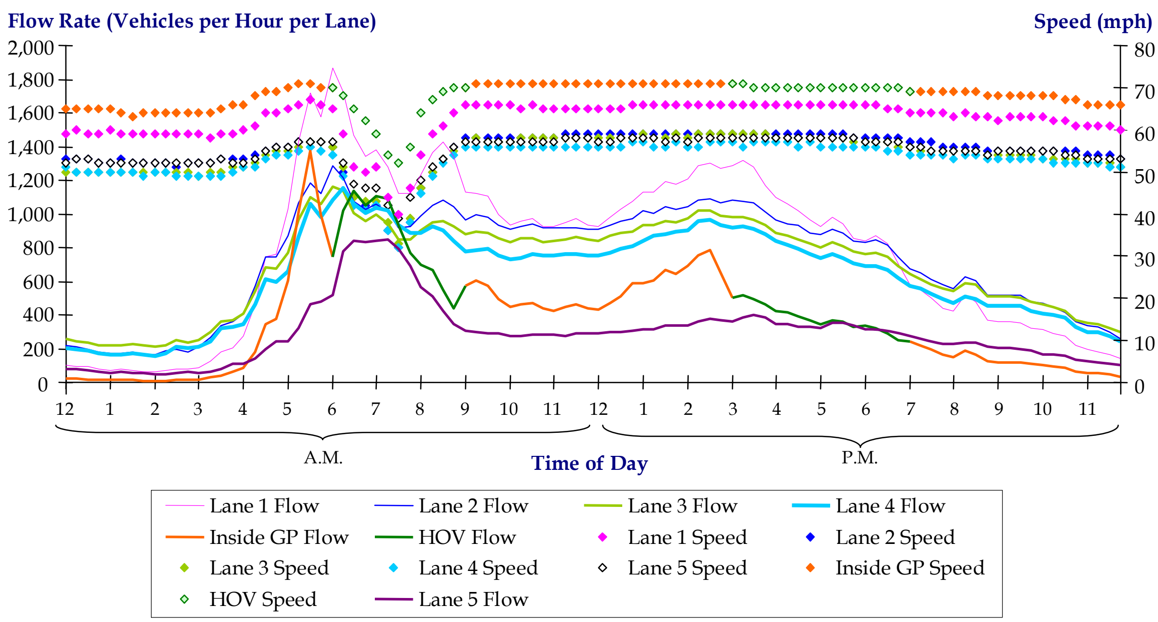
[a] http://mobility.tamu.edu/mmp.

8.2.3 Visually Review and Confirm Data Quality

There are certain traffic patterns and trends that may be more suitable for manual visual checks. These checks may be difficult to automate, or data analysts may intrinsically value the ability to visualize the data to be used in the performance monitoring analysis. In these cases, a "human-in-the-loop" can be used to visually review a standard chart, graphic, or table to determine whether the represented data portrays a reasonable pattern or trend. These visual checks will require more staff time, but are valuable in building confidence in the quality of the analysis database.

For example, Figure 8.2 shows the flow rate and speed profiles by time of day for a group of adjacent lane detectors west of downtown Phoenix. At this location, one would expect to see a strong morning peak to coincide with peak traffic driving east to Phoenix. Showing flow rates in conjunction with speed values helps to determine the typical times of congestion, as well as the reduced volumes during congestion.

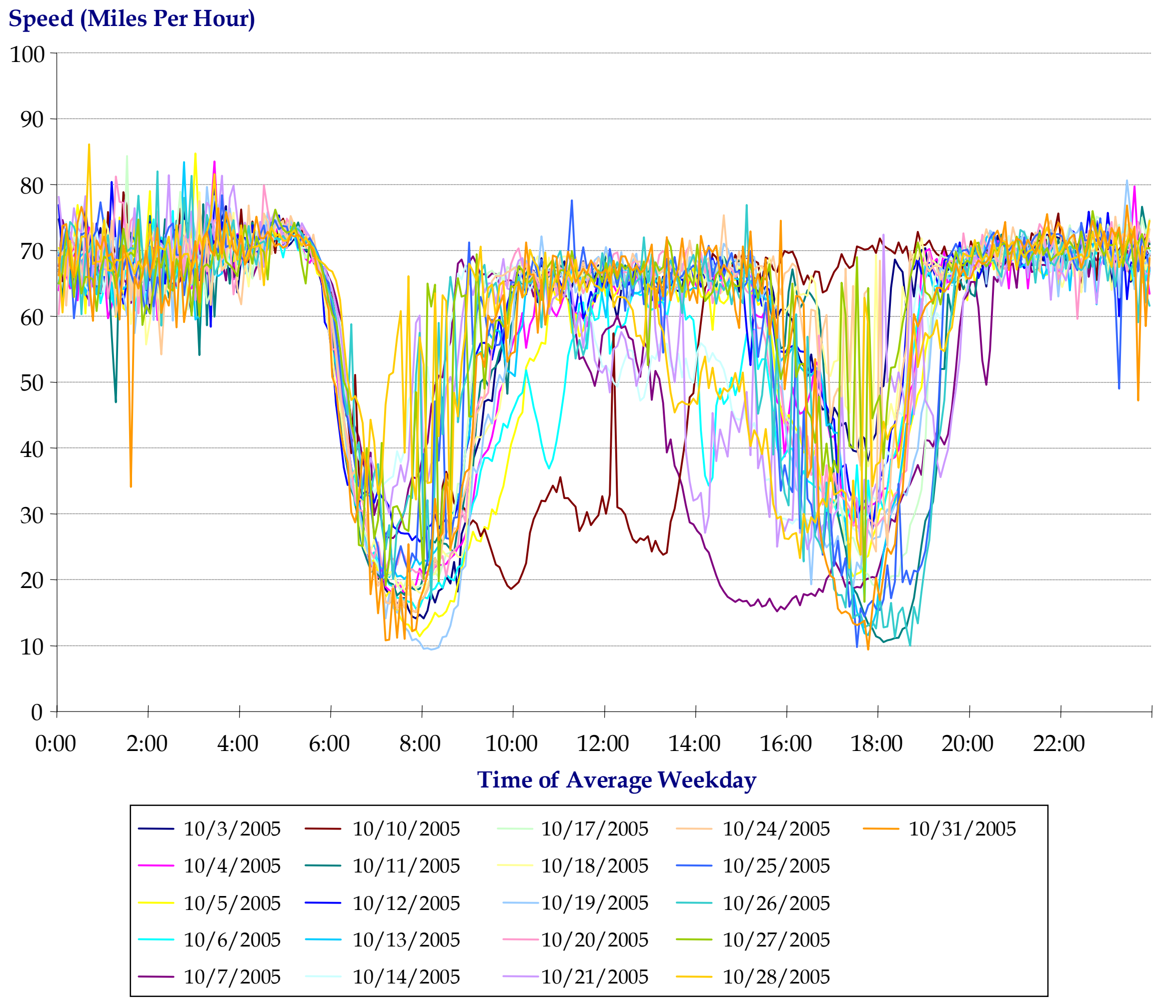
Figure 8.2 Flow Rate and Speed Profiles Used to Check Data Quality in Phoenix, Arizona
I-10 Eastbound; East of 83rd Avenue (Stn 2), Weekday, 2004



Source: *Freeway Traffic Conditions and Trends, 2004: Appendix* . Prepared by Texas Transportation Institute for Maricopa Association of Governments, June 15, 2005.

Figure 8.3 shows another example of a chart that is used to visually review large amounts of speed and travel time data in the FHWA's Urban Congestion Reporting Program. In this chart, average weekday speeds for an entire month are displayed together as a way to identify odd or suspect days. Depending upon the extent of the suspect data, further "drill down" analyses may be conducted for that day to determine if the speed data are plausible.

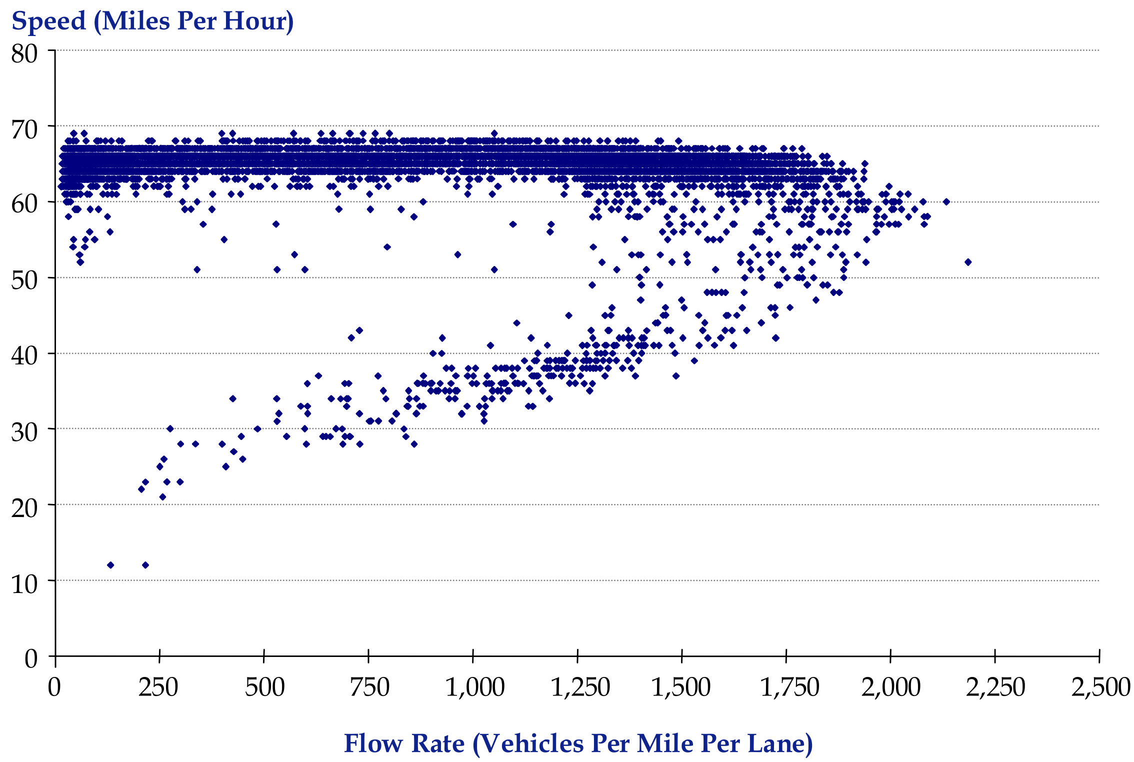
Figure 8.3 Average Weekday Speed Profiles Used to Identify Suspect Data in the FHWA's Urban Congestion Reporting Program



Source: Unpublished data, Mitretek Systems.

Another visual review approach uses highway capacity theory to identify suspect data.[7] Figure 8.4 shows a chart that plots traffic flow rates versus speeds (a full year of data is shown). This chart enables the data analyst to compare the shape of the field data points to the expected parabolic shape, as indicated in highway capacity theory. Figure 8.4 shows an example of loop detector data that embodies typical characteristics of a speed-flow curve: a near-parabolic shape with a flattened top that peaks at traffic capacities near 2,000 vehicles per hour per lane. Figure 8.5 provides an example of data that does not appear to conform to traffic flow theory. In this case, the data at this location should be further examined to determine its validity.

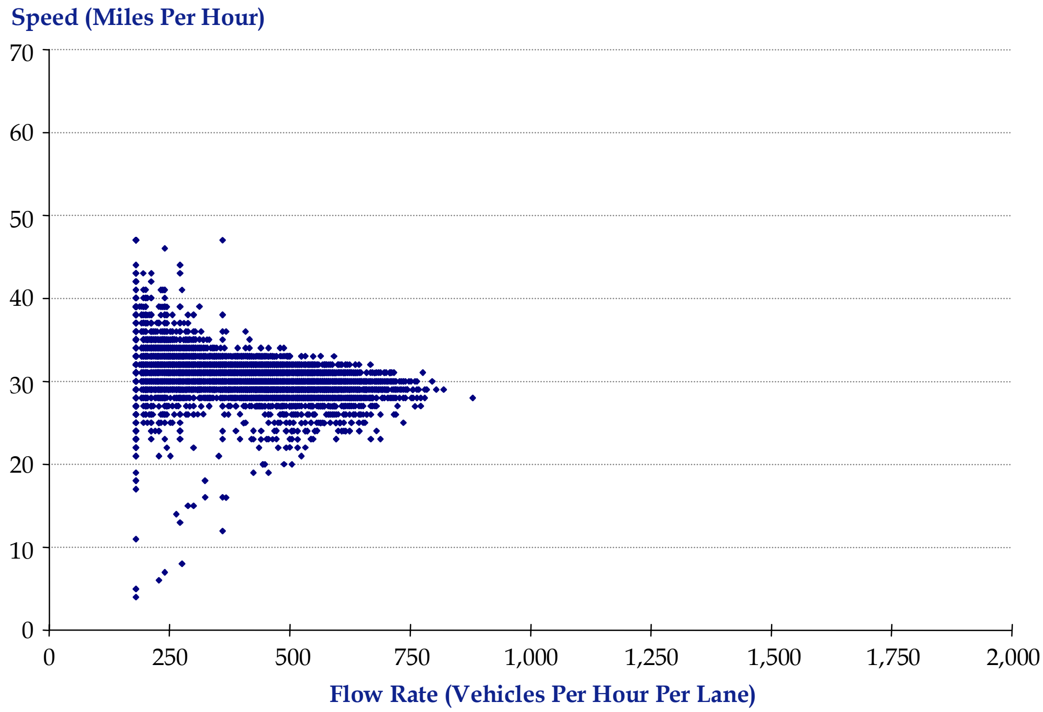
Figure 8.4 Example of Speed-Flow Curve Used to Visually Review Archived Data



Source: Unpublished data, Texas Transportation Institute.

[7] Eurek, E., *Improving Planning-Level Speed Estimation Models*, Undergraduate Fellows Program, Texas A&M University, August 2004.

Figure 8.5 Example of Speed-Flow Curve Identifying Suspect Archived Data



Source: Unpublished data, Texas Transportation Institute.

8.2.4 Communicate Data Quality Results to Data Collectors

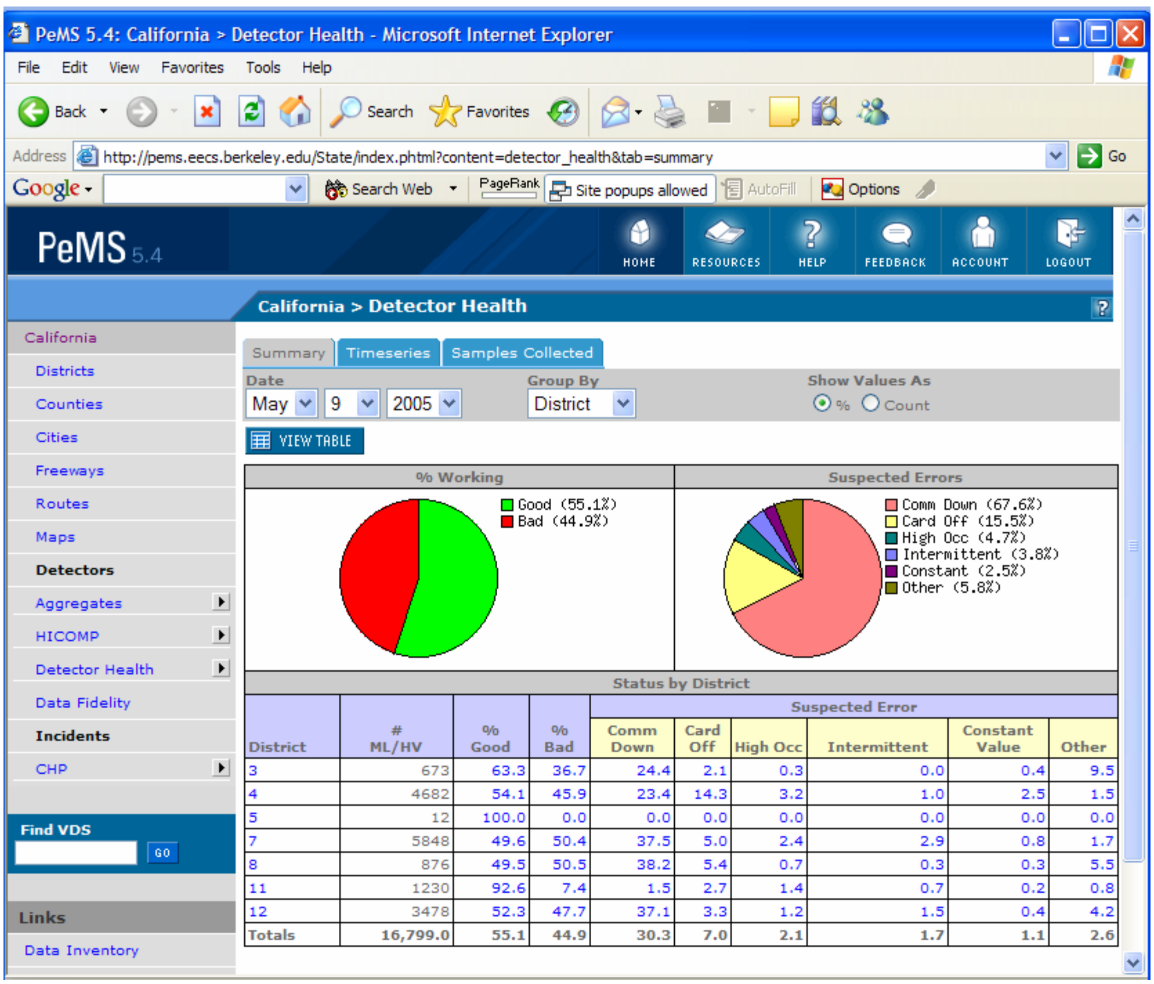
As the previous sections indicated, a "scrap and rework" philosophy should not become part of the business rule process. The results of the business rule process should provide a feedback loop to the data collection personnel, such that suspect data are not always scrapped and reworked after running business rules. In the previous example, consider that the data archive manager might notice high failure rates in certain business rules. The manager will ultimately have to flag this data as invalid; however, the manager also should communicate the high failure rates to the appropriate data collection or equipment maintenance personnel, so that the data quality problems are fixed at the source.

A brief data quality report could accompany a performance report, but the data quality results should be considered secondary in nature to the actual performance data being presented. The FHWA report, *Traffic Data Quality Measurement*, provides basic guidelines on defining, measuring, and reporting data quality.

Data quality feedback to data collectors can be provided through daily or monthly data quality reports. These data quality reports should be oriented to the organization structure, such that data quality issues can be easily dissected and fixed. For example, missing data due to communications problems (fixed by the IT workgroup) should be reported separately from hardware failures (fixed by maintenance workgroup). The data quality report can be relatively simple or more complex – again, consider the audience in developing the reports.

Figure 8.6 shows a Poems detector health report for nearly all operations traffic sensors in California (http://pems.eecs.berkeley.edu). Note that the screenshot shows a simple pie chart showing percentages of "good" and "bad" data, and then a second pie chart shows the type of errors encountered for bad data. This second chart allows managers to diagnose whether the bad data has been caused by communications problems, hardware failures, or other breakdowns. Because this data quality summary is provided on-line, it offers the capability to "drill down" from a statewide system level to specific problems that may be occurring in a single lane at a location.

Figure 8.6 Example of Data Quality Reporting Provided in PeMS



Source: Screenshot from: http://pems.eecs.berkeley.edu/Public/ .

8.2.5 Costs of Maintaining Quality Data

"Quality is free… What costs money are the unquality things…"[8] This quote from an information quality guru does not really mean that improving or fixing data quality issues can be done at no cost. Instead, this quote should be interpreted to mean that that the total costs for poor data quality (e.g., due to poor decisions, etc.) are much greater than the costs for improving data quality.

The costs for maintaining quality traffic detector data may vary considerably, depending upon numerous factors, such as the type, quantity, age, and condition of traffic detectors; type of field controller hardware and communications system; and other factors related to the data collection system. The FHWA report, *Traffic Data Quality Measurement*, provides some basic information on data quality targets for various traffic data applications, including performance monitoring. Costs estimates are also provided for monitoring and reporting traffic data quality; however, costs for meeting data quality targets are not provided for the reasons given above.

8.3 Data Management and Fusion

This section deals with general data management and fusion issues when using archived operations data for performance monitoring. Because of the wide variation and rapidly evolving software environment, the material in this section does not provide any specific guidance on database schemas or design, software, or programming languages.

8.3.1 Metadata Specification

Metadata is "data about data" and typically describes the content, quality, lineage, organization, availability, and other characteristics of the data. Metadata is typically used to: 1) determine the availability of certain data (e.g., through searches of a data catalog or clearinghouse); 2) determine the fitness of data for an intended use; 3) determine the means of accessing data; and 4) enhance data analysis and interpretation by better understanding the data collection and processing procedures.

Metadata provides information necessary for data to be understood and interpreted by a wide range of users. Thus, metadata is particularly important when the data users are physically or administratively separated from the data producers. Metadata also reduces the workload associated with answering the same questions from different users about the origin, transformation, and character of the data.

[8] See Chapter 1 in L. P. English, *Improving Data Warehouse and Business Information Quality*, 1999.

There are several different resources and standards that can be used to create and develop metadata for data archives. The Federal Geographic Data Committee (FGDC) has developed a standard for metadata used to describe geospatial data;[9] this standard can also be used to document traffic and other event data that is stored in data archive. In fact, the ASTM 2468-05 standard formalizes the use of the FGDC metadata for ITS data archives.[10] The FGDC and ASTM standards provide a nearly identical detailed structure for how to write metadata for data archives. A complimentary standard, ASTM 2259-03a standard (*Standard Guide for Archiving and Retrieving ITS-Generated Data*), provides basic guidelines for the types of metadata that should be considered in a data archive.

8.3.2 Data Archive Development

There are several resources that can be used in the development of data archives for performance monitoring or other applications. These resources are substantive; thus, a reference is provided here without including significant repetitive detail.

The National ITS Architecture (http://www.its.dot.gov/arch/) provides general user service requirements that can be used as a starting point in developing one or more of their three market packages: ITS Data Mart, ITS Data Warehouse, and ITS Virtual Data Warehouse.

The Archived Data Management System Data Model report was produced in 2002 to aid in the development of data archives (http://www.fhwa.dot.gov/policy/ohpi/travel/adus.htm). The Data Model provides several use case diagrams that more clearly define the key actors (entities that interact with the data archive system) and how they use the archived data system.

The ASTM 2259-03a standard, *Standard Guide for Archiving and Retrieving ITS-Generated Data* (http://www.astm.org), provides basic guidelines the development of data archives. Archive developers should note that this ASTM standard is not prescriptive in terms of system design, but provides general principles and further elaboration on user requirements.

Some of the material in the ASTM 2259 Standard Guide was derived from a TTI report, *Guidelines for Developing ITS Data Archiving Systems* (http://tti.tamu.edu/documents/2127-3.pdf), which also contains basic guidelines and case studies on data archives. For example, the Guidelines include these basic principles for data archiving systems:

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[9] The standard is *Content Standard for Digital Geospatial Metadata*, FGDC-STD-001-1998. There are resources available to implement this FGDC metadata at http://www.fgdc.gov/metadata/links/metalinks.html.

[10] See ASTM 2468-05, *Standard Practice for Metadata to Support Archived Data Management Systems*, available from http://www.astm.org.

- Determine the workgroup(s) or agency(ies) that should have primary responsibility for operating and maintaining the data archive;
- Start small but think long-term, and begin with modest prototypes focused on a single source of data (e.g., freeway or arterial street detector systems);
- Develop the data archiving system in a way that permits ordinary users with typical desktop computers to access and analyze the data;
- Provide access to and distribution of archived data through the Internet or portable storage devices, such as CDs or DVDs;
- Save original data as collected from the field for some specified period of time, but make summaries of this data available for most users;
- Use quality control methods to flag or remove suspect or erroneous data from the data archive; and
- Provide adequate documentation on the data archive and the corresponding data collection system.

8.3.3 Data Integration Issues

Using archived data from traffic operations centers will require a variety of data management and integration skills, particularly in cases where the data comes from more than one provider and includes more than one type of data. Two issues are discussed briefly here: location matching and version control.

Location matching is relevant when integrating traffic performance data with various other roadway event data (such as traffic incidents, work zones, weather, etc.). As is often the case, data from disparate sources or different agencies will likely not use the same location referencing system. In these cases, it will be necessary to develop a cross-reference between two or more location referencing systems. Depending upon the location referencing systems, this cross-referencing scheme could be a fully automated process within GIS, or it could be a manual process. Another consideration when location matching is the required accuracy and geographic scale. Traffic performance data may be aggregated to the route or corridor level, such that any location matching with other datasets would only need to consider locations that fall within the entire length of the route. Thus, exact locations may be less important in certain location matching applications.

It is near certainty that various changes will be made to the performance measure calculation procedures once reports have been publicly released. For this reason, it is essential that version control be considered during the development of a performance monitoring program. For example, consider the impacts that might occur when an improved travel time estimation algorithm is developed after several years of performance reports. The improved algorithm is more accurate, but it also estimates travel times that are consistently shorter. However, several years of performance reports have already been published that use the old algorithm which produces longer travel times. Instead of simply overwriting the old statistics, they should be retained in the data management system as a previous version that has "expired." The new statistics based on the improved algorithm would then be stored as the current version.

There are numerous possible methods for version control – one possibility is to use effective and expiration dates/times for all statistics:

- **Effective Date and Time –** The date and time at which the statistic became effective or replaced a previous version; and
- **Expiration Date and Time –** The date and time at which the statistic was expired or replaced by a newer version. If the statistic is still not valid, the expiration date and time can be missing/null or set to a date and time in the distant future, such as 9999 A.D.

8.4 Data Transformation

Data transformation is the act of changing data and is quite common in archiving real-time traffic data in a data archive. As collected, real-time traffic data is typically quite detailed and is stored in a database designed for quick access to current conditions. However, a data archive typically does not retain the original level of data, and the archive database must be designed for quick access to a wide range of historical conditions. Thus, transformation is a typical step in preparing real-time traffic data for permanent storage in a data archive.

A recommended practice related to data transformation is the adequate provision of an "audit trail" that can be used to trace the various changes made to data as it is received from the field and then prepared for permanent storage. This "audit trail" is typically stored in metadata, which has been discussed in earlier sections. The ASTM 2259-03a standard (*Standard Guide for Archiving and Retrieving ITS-Generated Data*) provides guidance on the type of "audit trail" information that should be tracked in data archives.

8.4.1 Aggregation Procedures for Detector Data

Just about any type of data analysis performed with archived data will require data aggregation – that is, summarizing data by date, time, or location. In many cases, the real-time data from operational systems will be aggregated before it is loaded into the data archive. Similarly, any type of summary reports generated from data archives will require data aggregation.

All database systems and data processing engines have stored procedures or functions for computing averages or sums. However, database developers must be cautious in using automated functions in several cases. These cases are described below.

- **Error Codes in Traffic Data –** Some traffic sensor systems may provide real-time data that contains error codes (such as "-1" or "255") or zero values. During the data archive loading process, aggregation procedures must address such values. In the case of error codes, null values may be assigned with accompanying metadata that documents the original error code. Zero values are acceptable for some traffic measurements, such as vehicle counts or lane occupancy; however, zero values should not be accepted for speed values, unless it can be confirmed that the sensors can detect/measure vehicles that are motionless. In most cases, zero speed values will be converted to null speed values with the appropriate explanatory metadata.

- **Use of Volume Weighting –** When computing average speed or lane occupancy values, subtotals should be weighted by the vehicle volume corresponding to the respective data value. This provides an accurate representation of time mean or space mean speed and average lane occupancy.

- **Dealing with Data That Fails Quality Checks –** When aggregating data for summary statistics, one will also need to determine how to deal with data that has been flagged by business rules as being suspect or invalid. In some data systems, flagged data is reviewed by a human and deemed reliable or invalid. Invalid data may or may not be replaced with other estimates. In other systems, the flagged data is automatically removed when computing summary statistics. Other systems with dynamic data aggregation provide users with the option of including flagged or suspect data in summary statistic calculations.

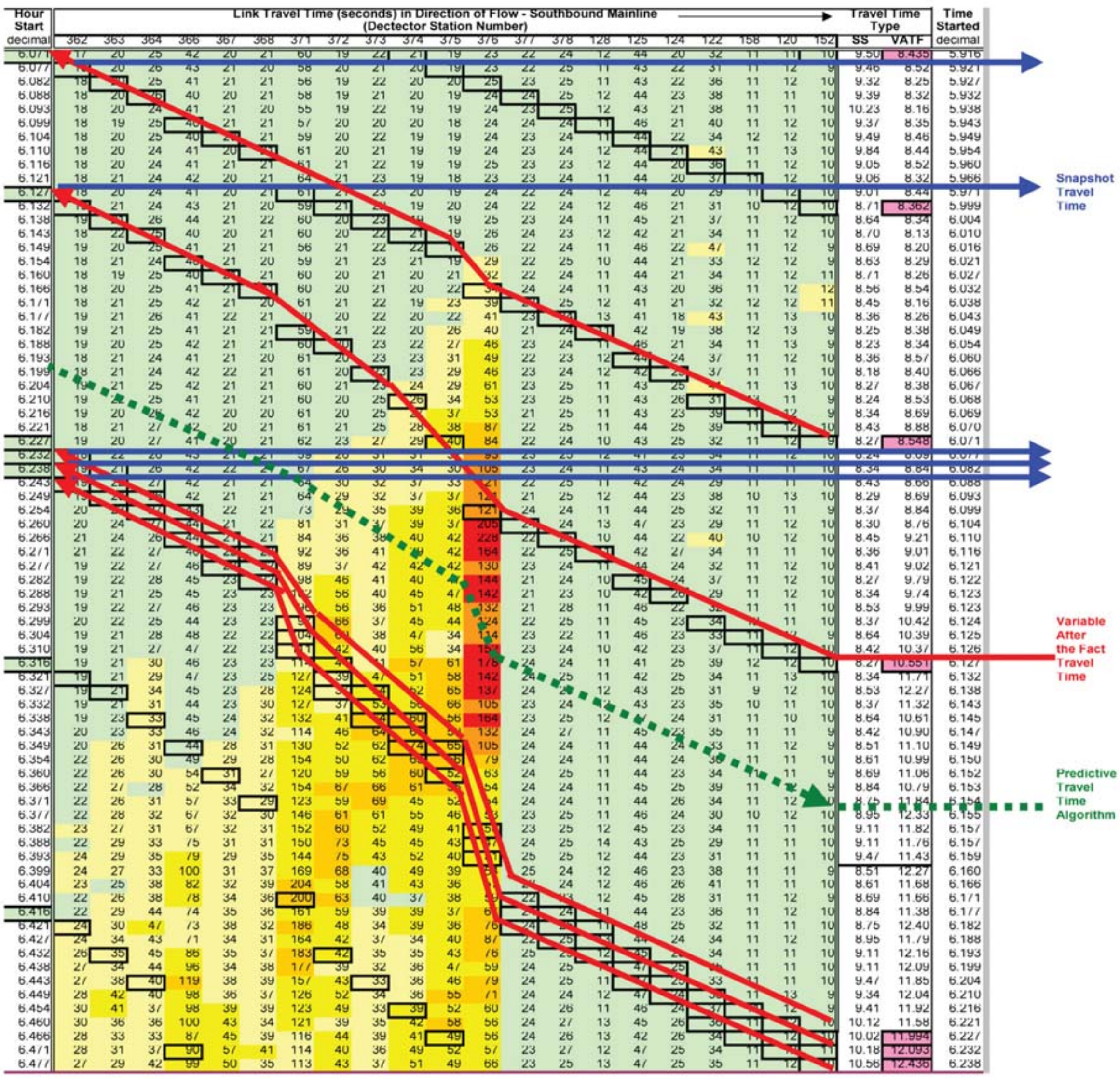
In many cases, there will be roadway lanes and time periods in which no data were collected or made available. This missing data should be tracked and reported when computing summary statistics. For example, assume we are calculating 5-minute averages from 20-second data values. Further assume that data values are not available during 1 minute of this 5-minute period. Thus, the sample completeness for the 5-minute summary statistic is 80 percent, or 12 of 15 data values were available for computing the summary statistic.

Carrying this example further, assume that we were missing vehicle counts for this 1-minute period. The 5-minute vehicle count subtotal would be incomplete, and thus would undercount the actual vehicles. The common practice has been to "factor up" incomplete summary traffic volume statistics such as this to account for missing data. In this case, the vehicle count subtotal would be divided by 80 percent to estimate the full 5-minute vehicle count. Metadata would be used to indicate the completeness for this subtotal, as well as the estimation method used.

8.4.2 Transforming Spot Speeds to Travel Times

In many current practices, one of two basic methods is used to estimate freeway travel times from spot speeds/link travel times: the "snapshot" method and the vehicle trajectory method. There are also slight variations to each of these two methods that attempt to improve travel time estimates. Figure 8.7 illustrates these two basic methods of travel time estimation: the blue arrows represent a snapshot travel time; whereas, the red arrows represent a travel time based on vehicle trajectory.

Figure 8.7 The Snapshot and Vehicle Trajectory Methods of Estimating Travel Times from Spot Speeds



Source: Travel Time Estimates, Displays, and Forecasts: Final Report.[11]

[11]Oz Engineering and Motion Maps, *Travel Time Estimates, Displays, and Forecasts: Final Report*, Technical Report No. 2, prepared for Maricopa County DOT and Arizona DOT, December 2004.

The snapshot method sums all link travel times for the same time period, regardless of whether vehicles traversing the freeway section will actually be in that link during the snapshot time period. This method (or a derivation of this method) is often used in real-time systems, in which the computer system simply adds all link travel times between a defined origin and destination. In real-time, one cannot directly measure what the link travel time will be when vehicles reach the destination link. Therefore, the snapshot method assumes that the link travel times are constant for the entire duration of the vehicle trip. For example, simply sum all travel times for the time period from 7:00 to 7:05 a.m. and that provides a section travel time for that time period. Because of this assumption, the snapshot method underestimates section travel time when traffic is building (travel times get longer as the vehicle traverses the section) and overestimates section travel time when traffic is clearing (travel times get shorter as the vehicle traverses the section). Some real-time systems apply correction factors or use estimation techniques that account for this error when traffic conditions are changing.

The vehicle trajectory method can only be used after the fact, which is acceptable for performance monitoring purposes. The vehicle trajectory method "traces" the vehicle trip in time and applies the link travel time corresponding to the precise time in which a vehicle is expected to traverse the link. For example, a section travel time that begins at 7:00 a.m. will use a link travel time for 7:00 to 7:05 at the trip origin, but could use a link travel time from 7:05 to 7:10, or 7:10 to 7:15 at the trip destination. The vehicle trajectory method attempts to more closely model the actual link travel times experienced by motorists as they traverse the freeway system.

8.4.3 Accuracy of Spot Speed Transformations

Error in freeway travel time estimates can be introduced by several factors. Sensor location affects the travel time error, in that sensors may be installed in areas of free-flow (downstream of a bottleneck) and, thus, speeds measured at a single point may not be representative of speeds along the full length of the link. Sensor spacing also affects travel time error for a similar reason. With widely distributed sensor spacing, a single location may not adequately represent the full length of the link. Long section lengths could also introduce greater error with the snapshot method than with the vehicle trajectory method. As mentioned, the timing will affect the snapshot method (is traffic building or clearing?). As always, missing data due to hardware failures or communications problems will also introduce error into the travel time estimates.

In several areas, field tests using actual probe vehicles have been used to determine whether this travel time error falls within acceptable limits for the given sensor system and travel time estimation algorithm. In Phoenix, AZTech partners did some testing to develop a travel time algorithm that has been deployed recently by the Maricopa County DOT (see Figure 8.7). In Virginia, however, simulation runs and field tests indicated that the travel time error was significant and that additional post-processing, and calibration was necessary to reduce errors in travel time estimates.[12] On the opposite end, the Georgia NaviGAtor TMC in Atlanta also did testing of the conversion algorithm for spot speeds to travel times using floating cars to provide the baseline. This was done because of the interest in posted estimated travel times on dynamic message signs (DMSs). The results showed good agreement between estimated and measured travel times (Table 8.2) and allowed NaviGAtor to proceed with its program of posting estimated travel times on DMSs. It should be noted that NaviGAtor has extremely dense detectorization: one-third-mile spacing between detectors for most of the system. Since many TMCs have sparser detectorization – and lack of maintenance funds is exacerbating this problem – the accuracy tests should be performed for networks with different detector densities.

The accuracy of field data collected by a freeway surveillance system is largely dependent on two factors: the spacing and density of field detectors and the reliability of the individual detectors and the detectors' data transmission and storage system.

Like the number of pixels in a digital camera, the quality and detail of a freeway detector network greatly improve when the number of detectors is increased along freeway study segment. For one, multiple detectors can serve as data quality crosschecks for each other. Data from two closely spaced detectors can be compared to establish the quality and consistency of the data being collected from each. A high concentration of detectors can also enhance the resolution of the data "picture" that is collected, providing fine-grained details of how traffic conditions evolve, and are affected by environmental and road geometric conditions.

The research team undertook an analysis of the effect of detector spacing on performance measures. Data from the Atlanta (NaviGAtor) and Cincinnati (ARTIMIS) TMCs were used. In this analysis, the actual sensor spacings were used as the baseline ("ground truth"). Experiments were run by deleting sensors until higher sensor spacings were achieved. The results showed that, when sensor spacing was increased relative to the baseline sensor spacing condition, error was introduced into congestion performance measures (Figures 8.8 and 8.9). The errors varied – sometimes one spacing pattern overestimated and at other times another spacing pattern underestimated the congestion performance measure. Further analysis showed that strategic location of sensors could improve the error rate versus the same sensor spacing for orderly deletion of sensors.

The quality of the data collected from detectors can also vary depending on the reliability and capabilities of the communications network that supports it. Communications components that are prone to failure, require constant maintenance, or that only transmit data at widely spaced intervals (e.g., a total count of traffic sent once a day) will not provide enough reliable data detail (resolution) to identify and describe variations in traffic conditions that can occur over time.

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[12] Smith, B. L., R. B. Holt, and B. Park, *Travel Time Estimation for Urban Freeway Performance Measurement: Understanding and Improving Upon the Extrapolation Method*, paper presented at the 2004 Annual Meeting of the Transportation Research Board, November 2003.

Table 8.2 Travel Time Run Comparisons – Metro Atlanta Interstate Travel Times May 2004

A.M. Peak (6:00 a.m. to 10:00 a.m.) Weekdays and P.M. Peak (3:00 p.m. to 7:00 p.m.) Weekdays

Segment Description	Length (Miles)	55 mph Travel Time (Minutes)	Date	Time	Run 1 Travel Time	VDS Travel Time	Difference	Date	Time	Run 2 Travel Time	VDS Travel Time	Difference
A.M. Peak Period												
1. I-75 NB (Int. I-75/I-285 NW – Wade Green Road)	14.00	15:16	3-May	8:02	11:41	12:11	00:30	5-May	7:42	11:01	12:16	01:15
1. I-75 SB (Wade Green Road – Int. I-75/I-285 NW)	14.55	15:52	3-May	8:17	26:31	20:29	06:02	5-May	8:03	23:38	19:47	03:51
2. I-75 NB (Brookwood Int. – Int. I-75 @ I-285 NW)	8.45	09:13	11-May	6:56	06:12	08:14	02:02	11-May	7:21	06:10	08:19	02:09
2. I-75 SB (Int. I-75 @ I-285 NW – Brookwood Int.)	7.86	08:34	5-May	8:27	07:34	07:38	00:04	10-May	7:20	07:52	07:45	00:07
3. I-75/I-85 NB (Int. I-20/I-75 – Brookwood Int.)	4.41	04:48	10-May	9:43	03:46	04:23	00:37	11-May	6:25	03:13	04:25	01:12
3. I-75/I-85 SB (Brookwood Int. – Int. I-20/I-75)	4.40	04:47	4-May	8:07	05:33	04:39	00:54	5-May	8:35	03:12	04:46	01:34
4. I-75 NB (Int. I-85/I-75 – Int. I-20/I-75)	3.88	04:13	4-May	9:22	04:57	04:08	00:49	10-May	7:50	10:42	NA	NA
4. I-75 SB (Int. I-20/I-75 – Int. I-85/I-75)	3.75	04:05	4-May	8:11	03:25	03:24	00:01	5-May	9:12	03:14	03:21	00:07
5. I-75 NB (Int. I-285/I-75 NW – Int. I-85/I-75)	4.00	04:21	4-May	9:18	03:38	03:20	00:18	10-May	9:37	03:26	NA	NA
5. I-75 SB (Int. I-85/I-75 – Int. I-285/I-75 NW)	4.12	04:29	4-May	8:15	03:14	04:19	01:05	10-May	9:08	03:16	03:56	00:40
6. I-75 NB (Hudson Bridge Road – Int. I-285/I-75 NW)	14.53	15:51	4-May	8:39	12:05	13:04	00:59	10-May	9:26	10:30	12:46	02:16
6. I-75 SB (Int. I-285/I-75 NW – Hudson Bridge Road)	14.45	15:45	4-May	8:18	11:40	11:56	00:16	10-May	9:11	10:26	12:44	02:18
7. I-85 NB (Int. I-85/I-285 (Spaghetti Junction) – Old Norcross Road)	10.71	11:41	4-May	7:09	08:26	09:54	01:28	5-May	6:42	07:41	09:51	02:10
7. I-85 SB (Old Norcross Road –Int. I-85/ I-285 (Spaghetti Junction)	10.66	11:37	4-May	7:29	19:33	17:17	02:16	5-May	6:59	27:16	20:09	07:07

Figure 8.8 Atlanta Comparison of Travel Time Index for Different Spacings for Southbound Traffic
I-75C South Bound

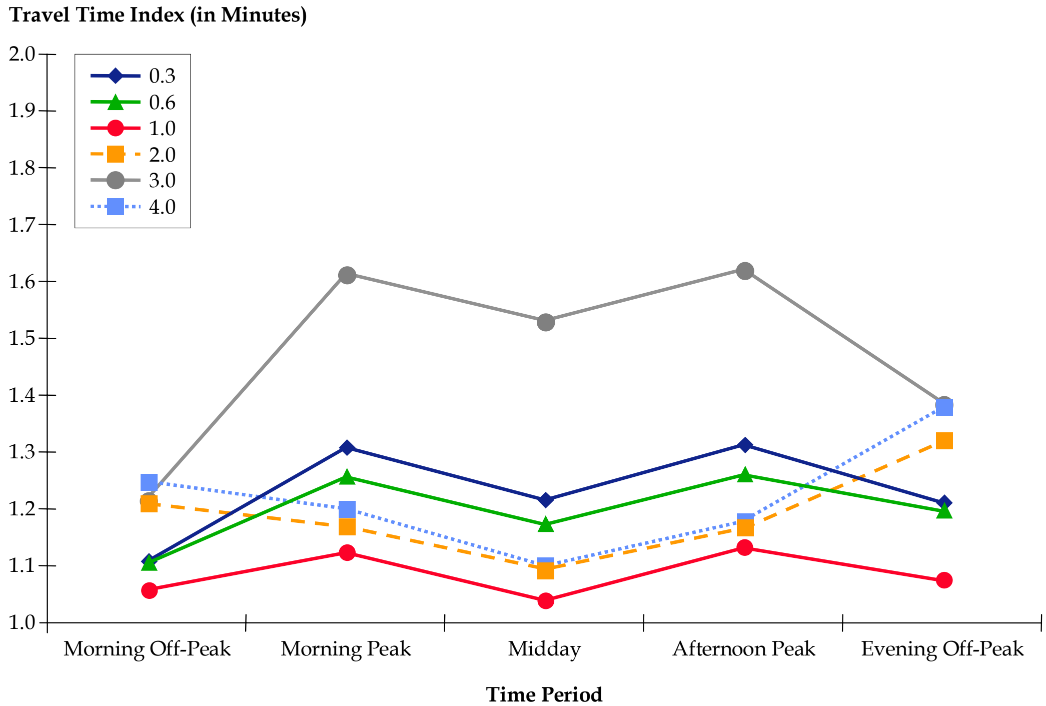
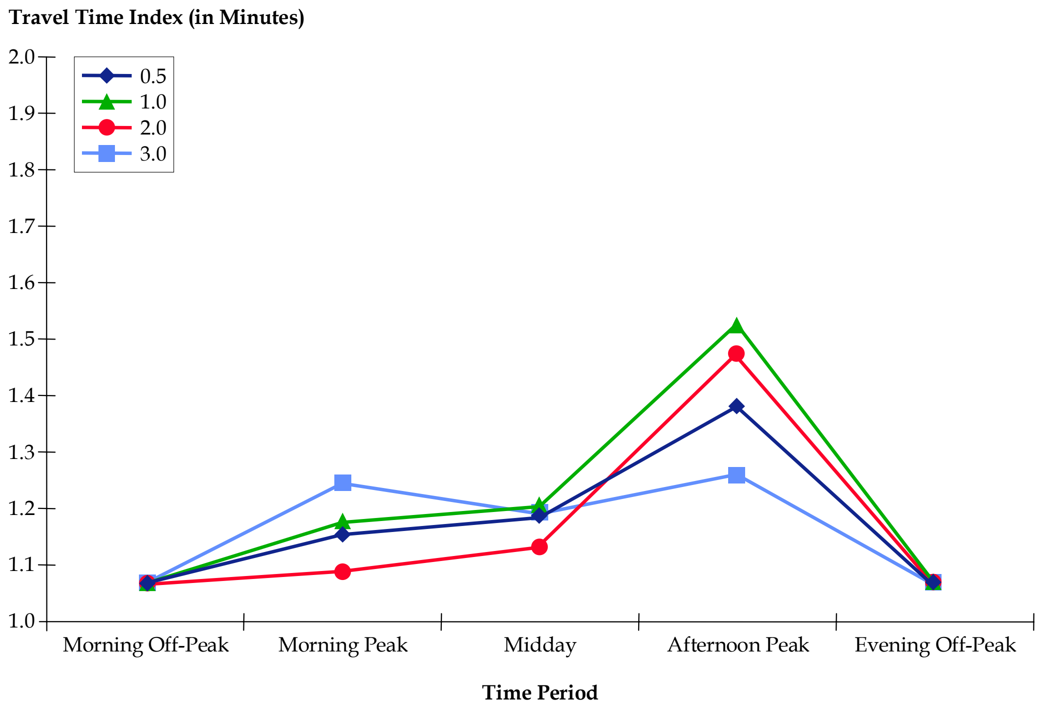


Figure 8.9 Cincinnati Comparison of Travel Time Index for Different Spacings for Northbound Traffic



Detector data accuracy (particularly for data that will be analyzed longitudinally) is also highly dependent on the reliability of the surveillance detectors and their supporting communications and storage systems. There are a wide variety of detectors ranging from permanently installed inductive loop detectors to somewhat more mobile non-intrusive microwave radar detectors to portable hose counters. Both the quality and reliability of the data collected using these detectors can vary considerably depending on the detector type employed.

However, detector (surveillance) data by itself can only record and report the outcomes of congestion in terms of reduced traffic flows and system reliability, and will not provide insights into the causes of congestion and delay, which is often caused by traffic incidents such as accidents, lane obstructions, or road maintenance. To identify and categorize congestion events by causation, detector data must be supplemented by and analyzed in conjunction with nonrecurring event data collected simultaneously with the detector surveillance analysis periods.

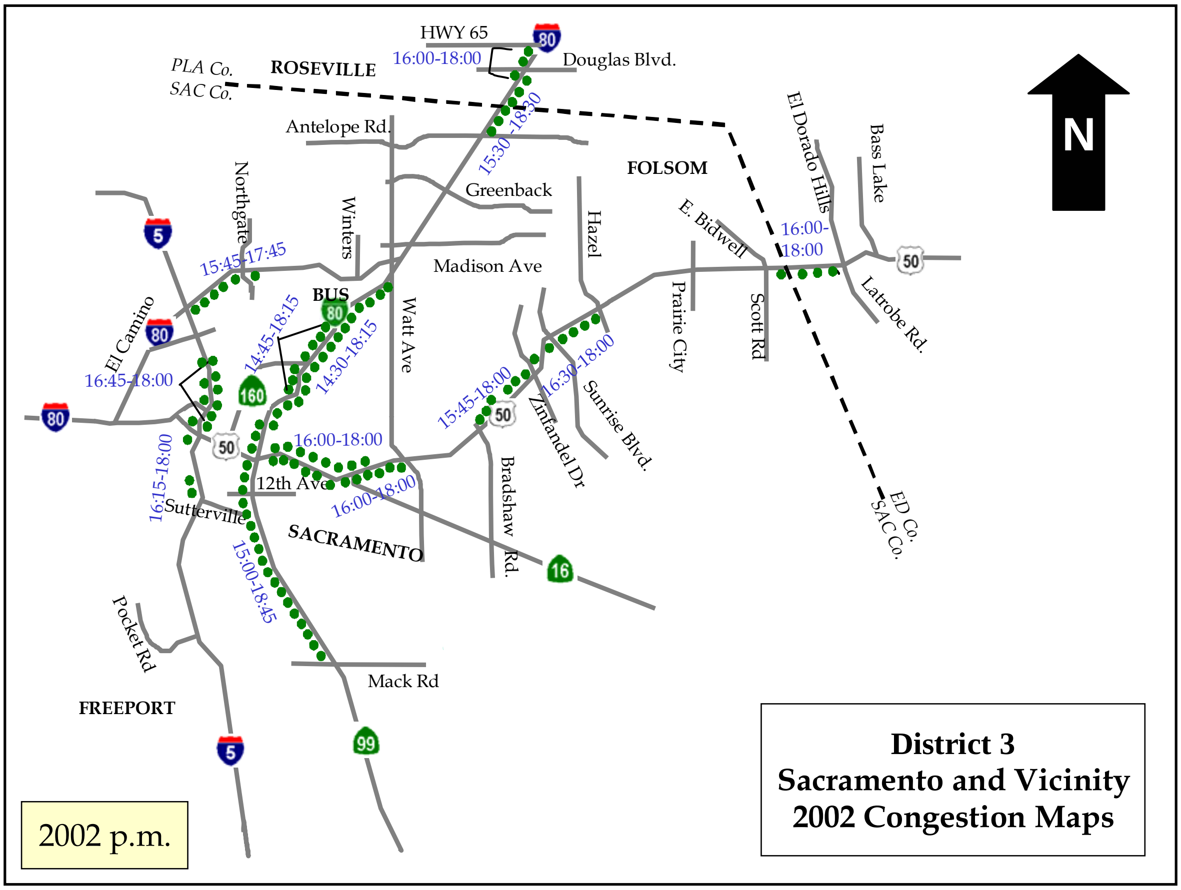
8.4.4 Probe Vehicle Measurements

Another common technique for gathering congestion and vehicle delay data for freeway segments is to deploy "probe" vehicles to travel up and down freeway study segments with computer tachometers or Global Positioning System (GPS) units that collect speed (and often location) data. Since the data collected from a single vehicle can be processed to develop trip based travel time estimates for select freeway segments, this method of data collection can be particularly attractive for those who wish to develop travel time reliability performance measures. Probe data is also useful for identifying freeway bottleneck locations. Basic guidance on sample sizes and other data collection parameters may be found in FHWA's Travel Time Data Collection Handbook.

8.4.4.1 Accuracy

The accuracy of probe data is largely dependent on two factors: the time spacing of probe vehicles and the total number of probe vehicle runs. Just as described for surveillance data, the resolution and quality of probe data increase as the number of probe vehicles increases and the time spacing between the runs is reduced. The data from closely spaced (in terms of time and location) probe runs can be used as data quality checks against one-another. Closely spaced probes also provide data that potentially capture changing traffic conditions in more fine-grained detail, offering a view of the severity of a congestion event (in terms of its impact on speeds), as well as its scope (in terms of its duration and geographical extent). The California Department of Transportation (Caltrans) typically develops its congestion statistics from probe vehicle data collected from one day without incidents (see Figure 8.10).

Figure 8.10 Probe Vehicle Speed Congestion Maps



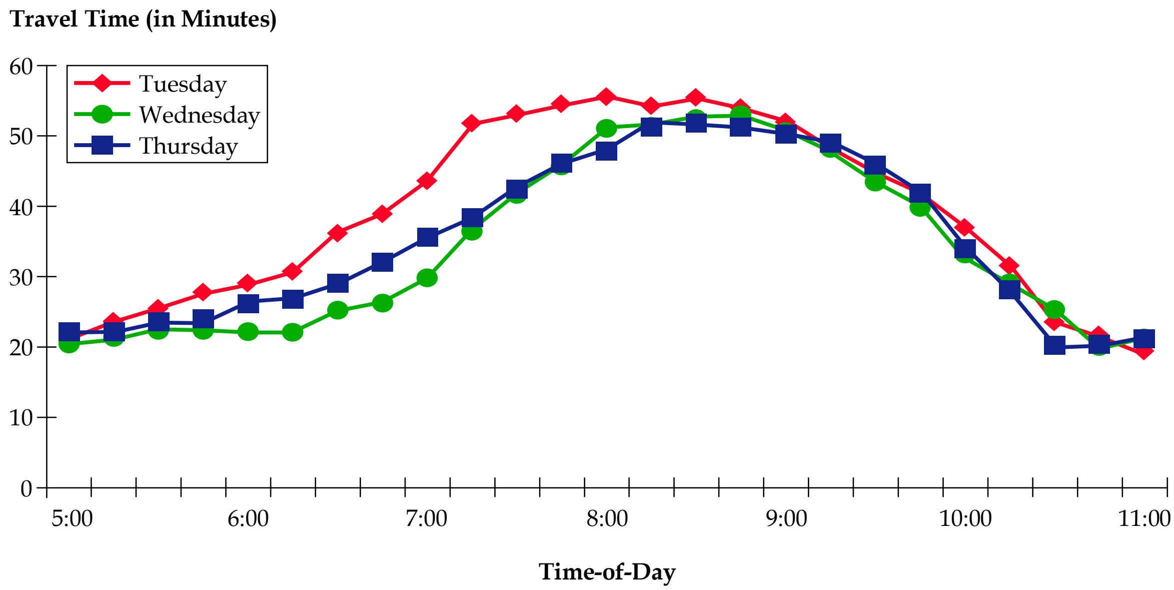
8.4.4.2 Limitations

With smaller numbers and frequencies of probe vehicle runs, this data collection method suffers, in that they often miss congestion events, particularly small events of short duration.

Probe data is similarly problematic for use under congested conditions caused by incidents. Consequently, as shown in Figure 8.10, probe vehicle data collection runs are typically collected and reported only for a single-day (or shorter) period under incident-free conditions.

Figure 8.11 shows the wide variability of travel time data collected by probe vehicles along a single freeway segment during congested conditions. These variations suggest that probe data may be inappropriate for use in developing "before" and "after" performance measures, unless the data is collected at a very high "resolution" (i.e., a high frequency of probe data runs). This figure also illustrates the need to gather probe data over multiple days to adequately account for the day-to-day variations that can occur on the same freeway segment.

Figure 8.11 Variability of Probe Vehicle Travel Times on Congested Routes

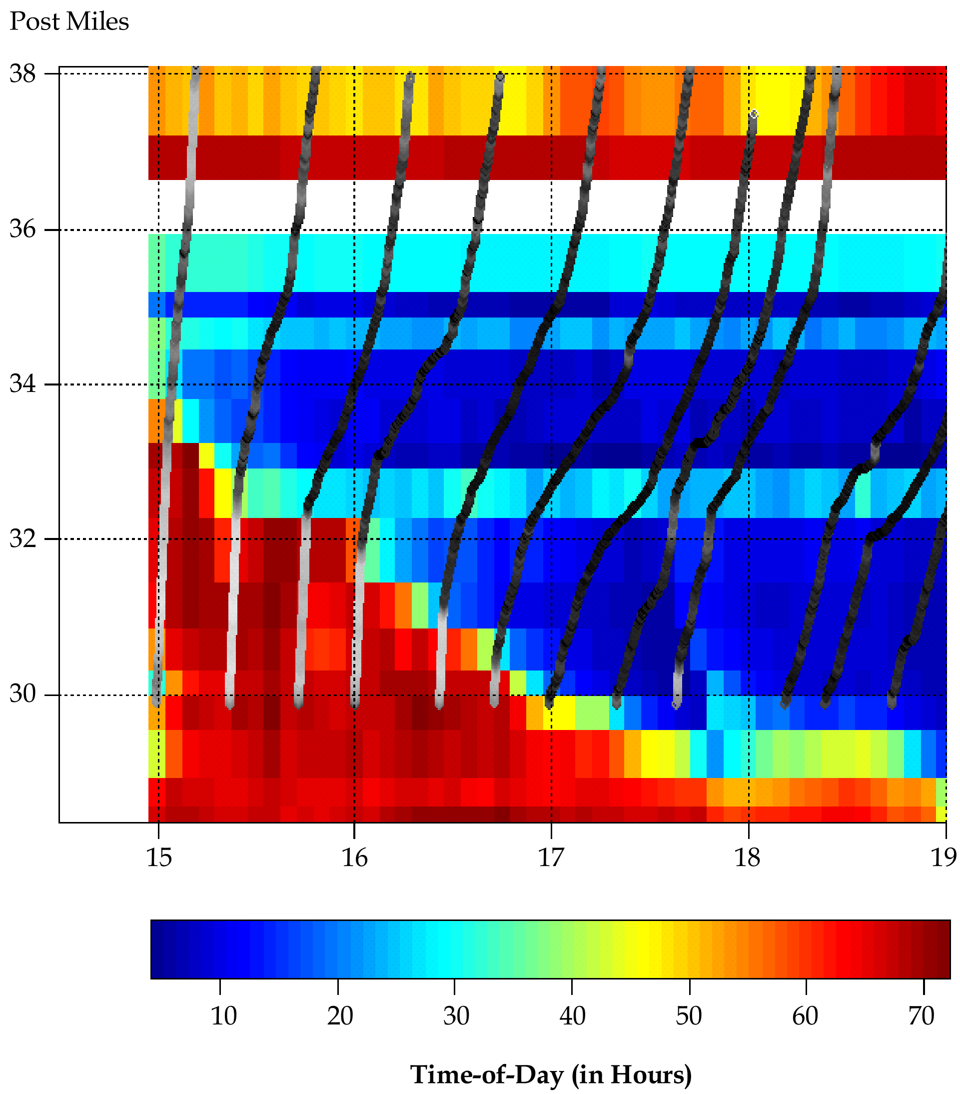


Even with frequent probe runs as shown in Figure 8.12, which were collected every 15 minutes, the detailed variations in congestion patterns can be lost or distorted by probe data. In this case, the probe data shown in Figure 8.12 show significant differences in speed contours between probe vehicle runs across similar congestion conditions.

Probe data is also limited in the number of performance measures it can be used to calculate. For example, to calculate vehicle-miles of travel (VMT) and vehicle-hours of travel (VHT) measures, probe data must be combined with segment volume counts collected during the same time period of each probe vehicle run. The need for these additional data and the process gathering, combining, and analyzing these data sources add complexity to the process of creating performance measures.

Furthermore, with these additional data requirements and the need to perform enough probe runs to achieve reasonable data "resolution," the use of probe vehicles to regularly produce freeway performance measures becomes an expensive venture and may be cost prohibitive for the purposes of producing a comprehensive set of freeway performance measures.

Figure 8.12 Comparison of Speed Contour Plots



8.5 Data Analysis

8.5.1 Geographic and Time Scales

8.5.1.1 Geographic Scale

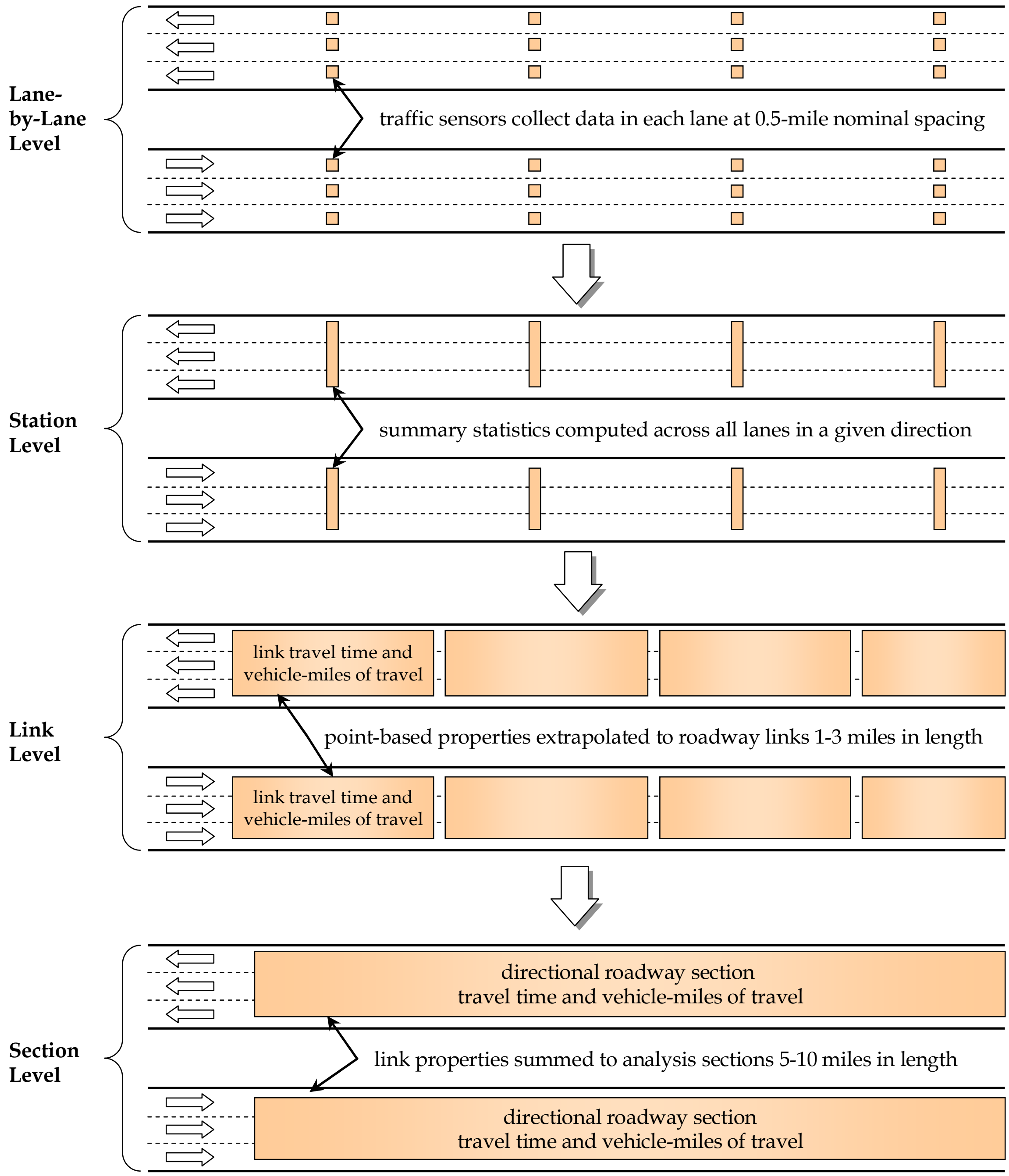
There are several different geographic and time scales for analysis and reporting. Ultimately, the intended audience will determine the geographic scale and level of detail provided in performance measure reports. For example, technical audiences of operations staff would likely be most interested in detailed scales, as the solutions they develop are more oriented to specific bottlenecks or critical locations. Elected officials or upper-level managers typically care more about the big picture, so areawide summaries are generally more appropriate than detailed statistics.

The geographic scales to be considered for most archived traffic operations data is:

- **By Lane** (point location);
- **By Direction** (point location), all functional lanes combined – This is sometimes referred to as a "station";
- **Link –** Typically between access points or entrance and exit ramps;
- **Section or Segment –** A collection of contiguous links;
- **Corridor –** Several sections/segments that are adjacent and travel in approximately parallel directions (e.g., freeway and arterial street, arterial street and rail line);
- **Subarea –** A collection of several sections or corridors within defined boundaries; and
- **Areawide/Regional –** A collection of several sections or corridors within a larger political boundary.

Figure 8.13 shows a schematic demonstrating how volumes and speeds from individual lanes can be aggregated to different geographic scales to estimate travel times for longer sections of roadway. The volumes and speeds are first combined across all through lanes (slow-moving auxiliary lanes are typically not included) in each direction. The second level, all lanes combined, includes an average speed and volume subtotals for all lanes. A "zone of influence" is assigned to each sensor location, typically using a length that is one-half the distance to the nearest upstream and downstream sensor. Based on this equivalent link length, the spot speeds are then used to calculate link travel time, and the volume subtotals are used to estimate link VMT. Once link travel times are calculated, one can either use the "snapshot" method or vehicle trajectory method to estimate travel times for longer sections of roadway or even trips. The estimated VMT is summed across all links in a roadway section or trip.

Figure 8.13 Aggregating Traffic Detector Data to Different Geographic Sites



Source: Turner, S., R. Margiotta, T. Lomax. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data.* Report No. FHWA-HOP-05-018, Accessed at http://mobility.tamu.edu/mmp/FHWA-HOP-05-018/ , December 2004

8.5.1.2 Time Scale

Section 6.0 presented guidance on how to construct peak periods for the recommended performance measures. Here, we extend the discussion more broadly. Similarly, the selection of time periods will depend on performance measures selected and prevailing traffic conditions. Average weekday statistics are typically used in most urban areas. Weekends have different traffic patterns than weekdays; however, in many cities the congestion and delay from both weekend days typically equals a weekday. Thus, performance measures should address both typical weekday, as well as weekend conditions (especially in areas near major recreation trip generators like the mountains, beach, etc.).

Time scales and periods that may be considered in performance monitoring programs are:

- Peak hour (based on maximum volume);
- Peak hour (based on minimum speed or maximum delay);
- Peak period (to encompass typical commuting times that include most delay);
- Mid-day or overnight;
- Daily or sum totals (to encompass all delay); and
- Weekday versus weekend.

Peak-Hour Statistics. For small cities, a single peak hour may be sufficient to encompass all congestion. However, this is not the case for most urban areas. Peak hours can still be used for some measures to show the "worst of the worst," but it should be recognized that peak-hour statistics may not show change as most traffic growth will occur outside of the peak hour. In calculating the actual time of the peak hour, one should be cautious in how the hour is selected. Using the *Highway Capacity Manual*, peak-hour definition (the hour with the highest volumes) typically yields the hour just before the freeway breaks down. Thus, the hour with highest volumes will not always correspond to the hour with lowest speeds. The peak hour based on lowest speeds typically lags the peak hour based on highest volumes by 30 to 60 minutes.

Peak-Period Statistics. For congestion analysis, most large cities define a multi-hour peak period that will fully encompass periods of slow traffic and delays. These peak periods may be from 1.5 to 4 hours long. Peak periods should be defined to allow for growth in traffic; thus, peak periods will typically include the free-flow traffic on either side of the peak traffic "shoulders." For example, if one is tracking the duration of traffic congestion, the peak period should be defined, such that it is always wider than the expected congestion duration.

Off-Peak-Period Statistics. Mid-day statistics can be computed as well – in some areas, the mid-day traffic near lunch resembles a third daily peak. In some cities, a diurnal traffic pattern has evolved into a single traffic "plateau" – that is, traffic volumes build during the morning peak period, but never drop significantly during mid-day. Mid-day statistics should be designed to capture these trends, as well as peak spreading.

Daily Statistics. Daily statistics will be more meaningful for some statistics than others. For example, a daily congestion measure may not be appropriate because averaging the peak periods with nonpeak periods "washes out" the true nature of the peak periods. Daily statistics are meaningful for statistics that are summed, such as traffic volume counts. Similarly, certain output measures (such as 511 calls received, vehicle assists, etc.) can be summarized to daily totals and still be meaningful.

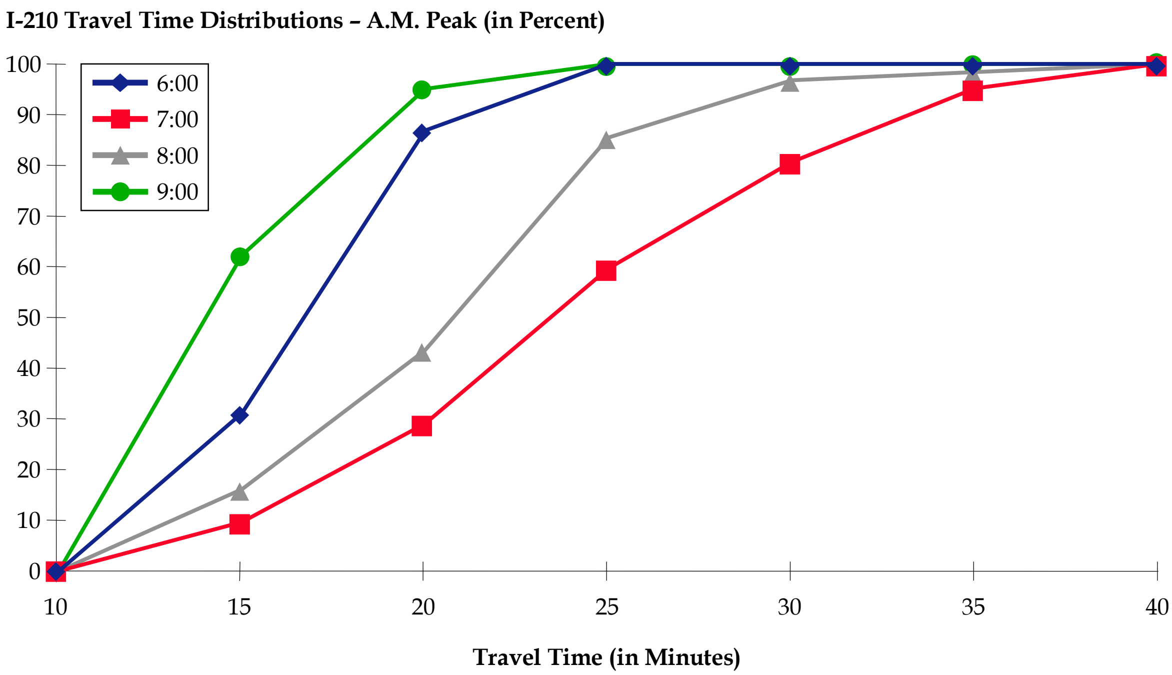
8.5.2 Computing the Recommended Minimum Set of Congestion-Related Measures

8.5.2.1 Measurement-Based Methods (Step-by-Step Procedures)

There are several reasons why measurement is the preferred method for developing freeway performance measures. First, measurement-based performance indicators can provide a wide range of options, including trip-based, corridor-level, or bottleneck-specific measures of system performance – all aspects that are beyond the capabilities of model-based performance measures. These additional capabilities provide a greater level of detail and diagnostic power to freeway performance measurement that allow system managers to focus in on the specific causes of freeway congestion, and can help identify options for congestion interventions and mitigations.

Second, since real-life conditions are constantly changing, surveillance systems can be designed and operated to run on a continual basis, providing real-time data updates on system performance. Instead of providing a more static image of congested conditions as offered by many model-based measures, surveillance-based measures can provide insights into how traffic conditions evolve over time. The nature of these ever-changing conditions can be summarized in terms of the reliability of the freeway system to the user. Reliability measures summarize performance data longitudinally to show how the system handles changing traffic conditions and how much drivers can depend on the performance of the system. Currently, there are no widely accepted methods of modeling reliability. Direct and continuous (or repeated) field measurements gathered over a period of time currently offer the only viable source of data for developing reliability performance indicators. As shown in Figure 8.14, the amount of time it takes to travel a freeway segment is highly variable, depending on the time at which the segment is traveled. Direct field measurements offer the opportunity to calculate travel time reliability estimates and understand how the users of this facility are budgeting "buffer time" into their daily schedules to account for this travel time variability.

Figure 8.14 Travel Time Distributions



Finally, field measurements provide the most expedient and cost-effective means to identify freeway bottleneck locations. While detailed freeway models can identify freeway bottlenecks based on theoretical principles of traffic behavior and freeway geometrics, variability in travel demand and traffic incidents can make model-based performance measurement difficult. Field measurement can help identify and describe the occurrence of freeway bottlenecks in far greater detail with greater accuracy, and at far less cost and effort than modeling. However, the accuracy of the field data, as well as the types of congestion that can be measured and summarized, depends on the type of data gathering methods employed. The two most commonly used data collection methods are the use of surveillance systems and probe vehicles.

This section shows the recommended minimum freeway performance measures, along with required data elements and calculation procedures.

Average Congestion Conditions (Quality of Service)

Travel Time

Required Data Elements:

1. Link or section travel times; **or**
2. Spot speeds at frequent intervals.

Calculation Procedures

The travel times can be measured directly using vehicle probes, or estimated using a variety of techniques. See Section 8.4.2 for estimating section travel times.

Travel Time Index

Required Data Elements:

1. Section travel times during peak times;
2. Section travel times during free-flow or light traffic; and
3. VMT by section (or other weighting factor).

Calculation Procedures

The travel time index is calculated as shown in Equation 1. The index values for different road sections and time periods are combined using VMT-weighted averages, as shown in Equation 2. The travel times can be measured directly using vehicle probes, or estimated using a variety of techniques.

Equation 1

For a specific road section and time period :

$$\begin{matrix}\textit{Travel time index} \\ \textit{(no units)}\end{matrix} = \frac{\textit{Average travel time (minutes)}}{\textit{Free} - \textit{flow travel time (minutes)}}$$

Equation 2

For several road sections and time periods :

$$\begin{matrix}\textit{Average travel time index} \\ (\textit{no units})\end{matrix} = \frac{\sum_{i=1}^{n} \left(\textit{travel time index}_n \times VMT_n \right)_{\text{each section and time period}}}{\sum_{i=1}^{n} \left(VMT_n \right)_{\text{each section and time period}}}$$

Total Delay (Vehicle-Hours and Person-Hours)

Required Data Elements:

1. Average link or section travel times;
2. Link or section travel times during free-flow or light traffic; and
3. Vehicle traffic or person volumes by link or by section.

Calculation Procedures

Delay for a link or section of roadway is computed using Equation 3. Total delay for a corridor, subarea, or area is computed as shown in Equation 4.

Equation 3

For a specific road section and time period :

$$\underset{\text{(vehicle or person – hours)}}{\text{Delay}} = \frac{\left(\underset{\text{(minutes)}}{\text{Average Travel Time}} - \underset{\text{(minutes)}}{\text{Free – flow Travel Time}}\right) \times \text{Volume (vehicles or persons)}}{60 \ \frac{\text{minutes}}{\text{hour}}}$$

Equation 4

For several road sections and time periods :

$$\underset{\text{(vehicle – hours)}}{\text{Total Delay}} = \sum_{i=1}^{n} \text{Delay}_n$$

Delay by Source (Bottlenecks, Incidents, Work Zones, Weather)

Required Data Elements:

1. Delay (computed from Equations 3 and 4); and

2. Roadway event data for incidents, work zones, and weather that include location references, dates, times, and other required information (see Section 8.5.3).

Calculation Procedures

See Section 8.5.3 for estimating delay by source. The basic procedures match the corresponding roadways events to a delay quantity, which is then allocated along all events occurring on that section of road for a specific date and time period.

Ramp Delay (Vehicle-Hours and Person-Hours, Where Ramp Metering Exists)

Required Data Elements:

1. Vehicle presence data from ramp queue detectors; **or**
2. Ramp queue and delay data from manual stopped delay studies.

Calculation Procedures

Ramp delay can be estimated in at least two ways: 1) using ramp queue detectors to estimate queue length and number of vehicles in the queue at frequent reporting intervals (an "automated" estimate of stopped delay); or 2) a manual stopped delay study as is used at intersections.

Delay Per Person

Required Data Elements:

1. Delay (computed from Equations 3 and 4); and
2. Estimate of total number of persons being delayed.

Calculation Procedures

Delay per person is a performance metric that commuters can relate to, as it can be compared with their personal experience. The total number of persons being delayed can be estimated using a variety of techniques: 1) use VMT and assume an average trip length and vehicle occupancy; 2) use population estimates and household surveys to determine percent of population making trips; or 3) other sketch-planning methods.

Delay Per Vehicle

Required Data Elements:

1. Delay (computed from Equations 3 and 4); and
2. Estimate of total number of vehicles being delayed.

Calculation Procedures

Delay per vehicle is a performance metric that most commuters can relate to, as it can be compared with their personal experience. The total number of vehicles being delayed can be estimated using traffic counts from real-time traffic monitoring systems, estimates from probe vehicle samples, or estimates from manual traffic counts.

Percent of VMT with Average Speeds Less Than 50 mph
Percent of VMT with Average Speeds Less Than 30 mph

Required Data Elements:

1. Point or link travel speeds, preferably continuous (24 hours per day, 365 days per year); and
2. VMT, derived from point/link traffic volume counts.

Calculation Procedures

Many point-based traffic monitoring systems provide the necessary data to compute this measure. Traffic volumes and spot speeds are associated with a link of known length. VMT is computed by multiplying the traffic volume by link length. The VMT is then computed for specified speed thresholds: 30 mph is commonly used for severe congestion; whereas, 45 or 50 mph is used for congestion.

Percent and Number of Minutes of the Day with Average Speeds Less Than 50 mph
Percent and Number of Minutes of the Day with Average Speeds Less Than 30 mph

Required Data Elements:

1. Point or link travel speeds, preferably continuous (24 hours per day, 365 days per year).

Calculation Procedures

Many point-based traffic monitoring systems provide the necessary data to compute this measure. The calculation of number of minutes and percent of time is then computed for specified speed thresholds: 30 mph is commonly used for severe congestion; whereas, 45 or 50 mph is used for congestion.

Average Speeds by Hour of the Day (Used Primarily as an Indicator of Air Quality)

Required Data Elements:

1. Point or link travel speeds, preferably continuous (24 hours per day, 365 days per year).

Calculation Procedures

Many point-based traffic monitoring systems provide the necessary data to compute this measure. Average point or link speeds are computed (preferably using traffic volume counts as a weighting factor) for each hour of the day.

Density (Vehicles per Lane-Mile); Rural Only

Required Data Elements:

1. Data elements collected through special studies.

Calculation Procedures

There are at least two ways in which traffic density can be measured or estimated: 1) density can be measured directly using aerial surveys, such as is conducted in several cities using fixed-wing aircraft; and 2) density can be estimated using procedures outlined in Chapters 21 (Multilane Highways) and 23 (Basic Freeway Segments) of the *2000 Highway Capacity Manual*.

Reliability (Quality of Service)

Buffer Index

Required Data Elements:

1. Section travel times during peak times;
2. Section travel times during free-flow or light traffic; and
3. VMT by section (or other weighting factor).

Calculation Procedures

The buffer index represents the extra time (buffer) most travelers add to their average travel time when planning trips. The buffer index is computed as shown in Equation 5. The buffer index values for different road sections and time periods are combined using VMT-weighted averages, as shown in Equation 6. The travel times can be measured directly using vehicle probes or estimated using a variety of techniques.

Equation 5

For a specific road section and time period:

$$\text{Buffer index (\%)} = \frac{\begin{array}{c}95^{th}\text{ percentile travel time}\\ \text{(minutes)}\end{array} - \begin{array}{c}\text{average travel time}\\ \text{(minutes)}\end{array}}{\begin{array}{c}\text{average travel time}\\ \text{(minutes)}\end{array}}$$

Equation 6

For several road sections and time periods:

$$\text{Average index value} = \frac{\sum_{i=1}^{n} (\text{index value}_n \times VMT_n)_{\text{each section and time period}}}{\sum_{i=1}^{n} (VMT_n)_{\text{each section and time period}}}$$

95th Percentile Travel Time Index and Planning Time Index

Required Data Elements:

1. Travel time index values as computed from Equation 1, preferably continuous (24 hours a day, 365 days per year).

Calculation Procedures

The 95th percentile travel time index is also known as the planning time index, and represents the total time travelers should use when planning trips for on-time arrival. The planning time index is useful, because it can be directly compared to the travel time index on similar numeric scales. The 95th percentile values of the travel time index are a built-in function in nearly all spreadsheet and database software applications.

Number and Percent of Trips (Corridor or O/D) with Space Mean Speeds <= 50 mph
Number and Percent of Trips (Corridor or O/D) with Space Mean Speeds <= 30 mph
Required Data Elements:

1. Section travel times during peak times, preferably continuous (24 hours a day, 365 days per year).

Calculation Procedures

Average travel times are computed for designated time periods and days. The number and percent of travel times are then computed, which exceed a specified tolerance, commonly space mean speeds of 50 mph and 30 mph over the entire section or trip. This tolerance or threshold may be adjusted locally.

<u>Throughput (Quality of Service)</u>

<u>HOV Vehicle and Person Volumes</u>

Required Data Elements:

1. Vehicle counts in the HOV lane or facilities; and
2. Estimated vehicle occupancy (for person volumes).

Calculation Procedures

Vehicle counts in HOV lanes are typically measured continuously in most ITS traffic monitoring systems. Person volumes can be estimated using vehicle occupancy values from special periodic studies.

Vehicle-Miles of Travel (VMT) and Person-Miles of Travel (PMT)

Required Data Elements:

1. Vehicle counts;
2. Link definitions that correspond with vehicle counts; and
3. Estimated vehicle occupancy (for person-miles of travel).

Calculation Procedures

Vehicle counts are typically measured continuously in most ITS traffic monitoring systems. Person-miles of travel can be estimated using vehicle occupancy values from special periodic studies. VMT are computed by multiplying the vehicle (or person) counts by the corresponding link length. Vehicle-miles and person-miles of travel can be computed for the following categories: 1) total vehicles, 2) combination trucks, and 3) total trucks.

VMT/PMT per Lane-Mile or VMT/PMT per Capita

Required Data Elements:

1. VMT or PMT estimates (see previous measure);
2. Road network inventories (for lane-miles); and
3. Population estimates (for capita).

Calculation Procedures

These metrics can be computed by dividing VMT/PMT by the appropriate quantity (lane-miles or capita). Lane-mile estimates are available in most roadway network or highway inventory databases. Population estimates are available from the most recent Census.

Traffic Stream Composition (Percent Combination Trucks, Percent Total Trucks)

Required Data Elements:

1. Traffic counts by vehicle classification.

Calculation Procedures

Some ITS traffic monitoring systems provide a basic vehicle classification (two or three classes); the consistency and accuracy of this data should be verified before it is used. Many state DOTs have permanent weigh-in-motion (WIM) or vehicle classification sites that are distributed throughout the state on urban and rural highways. These permanent sites are often spaced some distance apart. Short-term vehicle class counts may also be conducted over more of the network using portable classification equipment.

Lost Highway Productivity (Lost Capacity Due to Flow Breakdown)

Required Data Elements:

1. Traffic volume, preferably continuous at regular spacing; and
2. Traffic speeds, preferably continuous at regular spacing.

Calculation Procedures

The intent of this measure is to quantify the productivity or capacity of the highway that is "lost" when congestion occurs. The performance metric is relatively new at this time, so the analytic steps for computing the measure have not been rigidly established. However, the basic computation steps are as follows:

1. Identify and segregate the locations and days where traffic flow was congested (lower speeds at reduced volumes).

2. Calculate the difference between the congested vehicle throughput and the vehicle throughput at peak efficiency. The vehicle throughput at peak efficiency can be set to

a) the average demand on the days when traffic flows were not congested, or b) the traffic flows predicted at capacity by the *Highway Capacity Manual*. This difference is assumed to be the "lost" vehicle throughput or productivity.

3. Sum the lost throughput or productivity values for all days and locations.

4. Express the lost throughput in easy-to-understand terms. At this point, the units for lost throughput will be in total number of vehicles. This can be converted to a peak efficiency percentage ("the highway was only *x* percent efficient because of congestion"), or it can be converted to the number of physical lanes lost ("the freeway system lost *y* lane-miles because of congestion").

8.5.2.2 Model-Based Methods

While surveillance data is usually presumed to be preferable for developing performance measures to model-based data, under circumstances where real-time surveillance data is not available or when performance measures are being constructed for future conditions scenarios, data from models may be the best alternative. A third alternative, when an assessment of future conditions is needed, is a hybrid approach, where forecasted, future conditions data from the simulation model is stored, and later compared to field measurements gathered at the time of the original forecast year. This comparison is then used to re-calibrate the model for use in further forecasting applications.

The main benefit of using model-based procedures is that (depending on the model employed) the impacts of operational improvements and incident management measures on future traffic conditions can be predicted. Methods of model-based estimation of freeway performance range from relatively simple, spreadsheet-based methods derived from the *Highway Capacity Manual* method (often using default values where parameters data are not available) to more complex simulation models that require significant investments of time and resources. The following section describes a spreadsheet/HCM-based model that predicts total, recurring, and nonrecurring congestion components using historical traffic volume and incident data.

Procedures for an HCM-Based Modeling Application

The HCM-based modeling method for the estimation of congestion developed by Dowling Associates (2003) for Caltrans involves the steps described below.

Step 1: Select Sample Facilities, Sections, and Prototypical Days

Since it is not feasible to collect all of the data that would be required to measure congestion on 100 percent of a freeway system, it is necessary to select a subset of state highway facilities for analysis and extrapolate the results to the entire system. Selection of the sample facility is based on an inventory of the freeway system under study according to each section's facility type, area type, and terrain type. The analyst then determines how many centerline miles of facilities can be evaluated within available resources and time constraints.

The ratio of the number of centerline miles that can be evaluated divided by the total centerline miles in the district is the sampling percentage for the district. The analyst then selects a sufficient number of centerline miles of facilities in each facility type category, area type, and terrain type to achieve the target sampling percentage for each category.

Each selected sample facility will be analyzed for three prototypical days (weekday, weekend, and holiday) for each season of the year (winter, spring, summer, and fall).

Step 2: Collect and Prepare Data for Analysis

Historical data on traffic volumes and incidents is collected and processed into a format consistent with the spreadsheet application. The method requires geometric data, demand data, a collision history, frequency of maintenance and construction activities, frequency of inclement weather days, and frequency of special events. Default parameters and distributions are provided for use when local data is not available.

Step 3: Estimate Hourly Demand Profiles for Sample Days

The average annual daily traffic (AADT) for each analysis segment of the sample facility must be converted into estimates of directional hourly volumes for the sample days. A prototypical demand profile (percentage of total volume by time of day) based on historical detector data from similar facilities is used to make the conversion. The output of this step is hourly demands by direction for 288 hours of the year (3 days per season, 4 seasons per year, and 24 hours per day).

Step 4: Estimate Capacity

The capacity of each segment of the facility is estimated under normal operating conditions (i.e., no causes of nonrecurring congestion are present such as inclement weather, incidents, work zones, etc.). The capacities are computed using data and equations from HCM2000. The basic capacity equation is shown below.

$$c = N * c_{PL} * PHF * 1/(1+ET * PT) * A \qquad (1)$$

Where:

c = The maximum sustainable flow rate per hour;

N = The number of through lanes;

c_{PL} = The ideal capacity per lane (Table 8.3);

PHF = The peak-hour factor, the ratio of the peak 15-minute flow rate (vph) to the average hourly flow rate (vph);

ET = The truck equivalent to passenger cars (obtained from HCM);

PT = The percent of trucks in the traffic stream; and

A = Analyst selected adjustment factor to account for other factors affecting capacity.

Step 5: Compute Recurring Delay

Two measures of recurring delay are computed for each hour in the sample. The "free-flow" delay is the difference between traveling at the free-flow speed and the actual speed. The "35 mph" (56 kilometers per hour) delay is the difference between traveling at the 35 mph (56 kilometers per hour) and the actual speed, but only for hours of the day when the actual speed is less than 35 mph (56 kilometers per hour).

The computation is repeated for each segment and analysis hour and the totals accumulated. For simplicity of the computations, recurring delay is assumed **not** to impact upstream or downstream segments. Excess demand (demand that could not be served during the analysis hour) from one time period, however, is carried over to the following time period.

The average VHT (assuming only recurring congestion effects) is computed for each segment and analysis hour by multiplying the estimated hourly demand by the estimated segment travel time. The segment travel time is estimated using the following modified speed-flow equation from HCM2000:

$$TT = TT_0 + Dq + 0.25T\left[(x-1) + \sqrt{(x-1)^2 + \frac{16J \bullet L^2 \bullet x}{N^2T^2}}\right] \quad (2)$$

Where:

TT = Segment travel time (hr);

TT_o = Segment travel time at free-flow speed (hr);

D_q = Delay due to leftover queue from prior hour (hr);

T = The length of the analysis period, one hour (hr);

X = The segment demand/capacity ratio;

L = The segment length (miles); and

J = The calibration parameter.

The recurring delay is then computed as follows:

$$VHD = V * [TT-TTR] \quad (3)$$

Where:

VHD = The vehicle-hours of delay;

V = The demand in vehicles;

TT = Segment travel time (hr); and

TT_R = Segment travel time at the reference speed (hr). This is equal to the free-flow travel time *TTo* when the reference speed is equal to free-flow speed.

Step 6a: Estimation of Incident-Related Delay: Method 1

Incidents are essentially rare and random in nature, and their impacts will vary according to when they actually occur. A probabilistic approach is used to estimate their impact on mean delay. The amount of incident-related delay that could occur if an incident occurred during each hour of the year is multiplied by the probability of the incident actually happening during that hour to obtain an "expected value" of incident-related delay for each hour.

Estimation of Total Incidents by Type

Incidents are divided into injury collisions, non-injury collisions, breakdowns, and debris. Injury and non-injury collisions are further subdivided into those involving trucks and those not involving trucks.

In California, only injury and non-injury collisions are reported in the Traffic Accident Surveillance and Analysis System (TASAS) report. The breakdown and debris incidents must, therefore, be estimated. This is accomplished by applying a factor to the number of collisions based on standard default or historical data. A ratio of 7.33 is used to predict the number of serious, noncollision incidents (breakdowns and debris) based on the reported collisions *(11)*. The serious, noncollision incidents are divided between breakdowns and debris assuming a 50:50 split. This assumption can be replaced by the analyst with local data or more recent research, when available.

The number of truck collisions is assumed to be proportional to the percent of trucks on the segment.

The necessary equations are presented below.

$$A(H,S) = ACR * VMT(H,S) \quad (4)$$

$$SNCI(H,S) = 7.33 * A(H,S) \quad (5)$$

$$B(H,S) = D(H,S) = 50\% * SNCI(H,S) \quad (6)$$

$$TA(H,S) = (\%\ Trucks\ on\ Segment) * A(H,S) \quad (7)$$

$$PCA(H,S) = A(H,S) - TA(H,S) \quad (8)$$

$$TI\ (H,S) = A(H,S) + B(H,S) + D(H,S) \quad (9)$$

Where:

A(H,S) = Expected number of collisions on segment (S) during hour (H);

ACR = Average collision rate (total report annual collisions/annual segment VMT);

VMT(H,S) = Vehicle miles traveled during hour "H" on segment "S";

SNCI(H,S) = Serious, noncollision incidents during hour "H" on segment "S";

B(H,S) = Number of breakdowns on segment (S) during hour (H);

D(H,S) = Number of debris incidents on segment (S) during hour (H);

TA(H,S) = "Truck Involved" accidents on segment (S) during analysis hour (H);

PCA(H,S) = Passenger car accidents on segment (S) during analysis hour (H); and

TI(H,S) = Total Incidents on segment (S) during analysis hour (H).

Impact of Incidents on Capacity

Typically, the reduction in capacity due to an incident is disproportional to the physical lane blockage. Table 8.3 shows remaining capacities (percent of the original capacity) as a function of the number of travel lanes blocked and incident type. The information is adapted from HCM2000. These factors are used for both freeways and conventional highways.

The capacity values in Table 8.3 are for the duration of the incident. For incidents that last less than an hour, the reduced capacity for the entire hour is computed as the weighted average of the capacity during the incident and the capacity before and after the incident:

$$c(I,S) = c(I=0,S) * (1-t(I)) + c(I=0,S) * R(I,S) * t(I) \qquad (10)$$

Where:

c(I,S) = Average one-hour capacity on segment (S) for incident of type (i) (vph);

c(I=0,S) = Capacity on segment (S) under normal operating conditions (Equation 1) (vph);

t(I) = Average duration of incident type I (hr); and

R(I,S) = Percentage of capacity remaining during incident type (i) for segment (S).

If the incident duration is less than a full hour, the weighted average capacity is computed for the hour. The incident and non-incident capacities for the segment are weighted according to the proportion of the hour that the incident is present.

Table 8.3 Remaining Capacity Due to Incident

Incident Type	Location	Number of Lanes/Direction				
		1	2	3	4	5+
Collision	Shoulder	79%	81%	83%	85%	87%
	One-lane	0%	35%	49%	58%	65%
	Multilane	N/A	0%	17%	25%	40%
Breakdown	Shoulder	92%	95%	98%	98%	98%
	One-lane	0%	35%	49%	58%	65%
	Multilane	N/A	0%	17%	25%	40%
Debris	Shoulder	92%	95%	98%	98%	98%
	One-lane	0%	35%	49%	58%	65%
	Multilane	N/A	0%	17%	25%	40%

Source: Year 2000 *Highway Capacity Manual*.

Incident Duration

Incident duration is the total time that the incident lasts. It is the sum of detection, verification, response, and clearance times. The incident duration depends on the incident type (accident versus breakdown) and location (lane-blocking versus shoulder incidents), and also on the incident management strategies in operation – (FSP) or on-call rotational tow trucks. Table 8.4 shows the default clearance times for assisted incidents taken from available FSP records in the year 2000. The values can be replaced with local data or more recent research when available.

The reduced capacity for each in incident type is entered into the HCM speed-flow equation (as described above), and a new mean travel speed is computed for each incident type, each segment, each hour of the day, and each day in each season. The vehicle-hours of delay and of congestion are computed as explained above for recurring delay.

The difference in the computed nonrecurring delay computed in this step, and the recurring delay computed above is the amount of delay that would occur if an incident of type i) occurred during each and every hour of the sample period. This result is multiplied by the probability of occurrence for that incident type to obtain the expected value of delay associated with that incident type on each hour of each of the 12 sample days.

Table 8.4 Incident Duration Times from Freeway Service Patrol Records
2000

Incident Type	Blockage Type	Response Time (With FSP/ Without FSP)	Clearance Time	Total Duration (With FSP/ Without FSP)
Collision	Shoulder	5 minutes/30 minutes	20 minutes	25/50 minutes
	One lane	5 minutes/30 minutes	25 minutes	30/55 minutes
	Multilane	5 minutes/30 minutes	25 minutes	30/55 minutes
Breakdown	Shoulder	5 minutes/30 minutes	20 minutes	25/50 minutes
	One lane	5 minutes/30 minutes	15 minutes	20/45 minutes
	Multilane	5 minutes/30 minutes	15 minutes	20/45 minutes
Debris	Shoulder	5 minutes/30 minutes	10 minutes	15/40 minutes
	One lane	5 minutes/30 minutes	10 minutes	15/40 minutes
	Multilane	5 minutes/30 minutes	10 minutes	15/40 minutes
Truck Rear-end and Sideswipe	Shoulder, no injury			40 minutes
	Shoulder, with injury			55 minutes
	One lane			58 minutes
	Multilane			126 minutes
Truck Hit Object, Broadside	Shoulder, no injury			55 minutes
	Shoulder, with injury			110 minutes
	One lane			62 minutes
	Two lanes			111 minutes
	Three+ lanes			115 minutes
Truck Overturns				142 minutes

FSP = Freeway Service Patrol.

Adapted from Skabardonis, 2000 and Golob, 1987.

$$D_{dt}(I) = \sum_{H,S}^{24} E(I,H,S) * VMT(H,S) * \left[TT(I,H,S) - TT(I=0,H,S) \right] \quad (11)$$

Where:

$D_{dt}(I)$ = Total Delay for incident of type i) summed over all analysis hours (H) and segments (S) in units of VHT over one day of type 'dt';

E(I,H,S) = Expected number of incidents of type i) during hour (H) on segment (S);

VMT(H,S) = Vehicle-miles traveled on segment (S) during hour (H) (VMT);

TT(I,H,S) = Estimated mean travel time for segment (S) during hour (H) if incident type i) is present (hr); and

TT(I=0,H,S) = Estimated mean travel time for segment (S) during hour (H) if no incidents are present and weather is fair (hr).

Incidents with durations greater than one hour require that the impacts on delay in subsequent hours be tracked and included in the delay estimate.

The estimated delay by cause is extrapolated to district totals by multiplying the annual estimates for each sample facility by the ratio of total district annual VMT on all facilities of that type over the annual VMT on the sample facilities. Vehicle-hours of delay are converted to person-hours of delay assuming average vehicle occupancy for the district (provided by the analyst).

Step 6b: Estimation of Incident-Related Delay: Method 2

An alternative but similar approach to estimating incident delay used macroscopic simulation and incident characteristics[13] to develop a series of equations that predict incident delay as a function of:

- Number of freeway lanes;
- Base level congestion (AADT/C ratio);
- Incident rate;
- Accident rate;
- Incident duration; and
- Presence of usable shoulders.

[13]Cambridge Systematics, *Sketch Methods for Estimating Incident Impacts*, final report prepared for FHWA, December 1998.

The underlying macroscopic queuing model used to develop the data on which the equations were fit is stochastic. It "simulates" the performance of a test link over a long history and allows the occurrence of incidents and their characteristics to vary according to pre-established distributions. In this way, it replicates the ***cumulative effect of incidents*** over time, rather than estimating the impact of a single incident. This study is the basis for the incident delay equations incorporated into FHWA's Highway Economic Requirements System (HERS) model.

Limited examples of the fairly large set of equations are given below. As shown, the procedure also includes equations for recurring (bottleneck) delay. The method is meant to be applied in a corridor, rather than on isolated segments, so it is particularly appropriate for monitoring freeway sections' performance.

Freeway Peak Period Travel Time Factor without Queuing, H_u(hours per vehicle mile)

$H_u = 1/Speed = (1/S_{ff})\ (1 + 1.20E\text{-}11 * X^{10})$ for $X <= 8$

$H_u = 1/Speed = (1/S_{ff})\ (1.23 - 7.89E\text{-}02 * X + 8.31E\text{-}03\ X^2 - 2.36E\text{-}04\ X^3)$ for $X > 8$

Freeway Daily Delay Due to Recurring Queues, H_r (hours per vehicle per bottleneck)

H_r = RECURRING DELAY = 0 for $X <=8$

H_r = RECURRING DELAY = $4.69E\text{-}03 * (X-8) - 1.50E\text{-}03 * (X-8)^2 + 6.99E\text{-}04 * (X-8)^3$

for $X > 8$

Freeway Peak Period Delay Due to Recurring Queues (hours per vehicle per bottleneck)

H_r = RECURRING DELAY = 0 for $X <=8$

H_r = RECURRING DELAY = $5.56E\text{-}03 * (X-8) + 1.44E\text{-}03 * (X-8)^2 + 5.17E\text{-}04 * (X-8)^3$

for $X > 8$

Freeway Daily Delay Due to Incidents for Two Lane Freeways (hours per vehicle mile)

H_i = INCIDENT DELAY = $IncRate * DurFac^2 * (1 + 4.22 * (1\text{-}SFac)^{1.05})$

$* 3.98E\text{-}06 * X^{4.39E\text{-}01} * e^{5.32E\text{-}01 * X}$ for $X <= 8$

H_i = INCIDENT DELAY = $IncRate * DurFac^2 * (1 + 4.22 * (1\text{-}SFac)^{1.05})$

$* 1.89E\text{-}09 * X^{6.89} * e^{-1.89E\text{-}01 * X}$ for $X > 8$

Where:

X = AADT/C ratio (0 to 18);

AADT = Annual Average Daily Traffic;

C = Two-way capacity (sum of HCM capacity in both directions);

S_{ff} = Free flow speed;

IncRate = Incident rate factor;

= (Target incident rate)/(default incident rate);

DurFac = Duration factor;

= (Target mean incident duration)/(default duration factor);

SFac = Shoulder factor;

= 1.0 for usable shoulders both sides;

= 0.5 for usable shoulders one side only;

= 0 for no usable shoulders;

AccRate = Accident rate factor;

= (Target accident rate)/(default accident rate).

Note that the selection of the incident rate, accident rate, and duration factors are based on comparison to the default values, which are provided by the method; note that if the user wishes to use the default values, all these factors are equal to 1.0. The Users Guide produced for this project provides application instructions.

Summary of HCM-Based Methods

The above methodologies for estimating recurring and nonrecurring congestion will enable the analyst to systematically ascertain the magnitude of traffic congestion problems on the study freeway system. The analyst will be able to identify the relative magnitude and importance of the recurring and nonrecurring components of delay. In addition, the analyst will be able to estimate the true benefit/cost ratios for various real-time traffic management strategies to reduce nonrecurring congestion.

Travel Demand Models

Travel models provide the best-known way to estimate future travel on specific facilities. Travel demand modeling methods have been well established over the past 50 years, and there is a significant body of practice to refer to. Travel models are also recognized by legislators, courts, and the public as a means of identifying where improvements are necessary.

There are significant time and resource costs associated with setting up and maintaining travel demand models. These high costs are primarily a result of the substantial data requirements and the time-consuming process of model estimation. Data requirements include detailed road and transit network data, and a household survey to provide data to estimate the demand models. Model estimation itself is time-consuming and expensive. For a large urban area, data collection costs can be in excess of $1 million for a household travel survey, and over $1 million in additional costs for model estimation and validation. There are additional costs associated with the maintenance of a travel demand models as well. Over a model's useful life, costs are incurred from periodic needs for further data collection, network updates, and consequent model re-estimation activities.

There are also a number of performance issues with today's state-of-the-practice travel demand models. Although the models do reasonably well in forecasting total travel in a region, traffic estimates on individual road links can be off by a significant margin. Travel demand models are also limited in their treatment of the effects of congestion on trip generation. Most travel models forecast the same number of total trips in a region, regardless of congestion. The effects of congestion on the total number of trips have been hotly debated, especially in the past 10 years. The consensus among modelers now is that congestion does affect trip-making, but it is difficult to account for this in most models. Similarly, congestion affects the time of day when people choose to travel, which is manifested in the phenomenon of "peak spreading," where the peak congestion periods last longer as congestion grows. These effects are also not accounted for by most regional travel models. Travel demand models also do not account for the effects of congestion on vehicle queuing; therefore, they cannot model bottlenecks and queue formation and dissipation patterns.

Over the years, practitioners have developed a number of post-processing techniques to compensate for some of the shortcomings of travel demand models as described above. For project-level analysis, where the future traffic volumes of a specific facility are needed, individual link volumes can be developed by running the model for a base year (i.e., existing analysis year), running the model for the case with the project, taking the difference, and adding the difference to a current set of existing traffic counts. This technique allows the analyst to focus on the growth (or decline) in traffic models as predicted by the model, and ignore the substantial variability that travel demand models suffer from when trying to forecast the total volumes for an individual facility.

Post-processing techniques have also been developed to account for peak spreading. These methods divide up the peak period into time slices – generally ranging from 15-minute to one-hour periods. The total demand for the peak period is then divided up and allocated to these time slices. The specific volume allocations for each time slice are usually determined by the professional judgment of the analyst, or based on the time-slice demand data obtained from a similar facility with a similar peak-period demand profile. Each time, slice is then analyzed individually to determine level of service and performance characteristics. NCHRP Report 287 (below) is one of the easiest to use post-processing methods to use in conjunction with travel demand models.

NCHRP Report 387

The NCHRP Report 387[14] provides sketch-planning techniques to estimate the average speed and service volumes for planning applications. The report presents recommended procedure for long-range transportation planning (LRTP) and sketch planning. Any technique employed should be quick and simple, and require very little information on the facility.

The proposed procedure is performed in three stages:

1. Identify study section and critical point;
2. Estimate speed (facility space mean speed):
   a. Estimate free-flow speed,
   b. Estimate link capacity, and
   c. Compute average speed;
3. Estimate level of service and service volumes:
   a. Compute critical point v/c ratio,
   b. Compare with maximum service v/c ratios, and
   c. Compute maximum service volumes.

The recommended speed estimation technique for use in LRTP studies is the enhanced BPR speed-flow curve, which has been fitted to updated speed-flow data in the 1994 HCM and validated against empirical speed-flow data. The facility space mean speed is computed in three steps:

1. Estimate the free-flow speed;
2. Estimate capacity; and
3. Compute the average speed.

For the purposes of this report, Equation 9.1 for computing average speed (Step 3). Look-up tables of defaults can be used to skip the first two steps, but poor choices of the free-flow speed and capacity can seriously compromise the accuracy of the technique. If it is desired to compute mean speed for each hour of a day, once the link capacity and free-flow speed are known, then the following updated BPR equation can be used to predict the space mean vehicle speed for the link at forecasted traffic volumes. The same equation is used for both metric and customary units. This method requires that capacity be measured or estimated. The BPR speed-flow curve equation is shown below.

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[14]NCHRP Report 387, *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, Transportation Research Board, Washington D.C., 1997.

$$s = \frac{s_f}{1 + a(v/c)^b} \tag{12}$$

Where:

s = predicted space mean speed;

s_f = free flow speed;

v = volume;

c = capacity;

a = 0.05 for facilities with signals spaced two miles or less apart;

= 0.20 for all other facilities (including freeways); and

b = 10.

The two keys to success in applying the updated BPR curve are to have an accurate estimate of the free-flow speed and the capacity for the facility. Once those two key parameters are accurately known, the updated BPR curve can estimate speeds for both arterials and freeways with accuracies approaching those of the *Highway Capacity Manual* and simulation models.

Given the best technique for estimating free-flow speed is to measure it in the field under light traffic conditions, it may not be feasible when several thousands of links need to analyzed. Section 6.3.2 provides a discussion of how to determine free-flow speed.

Procedures for Simulation-Based Modeling Applications

A more data and time-intensive method of measuring freeway congestion is to employ a simulation model. Simulation models currently available include the FREQ, AIMSUN2, CORSIM, PARAMICS, and VISSIM software packages. The most labor and data-intensive steps involved in simulation modeling are network coding and model calibration.

For network coding, detailed geometric and traffic control information on the existing or future study segments must be gathered and entered into the model software package. Geometric details include the number, widths, and lengths of facility lanes, merge/diverge areas, on/off-ramps, and weaving areas. The dimensions of breakdown lanes, shoulders, and HOV lanes are also required. Traffic control details include speed limits and the locations of any ramp metering signals and their associated signal controller parameters.

The calibration of a simulation model can also be an expensive (in terms of time and money) undertaking. To properly calibrate a simulation, the analyst will need to acquire field surveillance data on the capacity and performance of the study segments. These data can then be compared to the capacity and performance outputs of the simulation model runs; and by process of iterative adjustments to the model parameters, the outputs of the simulation can be brought into line with the reported capacity and performance of the existing freeway study segments. When the analyst needs to forecast the performance of a freeway segment after the construction of a proposed capacity enhancement, the calibration of the simulation model to existing conditions (i.e., pre-construction) is crucial, allowing the analyst reasonable confidence that the coding of the proposed project the resulting forecast outputs will be as accurate as possible. Unfortunately, this also requires the analyst to code at least two simulation networks: one for existing conditions and a second reflecting post-construction project conditions.

The sensitivity of simulation model parameters can also lead to significant time investments and require the patient skills of an experienced simulation modeler. In most simulation models, the calibration process can be difficult since small changes in model parameters can lead to large changes in model output results. Consequently, finding the parameter changes that lead to the desired changes in the model's outputs can be time consuming, as the modeler is required to re-run the model numerous times in order to find the right combination of parameter settings.

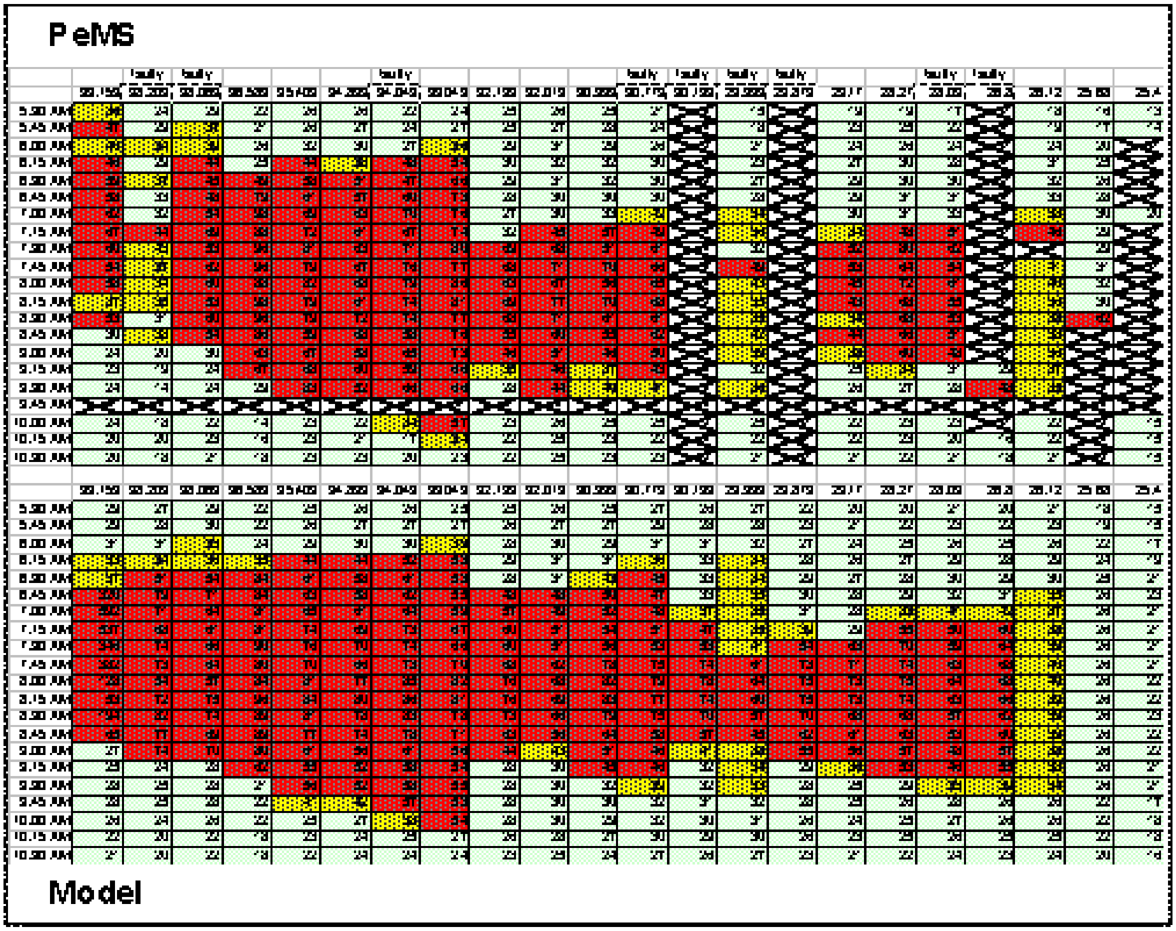
The stochastic nature of simulation models also leads to significant time investments. Since each simulation run varies in its output results (while the parameter settings are fixed), each model run is treated as a sample data point and multiple runs must be undertaken for each calibration change that is made. What results is that with each parameter change, small or large, multiple model runs must be performed to establish the results of that change and the costs of calibration multiply.

Hybrid Approach

A hybrid approach to forecasting future freeway performance combines the best aspects of both the measurement and modeling techniques to produce an empirically grounded assessment of future conditions. While the modeling approaches outlined above use field data for "one shot" forecasting applications, a hybrid model is calibrated multiple times over its lifetime. Forecast model files and results are stored and, when the evaluation period approaches, field measurements are taken and compared to the original model forecast output data. A comparison of field data obtained from the Freeway Performance Measurement System (PeMS) and model data is shown in Figure 8.15.

By periodically re-calibrating the model using feedback from field data, the model's predictive accuracy can be improved over time and can be used to produce more accurate forecasts of future conditions. A hybrid model developed for the San Diego Association of Governments (SANDAG) uses PeMS surveillance detector data (as shown in Figure 8.15) to calibrate against the model's previous forecast results for key freeway segments in the San Diego region. By tracking specific segments over time (as opposed to the whole freeway system), the overwhelming costs and time commitments of collecting field data and modeling the entire freeway system are avoided.

Figure 8.15 Comparison of Measurement (Surveillance) versus Model Data



8.5.3 Special Cases of Estimating Congestion-Related Performance Measures

8.5.3.1 Estimating Congestion by Source

Section 6.0 presented several performance measures for the amount of freeway delay caused by bottlenecks/physical capacity, traffic incidents, weather, work zones, ramp meters, and abnormally high traffic volumes. These are very important aspects of freeway performance, because they tell freeway managers which areas should receive emphasis. However, given the current state of the practice in methods and data for decomposing congestion into these sources, they are largely placeholders awaiting future developments.

Typically, delay is classified into two broad categories of causation: recurring and non-recurring congestion. Nonrecurring congestion – or the delay caused by incidents – is typically blamed for roughly 50 percent of all freeway travel delay. Therefore, any collection of freeway system performance measures must identify and measure the effects of incidents on study freeway segments.

Some recent work has been accomplished in this area, and freeway performance managers are encouraged to stay alert for newer developments that can be applied to their situation. A review of relevant past studies is provided below for interim guidance to practitioners.

A 1992 study by Dowling Associates for Caltrans was probably the first empirical study to tackle the issue of congestion by source.[15] Their methodology for measuring congestion on freeways was to use freeway surveillance data on traffic volumes and speeds to compute total delay, and then allocate total delay to recurring congestion and the various causes of nonrecurring congestion. This methodology was designed to analyze historic congestion data, rather than to forecast future congestion. They define the following components of congestion as a starting point:

- Nonrecurring congestion is that amount of delay to the traveling public that is caused by incidents (including collisions, breakdowns, and debris); work zones; special events; and/or inclement weather;
- Recurring congestion is any observed delay that was not caused by the above factors; and
- Total congestion is, therefore, the sum of the two components – recurring congestion, and nonrecurring congestion.

Their methodology is as follows:

- Estimate the expected value for recurring delay by summing up the vehicle-miles traveled (VMT) and vehicle-hours of delay (VHD) accumulated over the sample time periods and sample freeway facility segments for those hours not associated with any nonrecurring event (weather, incident, work zone, special event, other). Compute an average recurring rate of delay (obtained by dividing VHD by VMT).
- During time periods when there would be a normal background level of recurring delay, the delay associated with nonrecurring congestion is determined by subtracting the estimated level of recurring delay from the measured total delay. In other words, all of the extra delay measured during periods of nonrecurring congestion is considered to be nonrecurring delay (rather than being apportioned in some manner to recurring and nonrecurring causes).
- Adverse weather delay is the difference between the measured total delay during adverse weather periods and the expected amount of delay that would have been

[15] Dowling Associates, Berkeley Transportation Systems, and Systems Metrics Group, *Measuring Nonrecurring Traffic Congestion*, Contract No. 65A0120, prepared for California Department of Transportation, December 11, 2002.

present during a fair weather time period under similar demand conditions and during the presence of similar causes of nonrecurring congestion (incidents, work zones, etc.). This means that an estimate is made of what the average number and type of incidents, work zones, etc., would have been under fair weather conditions, and the delay associated with those is subtracted from the measured total delay to obtain the incremental delay associated with adverse weather.

- If multiple causes of nonrecurring congestion (besides adverse weather) are observed during a single time period, the incremental delay measured during that time period (over and above the recurring congestion delay) is split equally among the causes (incidents, work zones, and special events). Thus, if an incident occurs during a time period when a work zone is also present, the measured incremental delay during this time period is split 50:50 between "incidents," and "work zones." The rationale for this rule is to simplify the allocation of nonrecurring congestion to its various nonweather-related causes, and to avoid the additional steps of computing the portions of measured delay associated with all possible combinations of incidents, work zones, and special events in each time period.

Unfortunately, the methodology has not yet been implemented by Caltrans due to data limitations. Also, the methodology is a bit simplistic, in that, it does not consider the time and space effects of events very well. For example, if an incident was present in an hour, then that entire hour is considered to be under the influence of the incident. On the other hand, a great advancement was the notion that there is a base level of recurring congestion that must be accounted for; that is, some amount of delay will occur even in the absence of an event. Assigning the total delay to the event in these cases would overestimate its value.

Using the same concept of identifying recurring delay as delay that is "normal," "typical," or "average," Kopf, Nee, Ishimaru, and Hallenbeck developed a more sophisticated and automated method for tracking individual queues (backups) using freeway surveillance data onto which incident data was superimposed.[16] In their study, recurring congestion was assumed to be any delay that occurred up to a threshold value, set at the median lane occupancy rate plus five percent for each location (detector) by day of week and time period.[17] Any delay above the threshold was assumed to be nonrecurring. The nonrecurring portion was then allocated to incidents and weather. For incidents, the time and location were noted, and any resulting queue was tracked as it grew and dissipated upstream of the location. The specifics of the procedure are:

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[16] Kopf, J. M., J. Nee, J. M. Ishimaru, and M. E. Hallenbeck, *Measurement of Recurring and Nonrecurring Congestion: Phase IIB*, Washington State Transportation Center (TRAC), prepared for Washington State Transportation Commission, June 2005.

[17] Because the study area was in Seattle where the freeway surveillance system is mainly single loop detectors, direct estimates of speeds were not available. Therefore lane occupancies were used.

1. **Prepare incident and events data.** Clean incident databases (e.g., remove typographical errors and ambiguous data), and prepare listings of the relevant incidents (blocking, shoulder) in the proper format for processing. Prepare a list of special events and their time and location.

2. **Prepare hourly precipitation data.** Collect precipitation data from regional weather stations. Re-code the hourly precipitation levels to the following categories: no precipitation, low, moderate, or heavy. Assign each station's data to a corridor segment. Format the data as time-space matrix overlays with the same dimensions as the freeway condition matrix. Each time-space matrix (milepost versus time period) will show hourly precipitation levels on a given corridor for a given day. (The weather information is used as a mask to allocate subsets of the delay to different precipitation conditions.)

3. **Prepare freeway condition data**. Compute each day's time-space matrix (i.e., time of day versus location) of estimated vehicle volume, lane occupancy percentage, and speed, using loop data.

4. **Compute Background Matrix:**

   a. Identify which days have incidents in the database for a given time period. Do this for each month.

   b. Compute the median occupancy matrix for each month, based on the occupancy matrix for those days that have no blocking incidents. The median is computed individually for each matrix element (i.e., a given milepost/time combination). This median time-space matrix is used as the background condition for that month. (The use of the median value reduces the potential biasing effect of outlier days.)

5. **Compute the Difference Matrix**. Subtract the monthly background condition (median matrix) from the freeway condition matrix of each day. (Use the background condition appropriate for the month being analyzed.) The result is a difference matrix that is used to highlight unusual time-space regions.

6. **Detect Regions of Congestion associated with each incident**:

   a. Evaluate each element of the difference matrix for each day, based on the value of the difference. Any element in the "+5 and higher" difference category is considered a time/location combination of nonrecurring congestion.

   b. Identify the time-space location (day, milepost, start time, clear time) of each **lane blocking** or **shoulder** incident of that corridor.

   c. Identify the time-space location (day, milepost, start time, clear time) of each virtual **spillover event** produced by incidents on a related (adjacent) corridor, using the off-ramp to the adjacent freeway as the location of the spillover "incident," with the start time determined by the first appearance of nonrecurring spillover congestion in the difference matrix, and clear time determined by the duration of the original incident that produced the spillover. Note that spillover congestion is defined based on its time-space proximity to the original incident; there is not necessarily a direct cause-effect relationship.

d. Identify the time-space location (day, milepost, start time, clear time) of each **special event** incident on that corridor. The location of a special event is a "virtual" one, defined as the start of the off-ramp that is most likely to serve traffic on that corridor that is going to the event. The virtual clear time is defined to be the event start time, while the virtual start time is defined to be (event start time minus 1 hour).

e. Locate the congestion region of each incident (both real and virtual) by looking for a cluster of contiguous difference matrix elements near the incident location that have high difference values (i.e., +5 or greater, which is defined as nonrecurring congestion as noted in Step 6 a). The edges of this region are determined by looking for local minima (a "valley") of the difference values, or a difference that drops below the +5 threshold (+5 defines nonrecurring congestion).

7. **Compute Vehicle-Hours of Delay.** Compute the delay for each congestion region from Step 6e), using the volume and speed matrix of the corresponding day. Assign each region's delay estimate to the corresponding nonrecurring category, as well as any category combinations. Also, allocate the congestion delay of each nonrecurring category by weather category, using the precipitation overlay.

A simplified version of the Kopf procedure was also developed by the research team. Instead of tracking the queue, a "region of influence" in time in space was established upstream of the incident (Figure 8.16). Any delay in this region above the threshold is subject to being allocated to the incident. One extension of the Kopf procedure was to include an indicator of high volume (the Traffic Demand Indicator discussed in Section 6.0); high-volume days defined as those with peak + shoulder hours with volumes less than five percent above the average for that day of week.

Recent work by Kwon, Mauch, and Varaiya[18] used data from a 45-mile stretch of I-880 in the San Francisco Bay Area to develop regression equations that predict nonrecurring delay as a function of:

- Number of incidents that occur;
- Number of congestion-inducing special events such as sport games;
- Number of lane-closures;
- Adverse weather condition (binary variable: yes/no).

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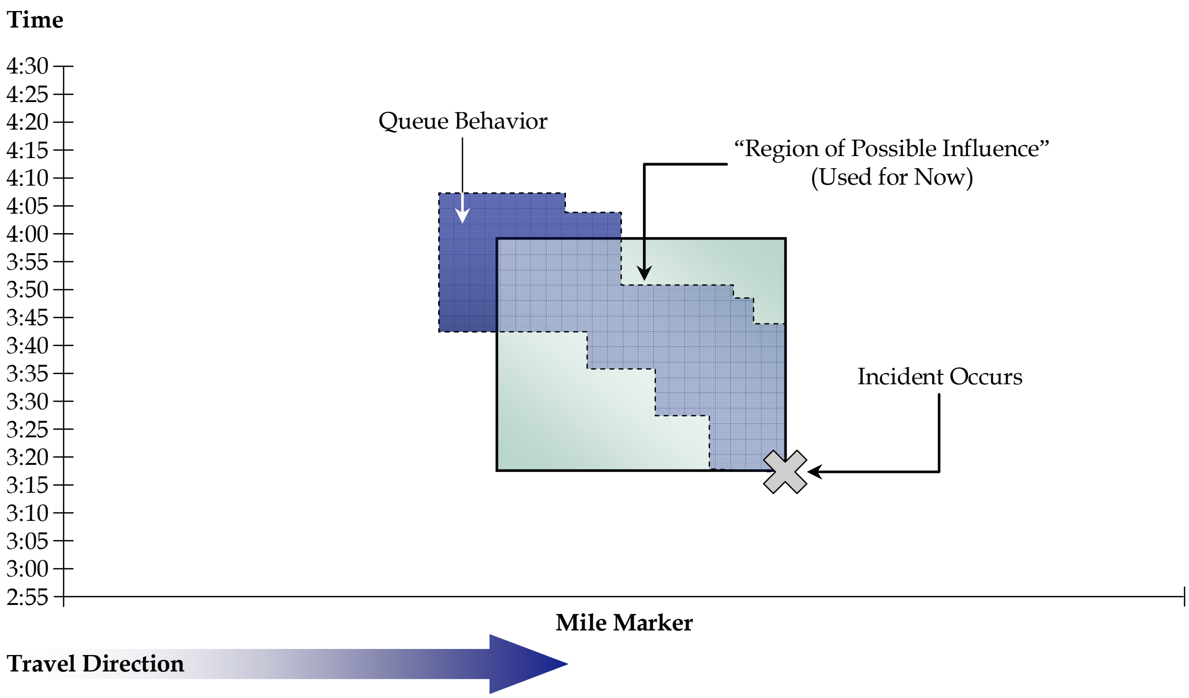
[18] Kwon, J., M. Mauch, and P. Varaiya, *The Components of Congestion: Delay from Incidents, Special Events, Lane Closures, Potential Ramp Metering Gain, and Excess Demand*, presented at 85th Annual Meeting Transportation Research Board, January 2006.

Figure 8.16 Tagging Traffic Data for Incident Effects



Separate equations were developed by direction and AM/PM peak periods. Total delay is measured with freeway surveillance equipment and recurring delay is the found by subtracting nonrecurring delay from total delay. The problem with this approach is that the explanatory variables are very general (incidents are all assumed to have the same characteristics) and the R^2 values (predictive power) were very low (0.12-0.17).

The Capital District Planning Committee (the Albany, New York MPO) undertook a similar study to the above by fusing freeway traffic surveillance data with incident data.[19] This study did not attempt to establish a recurring baseline but rather, if an incident occurred, assigned all delay to the incident.

The results from these studies are summarized in Table 8.5.

[19] Capital District Planning Commission, *New Visions Regional Transportation Plan Update: Working Group B Draft Report – Expressway System Options*, August 2005.

Table 8.5 Results from Previous Studies Identifying Congestion by Source

Statistics	Study			
	Dowling	**NCHRP 3-68**	**Kwon *et al.***	**CDTC**
Metro Area	Los Angeles	Seattle	San Francisco	Albany
Routes	I-10	I-405, I-90, SR-520	I-880	I-87, I-90
Freeway Miles	10 miles	42 miles	45 miles	15 miles
Amount of Data	7 days	4 months	6 months	1 year
Total Delay				
Recurring Delay	69%	71%	80%	72%
Nonrecurring Delay	31%	29%	20%	28%[b]
Nonrecurring Sources				
% Incident	31%	16%[a]	13%	28%
% Work Zone	0%	0%	0%	Not studied
% Weather	0%	9%	2%	Not studied
% Special Events	0%	Not studied	5%	Not studied
% High Volume	Not studied	4%	Not studied	Not studied

[a] Includes two percent opposite direction rubbernecking.

[b] Assigned all delay under an incident condition to incidents, rather than setting a "recurring baseline."

Several caveats must be made:

- All of these studies represent the first step in developing congestion by source and none can be considered to be definitive.
- It should be noted with care what sources of nonrecurring congestion are included in each study. No study was able to incorporate all the potential sources.
- All of the studies used data from freeways that experience a significant amount of bottleneck-related (recurring) congestion. As bottleneck conditions worsen, they will tend to dominate delay from a percentage viewpoint. The increased "baseline" congestion will also cause an increase in nonrecurring congestion, all other things equal, but since recurring congestion happened more of the time, on a percentage basis it will be higher.
- The occurrence of work zones during the relatively brief study periods is mostly nonexistent.

8.5.3.2 Estimating Recurring and Nonrecurring Delay

The first steps of the Kopf *et al.* method adapted for this *Guidebook* can be used to estimate the recurring/nonrecurring delay split where continuous freeway detector measurements exist. First, the threshold speed is set at the median speed for each time slice by day of week for each detector (one detector per freeway section). Median speed plus a small buffer (2.5-5.0 mph) can also be used if local analysis suggests that this threshold provides a better cutoff between the two delay types, as long as the maximum is set at the free flow speed. Then, total delay (measured as the actual travel time minus the free flow travel time) is calculated for each freeway section. Recurring congestion is the delay that occurs up to threshold speed value. Any delay above the threshold is assumed to be nonrecurring.

8.5.3.3 Estimating Congestion Performance Measures From Density Measurements

Aerial photography (and in the future, perhaps satellite imagery) can be used to estimate freeway density (vehicles per mile). These measurements can be transformed into speed measurements using traffic flow equations. The simplest form of these relationships is:

$k = q/u$

Where:

k = density (vehicles per mile);

q = flow rate (vehicles per hour); and

u = space mean speed (miles per hour).

This simple relationship has been expanded to match observed traffic flow better. One of the better known extensions is that of Van Aerde,[20] which relates density to speed:

$k = 1/(c_1 + (c_2/u_f - u) + c_3 u)$

$c_1 = (u_f(2u_c - u_f))/(k_j u_c^2)$

$c_2 = (u_f(u_f - u_c)^2)/(k_j u_c^2)$

$c_3 = 1/q_c - (u_f/(k_j u_c^2)$

Where:

u_f = free flow speed;

u_c = speed at capacity;

k_j = jam density (density when speeds are 0); and

q_c = flow at capacity.

[20] Van Aerde M., *Single Regime Speed-Flow-Density Relationship for Congested and Uncongested Highways*, presented at the 74th TRB Annual Conference, Washington, D.C., paper No. 950802, 1995.

Local values can be used for these parameters, but in their absence, the HCM can be used. Assuming that u_f = 60 mph, u_c = 50 mph, k_j = 210 vehicles per mile, and q_c = 2,200 vehicles per hour produces:

Speed (mph)	Density (vphpl)
59	27.72
55	39.11
50	44.00
45	48.44
40	53.32
35	59.04
30	65.96
25	74.60
20	85.75
15	100.71
10	121.91
5	154.31
0	210.00

8.5.3.4 VMT Estimation Where Gaps Exist in Continuous Data

While continuously collected traffic data from sensor-rich ITS deployments offer great potential for improving traffic measurements of all kinds, data quality problems may lead to incomplete data sets for computing performance measures. The reality is that the data are rarely complete – due to poor communication and detector problems, much of the data can be missing or below quality thresholds. The data will then be incomplete for long spans of time (due to detector quality problems) or intermittently (due to short-term communication problems). For estimating travel time and associated measures, this is not a problem unless a large amount of data are missing or unusable – it can be treated as a sample. However, since VMT requires continuously measured volumes, missing data will cause VMT calculations to be low. Several options exist for dealing with this shortcoming, as outlined below. The starting point for all of these alternative is first to derive hourly volumes. Because operations data are usually present in sub-hour aggregates (e.g., 5-minute bins), some bins may be missing. If this is the case, the analyst can factor up the existing data if at least 50 percent of the bins are present in the hour. The threshold for how much should be present before the factoring is allowed to occur is not known at this point, but 50 percent is a good starting point. If not, the hour can be assigned a missing volume, and the methods take it from there.

1. ***Method 1: Impute missing data using average hourly volumes by location.*** Several methods exist for filling in missing data with imputation.[21] For those hours left with missing volumes, substitute in the average hourly volumes for each detector based on day of week. More sophisticated methods exist that involve looking at other detectors in other lanes and upstream/downstream.

2. ***Method 2: Impute missing data using average hourly growth rates by location.*** This is a variant of Method 1. Instead of the actual average hourly volumes, average growth rates between the previous hour and current hour are computed and applied to the previous hour volume. A test of this method using data from Detroit produced reasonably good matches, less than eight percent error overall.[22]

3. ***Method 3: Expand the AASHTO Method to Use Hourly Data (Annual VMT only).*** The AASHTO method uses a series of successive averaging to compute Average Annual Daily Traffic (AADT), which can then be multiplied by section length and number of days in the year to derive annual VMT. The successive averaging used is: 1) day-of-week by month Average Daily Traffic values (ADTs), 2) monthly ADTs, and 3) AADT (calculated as the average of monthly ADTs). An extension of this method is to compute the average hourly ADTs for each month/day of week combination as the first step before the existing three averaging steps are applied. This process requires that sub-hour measurements be factored up to hourly level (as in Method 1.)

4. ***Method 4: Find continuous strings of 24-hours of data; treat as short counts (Annual VMT only).*** This approach basically treats data from ITS detectors as short-counts. These counts must be factored just like any short-duration traffic counts, which comprise the bulk of traffic data currently maintained by transportation agencies. This approach of course assumes that ITS traffic data will exist for at least two 24-hour periods. If the data are incomplete for an individual hour, the factoring method above may be employed.

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[21] Conklin, James Howard, *Data Imputation Strategies for Transportation Management Systems*, Masters Thesis, University of Virginia, May 2003.

[22] Battelle Memorial Institute and Cambridge Systematics, *Potential Use of Archived Intelligent Transportation Systems Data for Government Reporting*, prepared for FHWA Office of Highway Information Management, February 10, 2003.

8.5.3.5 Estimating Reliability Without Continuously Measured Travel Times

Travel time reliability is becoming a major aspect of congestion-related performance. Unfortunately, modeling techniques for estimating travel reliability measures are only now being considered. The incident modeling methods discussed previously are a start in this direction, but using incident delay as a surrogate for overall reliability is insufficient; it is clear that reliability is a function of many other sources than just traffic incidents. The Southern California Association of Governments (SCAG; the MPO for the Los Angeles metropolitan area) has recently incorporated reliability into its long-range planning activities; reliability analysis is done between O/D pairs in order to capture the individual's travel experience.[23] SCAG used the concept displayed previously in Figure 5.5 to develop regression equations predicting Buffer Index as a function of the Travel Time Index, using freeway detector data from the Los Angeles area. This is a definite innovation in this area, but a problem with this approach is that it makes reliability solely a function of base congestion level, when clearly other strategies – particularly demand management and operations – can have a dramatic impact on reliability. Note too that this is used to ***forecast reliability*** with the luxury of having current reliability directly measured. Still, the approach has merit and the inclusion of additional explanatory variables in this statistical-based approach should be explored. These would be variables that relate to the sources of congestion, much like the variables included in the incident modeling section above.

8.5.4 Secondary Crashes

Traffic incidents can cause secondary incidents that would not have occurred without the presence of the initial incident. Secondary incidents are not just crashes but also include engine stalls, overheating, and running out of fuel. Approximately 20 percent of all incidents are secondary incidents.[24] However, in terms of performance monitoring, only secondary crashes are recommended for tracking in this *Guidebook.*

Determining causation – would the "secondary" crash have occurred even if the initial incident had not – is highly problematic. As with determining the contribution of congestion sources to total delay, methodologies for estimating secondary crashes are not well-formed, and practitioners should remain aware of new developments in this area. In the interim, the following guidance is offered. While an automated procedure would be best, the procedure can be applied manually since we are restricting it to freeways.

The basic premise is that crashes that occur in close proximity in time and space of a prior crash are candidates for a secondary crashes. The possible causal factors for secondary crashes are queues formed by the initial crash (especially ones that spread upstream rapidly on segments where queues are unexpected by travelers), emergency vehicle maneuvers, and driver distraction caused by rubbernecking.

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[23]Southern California Association of Governments, *Final 2004 Regional Transportation Plan*.

[24]FHWA Office of Operations, http://ops.fhwa.dot.gov/aboutus/one_pagers/tim.htm.

- ***Step 1: Assemble Crash Data.*** The crash data must be geocoded to allow locating crashes along a freeway section. Linear referencing is fine for this application (e.g., route/direction/milemarker). Either data from the traditional state reporting system (derived from police accident reports) or incident management data files can be used. As it is known that both of these sources do not capture the full universe of crashes.[25]

- ***Step 2: Establish Thresholds for Time and Space Proximities.*** For crashes in the same direction of travel, the potential secondary crash must occur later in time and upstream of the initial one. The trick here is to estimate if the queue from the first crash has spread far enough in time and space to influence the second crash. Since crashes usually consume at least one lane, the resulting queues are likely to be long in extent and duration. A good starting place would be to use one hour and three miles for peak periods and shorter thresholds for off-peak periods. These thresholds should be adjusted to local conditions as practitioners gain more experience. If incident management data is used – and incident durations are present – the time threshold may be tied to incident duration, ensuring that the threshold is much greater than the actual duration (by orders of magnitude to allow for queue formation and dissipation). Begin/end times are usually not available from police-reported crashes.

- ***Step 3: Sort Crashes in Time and Space.*** Figure 8.17 shows incident management data collected by the ARTIMIS system in Cincinnati, Ohio, and the identification of potential secondary crashes. In this example, the northbound direction is shown and milemarkers increase in this direction.

- ***Step 4: Identify Potential Opposite Direction Rubbernecking Secondary Crashes.*** Crashes that occur up to a time threshold within one-half mile or so upstream of the initial crash may be considered to be secondary crashes. Note again that one-half mile is a guideline – definitive research has yet to be conducted to establish threshold values.

A more precise method rather than setting fixed thresholds is to use the queue tracking methodology identified in the last section for estimating congestion by source, for identifying same direction secondary crashes (see Figure 8.16). In this approach, incidents are plotted on the same time/space diagram as is used for queue tracking. This allows the analyst to see if the queue from the initial crash was present at the time of the second (or third, or fourth) crash occurred. Some allowance should be made for same direction rubbernecking if the actual queue is tracked – this would mean that any crash within one-half mile or so could be considered to be secondary regardless of queue presence.

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[25] Some crashes are not investigated by police, some are below the police reporting threshold, and incident management recordkeeping may be inconsistent.

Figure 8.17 Use of Incident Management Data to Identify Potential Secondary Crashes, Cincinnati, Ohio

Crash No.	State	Route	Direction	Date	Mile Marker	Crash Time
2369	OH	I-75	N	10FEB2002	14.0	14:25:00
2370	OH	I-75	N	11FEB2002	7.4	17:20:00
2371	OH	I-75	N	12FEB2002	3.3	17:47:00
2372	OH	I-75	N	12FEB2002	3.5	16:49:00
2373	OH	I-75	N	12FEB2002	7.7	15:53:00
2374	OH	I-75	N	12FEB2002	8.6	14:55:00
2375	OH	I-75	N	12FEB2002	17.0	21:54:00
2376	OH	I-75	N	14FEB2002	2.3	12:39:00
2377	OH	I-75	N	14FEB2002	8.3	15:51:00
2378	OH	I-75	N	15FEB2002	9.0	15:43:00
2379	OH	I-75	N	15FEB2002	13.4	17:00:00
2380	OH	I-75	N	15FEB2002	15.0	12:52:00
2381	OH	I-75	N	16FEB2002	4.5	20:36:00
2382	OH	I-75	N	18FEB2002	4.0	17:20:00
2383	OH	I-75	N	18FEB2002	13.5	10:12:00
2384	OH	I-75	N	19FEB2002	15.8	21:41:00
2385	OH	I-75	N	20FEB2002	2.0	14:56:00
2386	OH	I-75	N	20FEB2002	4.0	13:26:00
2387	OH	I-75	N	20FEB2002	4.6	16:08:00
2388	OH	I-75	N	20FEB2002	5.8	14:26:00
2389	OH	I-75	N	20FEB2002	14.2	15:44:00
2390	OH	I-75	N	20FEB2002	15.6	18:52:00
2391	OH	I-75	N	20FEB2002	16.9	19:50:00
2392	OH	I-75	N	23FEB2002	15.0	11:47:00
2393	OH	I-75	N	25FEB2002	5.3	21:43:00
2394	OH	I-75	N	26FEB2002	3.5	17:26:00
2395	OH	I-75	N	26FEB2002	11.9	11:12:00
2396	OH	I-75	N	27FEB2002	2.3	22:52:00
2397	OH	I-75	N	27FEB2002	11.2	7:29:00
2398	OH	I-75	N	27FEB2002	11.7	6:25:00
2399	OH	I-75	N	28FEB2002	3.5	18:04:00
2400	OH	I-75	N	28FEB2002	8.0	18:03:00
2401	OH	I-75	N	28FEB2002	8.9	15:48:00
2402	OH	I-75	N	28FEB2002	11.4	16:09:00
2403	OH	I-75	N	28FEB2002	13.6	10:05:00
2404	OH	I-75	N	01MAR2002	0.7	14:46:00
2405	OH	I-75	N	01MAR2002	1.2	10:20:00

8.5.5 Estimating Environmental Performance Measures

The emissions and fuel use performance measures must be estimated with models since it is not possible to measure these events directly on freeways. For emissions, the Environmental Protection Agency's MOBILE model can be used. MOBILE provides emission rates (grams per mile traveled) as output, which corresponds with the recommended performance measures. MOBILE's "transportation activity" inputs must be modified to deal only with freeways.; all remaining inputs can be left the same as for areawide runs of MOBILE. The runs are most appropriately made once per year, using data from the previous 365 days. This is a simplification, but trying to derive these other inputs solely for freeways is extremely problematic. Specifically, the two inputs that should be changed are:

- Fractions of VMT – these should be changed to reflect the vehicle class distributions found only on area freeways. If section by section data are not available, areawide default values may be used.

- VMT by Facility by Hour and Speed – only freeways and ramps should be included in the MOBILE runs.

For each freeway section, separate MOBILE runs should be made for each direction. Each direction should be identified as peaking in the morning or afternoon. ***Where continuously collected volume and speed data exist***, separate runs should be made for several representative days. That is, the 24-hour speed distributions should be developed separately for different days that are defined by different moments of the actual speed distributions. These are identified by identifying the four days of the year when average peak period speeds on the section were at the following percentile levels: 1st, 5th, 25th, 50th (median), 75th, and 95th, and 99th. For these days, the entire 24-hour distribution of speeds is used. VMT for these days is calculated and used to weight the results.

In lieu of running the MOBILE model, the simplified procedures from FHWA's HERS model can be used. (These were derived from the MOBILE5a model.) Table 8.6 shows these equations. The same approach to developing speeds and VMT as described above should be used with these equations.

8.5.6 Dealing with Uncertainty in Estimates of Performance Measures

Good statistical practice suggests that uncertainty estimates be included with performance statistics. In practice, however, very few agencies currently report uncertainty estimates in their performance reports. The reasons for this are unknown. The Bureau of Transportation Statistics provides some basic guidelines for including uncertainty estimates in transportations statistics.[26] Uncertainty estimates are typically provided through the use of confidence intervals that show, to a specified probability, the likelihood of the true actual value being between the lower and upper confidence interval values (see Figure 8.18).

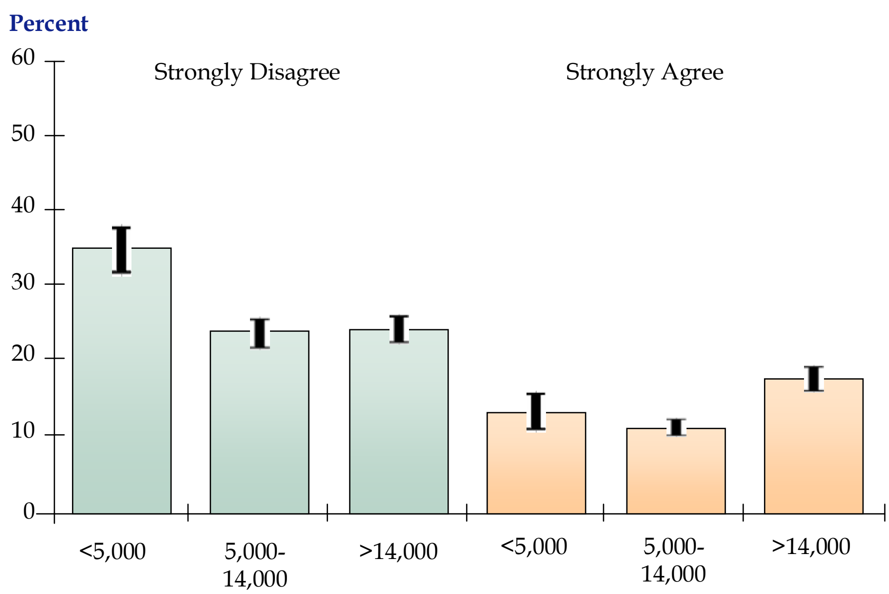
[26] *Guide to Good Statistical Practice in the Transportation Field*, Bureau of Transportation Statistics, May 2003, available at http://www.bts.gov.

Table 8.6 Emission Rate Equations

	Consolidated Section Group	Coefficient on Variable Equation for Emission Rate (g/mi)						
		Constant	Speed	Speed	Speed	Speed	Speed	Speed
Carbon Monoxide (CO)								
2006-2010	Rural Interstate	114.17363	-16.827916	1.3701258	-0.0596681	0.0013845	-0.0000162	0.0000001
	Urban Interstate	114.17298	-17.043957	1.3963221	-0.0608872	0.0014105	-0.0000165	0.0000001
2011-2016	Rural Interstate	111.76610	-16.485495	1.3504753	-0.0591227	0.0013766	-0.0000161	0.0000001
	Urban Interstate	112.14462	-16.746249	1.3795722	-0.0604532	0.0014050	-0.0000164	0.0000001
Volatile Organic Compound (VOC)								
2006-2010	Rural Interstate	9.8994526	-1.3735297	0.1048065	-0.0043525	0.0000985	-0.0000011	5.298E-09
	Urban Interstate	10.154998	-1.4733830	0.1145351	-0.0047948	0.0001089	-0.0000013	5.880E-09
2011-2016	Rural Interstate	9.5859661	-1.3208984	0.1006140	-0.0041756	0.0000944	-0.0000011	5.068E-09
	Urban Interstate	9.8415541	-1.4214115	0.1104162	-0.0046213	0.0001049	-0.0000012	5.654E-09
Nitrogen Oxide (NO_x)								
2006-2010	Rural Interstate	4.2386051	-0.1450051	0.0013180	0.0002465	-0.0000108	0.0000002	-9.558E-10
	Urban Interstate	3.0017081	-0.0829004	-0.0014691	0.0003469	-0.0000133	0.0000002	-1.130E-09
2011-2016	Rural Interstate	4.0842899	-0.1408217	0.0013903	0.0002330	-0.0000103	0.0000002	-9.223E-10
	Urban Interstate	2.9219077	-0.0815919	-0.0013321	0.0003338	-0.0000128	0.0000002	-1.101E-09

Source: Apogee Research (1996), Technical Note B, Tables B1-B5.

Figure 8.18 Use of Confidence Intervals to Indicate Uncertainty in Data Values



Source: *Transportation User's Views of Quality*, FHWA, 1997).

9.0 Using Freeway Performance Measures

9.1 Introduction

9.1.1 Purpose of Chapter

This chapter ties the guidance together in examples to illustrate common considerations and decision-making processes. The role of data sources, types of analyses, strategies that might be used to address the problems and the audiences and users of performance measures will be examined in the examples.

9.1.2 Background and Overview

Key Considerations

Performance measures are only worth reporting if they are used to inform decisions. When used properly, they inform the freeway agency's decision-makers about the condition of the facility. They describe the nature of problems on the facility, and when tracked over time, describe how those conditions are changing.

When produced in light of the policies being implemented, control systems being applied, and management actions being used, they become statistics that describe whether operational and policy goals are being reached, and whether management decisions are having the effects desired. This in turn leads to more informed decision-making as those decisions that improve system performance can be defended and continued, while those that have little impact or that actually hurt freeway performance can be abandoned or revised.

Thus freeway performance reporting has the most benefit when it is used to examine the results of key policy and management decisions.

Perhaps the most important consideration of performance measures is that they are measures of what has happened. By themselves, performance measures are not predictions of what **will** happen. As a result, they are particularly well suited for setting the stage for decisions, and they are excellent at measuring the impacts on freeway performance of the total range of policy decisions given the external factors (growth, weather, etc.) which detract from freeway performance.

Performance measures are not, by themselves, well suited to making decisions. They inform the decision-making process, but by themselves they cannot tradeoff the different priorities, interests, and values that must be incorporated in the decision-making process. However, having the information provided by a well designed performance measurement system greatly increases the chance that good decisions will be made.

Because performance measures require time and energy to produce, it is important that those in charge of computing those measures have an accurate understanding of what information is needed by, or useful to, decision-makers. With an understanding of the basic needs of the decision-makers, it is possible to prepare the statistics needed prior to the time they are needed, reducing allowing for careful data review and analysis. A good way to gain this understanding is to think through what major policies are being considered and/or implemented. In addition, what subject areas are controversial? Once these topics are understood, select and report those performance statistics which describe freeway performance relative to those topics.

For example, if the level of use of HOV lanes is a politically important topic, develop performance measures that describe HOV lane use, how that use is changing over time, and how it compares to general purpose lanes. Because HOV lanes are designed to move people more than vehicles, make sure that both person and vehicle movements are measured and reported.

If performance measures inform key policy decisions, they will have high visibility and high levels of support from decision-makers and upper management. If the performance measures are not useful in addressing key policy issues, they will have much lower visibility and commensurately lower levels of support. Consequently, if only limited funding is initially available for performance measurement, make sure that the measures collected supply key information for policy-makers considering highly visible public decisions. Meeting such a visible need is likely to help create the upper management support for additional performance measurement funding. If the performance measurement process cannot meet the information demands of high-visibility decisions, little additional support is likely to flow towards the process, as the worth of the program cannot be effectively demonstrated.

9.2 Stakeholders for Freeway Performance Measures

Freeway operations are impacted by a wide variety of factors, and consequently affects, and is affected by, the actions of a large number of agencies and groups. Each of those agencies and groups is a potential stakeholder in freeway performance reporting. Each has an interest in freeway performance as it relates to their own operations. Among the obvious stakeholders are:

- The operator of the freeway, which contains multiple groups with different performance measure interests, including (but not limited to) staff involved in:
  - Selecting implementing, and operating traffic management plans, including both day-to-day operational plans and special plans for unique events;
  - Recommending capital improvements;
  - Making safety improvements;
  - Selecting time periods when construction and maintenance crews can work within the right-of-way, and that must design and/or approve the traffic control plans for those construction activities; and
  - Responsible for coordinating agency activities and plans with those of agencies/ jurisdictions that operate neighboring transportation facilities.
- Transit agencies that provide service which use the freeway;
- Transportation and land use policy-making bodies;
- State, regional, and local planning groups that help identify, design, prioritize, and fund transportation improvement projects;
- Regulatory bodies that oversee distribution of national and state funds;
- The agencies that perform emergency response on the freeway;
- Police agencies that are responsible for law enforcement and major accident investigations;
- The local news media that wish to report on the condition and operation of the local freeway system;
- Private businesses such as trucking companies that routinely use the freeway system and whose business practices are therefore affected by the freeway's operational performance; and
- Individual taxpayers that either wish to use performance information directly, or desire that the freeway operating agency to use that information to develop and publicize travel information that improves the quality of their lives.

The good news is that many of the agencies interested in freeway performance measures also can provide data related to their own use or interaction with the freeway. These data are frequently key inputs to the performance measurement process. For example, a transit agency that operates buses on the freeway would be able to provide ridership on those buses and potentially average travel time and on-time performance for busing serving those routes. Ridership statistics are necessary for estimating person throughput on the roadway, and the travel time and on-time statistics are useful for determining the value of changes in freeway travel time and travel time reliability to the transit agency. Thus, the transit agency is really a customer for freeway performance measures, a contributor to those measures, and a stakeholder in the decisions that are made using those measures.

The "bad" news is that each involved group/agency is likely to be interested in their own "spin" on freeway performance, and may thus be interested in slightly different sets of performance measures. This is likely to increase the number of performance statistics that need to be produced to answer all of the questions that will be asked. What many agencies that are actively producing and using freeway performance measures have found is that interest and demand for performance information increases the more performance measures are used to inform key policy debates and decisions. Thus, once freeway measures become available, stakeholders will look to the performance monitoring effort to provide answers to key policy questions of their own. Luckily, in many cases, the freeway agency has a strong interest in those same issues.

As an example of how different stakeholders view a single topic, the HOV lane example introduced above will be revisited.

- The agency in charge of the freeway is interested in the freeway's performance; how many customers it is carrying, and how much delay they are experiencing. They are interested in both HOV and GP lane performance, especially in determining whether the HOV lane is effectively using the available right-of-way.

- Transit agencies will be interested in what percentage of those HOV lane customers are in buses, and how the freeway delays are impacting transit performance.

- Both agencies will be interested in the trends in vehicle and person use of the HOV lane to determine if HOV lane performance advantages are successfully encouraging a shift to shared ride modes of transportation.

- Policy-makers will be interested in all of those questions, as they are the ones that must decide whether to change the policies that define how the HOV lane operates.

- Newspapers will be interested in how the HOV lanes are operating, because HOV lanes tend to generate significant public interest, and thus make good news stories.

Just as with HOV lanes and transit authorities, interest in performance measures that describe the incidents occurring on freeways and the response actions being taken in response to those incidents exists across all of the agencies participating in those activities. In addition, all of those agencies are potential suppliers of data that can be used to compute the desired performance statistics. All agencies involved are interested in the number and nature of incidents and their location and timing. They also are interested in how long it takes for staff to respond and clear those incidents. Each agency is likely to track these basic statistics for their own staff and equipment. Gaining access to those data reduces the amount of "special study" data collection and therefore reduces the total cost of the performance measurement system.

The fact is that these agencies must work together on the roadway, and having knowledge of how effectively they are working together is beneficial to both agencies. The only real difference is the perspective with which they view the statistics being generated. Each agency will view the statistics first in relation to **their** operations, and only then from the aspect of the broader multiagency perspective.

9.3 Use of Performance Measures in Decision-Making

There are two very different purposes for performance information reporting. One is for technical staff that plan, design, operate, and manage the roadway network. The other audience is the nontechnical people who actively use and/or are affected by, the performance of those freeways. These nontechnical audiences include both the general public (including the media) and the political decision-makers who decide to fund the construction, maintenance, and operation of the system. Note that if the public is happy with how their money is spent, they also are more likely to vote for expanded programs and support leaders who vote for more spending or more innovative finance and operations programs. This is the connection between the two audiences and between the technical activities and public understanding.

The fact that there are two different audiences does not change the nature of the analyses that are performed with the data. The two different audiences usually need or are interested in the same data and results. They just need it presented at different levels of detail and in different ways.

This often means more than simply presenting the collected data. The data must be analyzed, reported, and used to make decisions. This takes time, energy, people, software, and direction. This section provides the analyst with some ideas and directions. The information builds on the measure definitions in Chapter 6 and leads into the applications presented in Chapter 10.

9.3.1 Audiences

The goals of the technical audience are pretty straight forward. Their role is to make the current system function as well as possible, and to decide where improvements need to be made. Those improvements might include capacity increases, operational improvements or demand management.

If these jobs are to be done correctly, the first thing technical audiences need to know is "how well is the system working?" This is quickly followed by, "where is it not working?" and "why is it not working well there?" And if the measures or steps they are taking to make things better are, in fact, making things better. Since the number of problems is likely to be bigger than the available budget for fixing those problems, they need a way to gauge the relative size of the different problems and potential effect of alternative solutions. Did things get better because we took these specific steps (and therefore should use them again), or did they get better because of random chance, or some other cause?

Technical staff must share their data and findings with other agencies. There are many reasons for sharing performance results with other agencies and legislative bodies, including documenting the reasons for action or collaborating across regional or jurisdictional boundaries. Agency oversight and accountability commissions or boards are another group that technical staff relates to in technical ways. Those groups also have leaders that might require nontechnical information, but the staff of these groups are a different audience with different reporting formats and levels of detail.

Elected and appointed leaders are concerned about the success of the programs and policies and how well the system serves the needs of travelers, shippers, and business. They wish to know the trends in system and agency performance and whether more or less investment is required. Leaders examine the effect of previous decisions and hold staff accountable for the performance.

The public is generically concerned about the quality of service provided, but they usually relate to performance on a trip or daily basis. They want to know when, where and how they can use the system and how much time to allow for their trip. When they think longer term, they want to know what changes are being considered, how much it will cost and who is accountable for the decisions at the leadership and staff level.

The big difference in audiences is not only in what interests them, but how the material is presented to them, and what they are going to do with it once they have it. An important aspect of performance monitoring is that what is analyzed, concluded, and done as a result of those analyses is only one part of the process. What is said and how it is communicated also is important.

In general, to design a comprehensive freeway performance monitoring system (including measures of traveler expertise and as it affects the day-to-day use of staff and resources) relatively detailed analyses are required. However, those analyses must be summarized in ways that are useful to the various audiences. In many cases, the information needed is the same, but the way it is used and explained is quite different.

There is a distinction between external and internal reports. Internal agency programming or funding decisions will rely on complex analyses, detailed data sets, and clear written reporting that would not normally be communicated to external audiences. There are often occasions, however, when agencies have to explain this technical information quickly and in some level of detail to external audiences.

The reality is that some measures are useful for local needs, some are good for working with the public, and some are good for national or state audiences. But the measures which work best for the locals or for real-time traveler information may not work well for national audiences or performance monitoring. This does not typically require different data sets, but may require different calculation processes or different geographic or time scales. Agency performance measure reporting may begin from several different motivating factors, but most eventually encompass measures and data in all four application types for both internal and external purposes.

Effective reporting often becomes the presentation of simple conclusions, backed up by good examples (taken from real life) that effectively illustrate the points that you wish to make as a result of very complicated and/or sophisticated analyses. With less technical audiences, the goal is to strip away the complexity and simply present an information summary that answers their real question or interest. This can be hard, but it is not impossible. The following figures and text are the types of report outputs and displays that can be used (and have been used across the country) to effectively make those presentations.

It should be recognized that the audience does have an affect on the data, measures, and reporting styles. Experience suggests that once reporting begins, not only does the search for more knowledge continue, but as the importance of the data becomes clearer data quality also improves. Leadership commitment to using measures has a particularly significant effect.

9.3.2 Points to Remember

There are several overriding ideas that appear to be keys to good practice and efficient use of measures and data to evaluate freeways and present information to a variety of audiences. Using measures and presenting appropriate information will lead to improved operations and better communication methods. This is true for a range of uses from real-time displays to analyzing alternative future improvement strategies.

Types of Measures

Begin with the end in mind. Everything that is or might be important should be considered in the measure development and data collection plans. The stories that might be told about the programs, projects, effects, and costs should be supportable by the measures that have been chosen.

Include measures to analyze and communicate information about the quality of service (how the public is being served) and agency activity (how well the transportation agencies are doing the actions that affect the quality of service).

- Quality of service measures are what the public experiences. They are the result of the interaction of basic infrastructure, operating strategies, the demand for travel and the outside influences on those three items. These measures tell how effectively the transportation system works.

- Agency activity measures describe the actions that are being taken and the efficiency and effectiveness of those programs.

Using both types of measures allows agency staff and the public to see whether the **activities being produced** are having the desired effect on the **quality of service the public is experiencing**. This process directly connects the evaluation of agency operations with the public's view of the results of the operations. Typically what happens as a result of this linkage is that many data collection items and processes are identified as having multiple uses, thereby improving the data collection efficiency and data quality.

Using the Measures – Consider the Future

Performance measure usage is an evolutionary process. A flexible set of measures and calculation tools provide the capability to compute a lot more measures than might be needed at any single time or for one type of report.

Evaluation efforts typically answer questions and judge the effect of new programs or changes in existing programs. Monitoring programs provide regular and periodic reporting on general and specific issues. Both of these usage types can provide information on any freeway performance attribute. Both types are important and should include trends that identify the current situation as well as the situation over time.

Measure types vary according to the use, but can draw on the same datasets. For example:

- Origin-destination travel times work better for real-time and corridor analyses.
- Index measures are better for larger geographies or combinations of system elements.

Multimodal and single mode measures are needed to evaluate the transportation system and the operations within the system.

A few very important and illustrative measures should be selected for occasions where a Mayor, Governor, or Board member asks for "the three measures that justify the operations and programs." The specific measures that are computed also will change with how those measures are used and to whom the results are communicated.

Show targets and levels. Determining targets may not be easy and in some situations it is not appropriate, but when possible a target focuses effort on measures that need improvement.

Measure Explanation

Explain the measure in easily understood terms. Measures and information do not have to be obvious, but they should be accompanied by a short, nontechnical explanation and example of the meaning.

Explain conclusions. Small text boxes or short statements should be used to provide focus on the ideas that should be derived from the measure values.

The measures and thresholds should be relevant. For example, residents of small cities do not expect to suffer the same congestion levels of very large metropolitan regions.

How is the measure connected with goals? The vision and goals for a system or society should be the beginning of measure development. The measure presentation should include this direct connection.

Connect the measures with explanatory data when possible and useful. Population and employment growth, traffic collisions and weather are among many factors that affect the service provided to users of the transportation system.

Identify where to go for more information. Web sites are excellent for this, but there should be some location to access more knowledge, especially when the measures are presented at a relatively light level of detail.

Measure Calculation

Detailed calculation steps should be shown in an appendix or resource material. Explaining the measure is more important than showing the formulas.

Weighting of links or trips is best done using terms that are common to many modes. Person-miles of travel and number of trips are good factors to weight condition and quality of service. Person-miles also can be used to combine road and public transportation travel conditions for system comparisons. Miles and lane-miles of road or route miles are good weighting factors for road condition or maintenance evaluation.

Aggregating system elements is best accomplished with section lengths that are significant to the audience and agencies. Travel time over road sections between two and five miles or between major interchanges or activity centers are distances that are easy to understand and long enough to eliminate the small time variations caused by minor detector calibration problems.

Data Used for Calculation

Use data that already is being used for internal agency decisions. The quality will be better, the cost of data collection will be minimized and agency buy-in to using the measures will be easier to obtain. The data used in the analyses do not have to be simple for the measures to be simple. Likewise, simple measures do not have to be prepared from simple data.

Describe the differences. Where seasonality or change in system is an issue, conditions should be explained. It may be tempting to remove, add, or adjust the base data to reflect the “similar system” comparison, but this is usually not a good idea. It is better to explain why they are different and show the revised statistics in another graph. This avoids the appearance of attempting to change history. This is a different issue than acquiring better data, correcting errors, or changing methodologies to produce more accurate statistics.

Attempt to develop a flexible dataset that supports as many uses as possible, but recognize that data needs and uses will expand as users become familiar with the data.

All time periods can be important. Peak-period and offpeak analyses can both be useful and can point to different improvement needs.

Reporting Frequency

Another consideration in the presentation and communication of freeway performance measures is the frequency of reporting. This will vary depending upon the intended purpose (and audiences). It is often outlined in a strategic or business plan. Typical frequencies include annual, seasonal, or monthly. Most of these considerations apply to short- and long-term reporting rather than real-time which is defined by its nature, and operations which also has an immediate focus.

Timing is important. Quarterly performance reports will have more effect than annual reports.

One-page summaries are not inherently evil. They present a challenge to provide technical information without significant explanations, but they also can provide an attractive "front page" to the wealth of information available about transportation's importance. Table 9.1 outlines some of the benefits and challenges to the frequency of performance reporting.

Display and Presentations

Only the most curmudgeonly person is not swayed to some extent by packaging. The cost of a 30-second commercial during the Super Bowl shows that marketing and appearances are important to consumers. Data and analyses will form the basis of any program, but pictures, tables and graphs are the "face" that most nontechnical audiences will see and the view that many technical readers will use to identify problems.

Colors are good, but graphs should work with black and white copiers or those readers with color viewing problems. Light colors or open characters are intuitively associated with good conditions or low volumes.

Washington State DOT[1] has developed a set of practices in their performance journalism approach that pertains to most analyses. Their approach is a combination of data presentation in charts, graphs and other measurements along with special features and text that highlights agency programs and evaluations. The basic recommendations shown below are based on many of their principles along with other elements of good practice.

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[1] Washington State Department of Transportation web site: http://www.wsdot.wa.gov/accountability/default.htm.

Table 9.1 Regular Monitoring Report Considerations

Frequency of Regular Monitoring Reports	Possible Advantages	Possible Disadvantages
Quarterly	• Better connection to strategic agency goals and decisions. • An active reporting system improves the visibility of performance measurement. • Improves communication between agency departments (e.g., modal administrations). • If formatted for public view, it also can be a good public information and accountability tool. • Encourages improvements in data organization and quality. • Builds internal agency support and accountability. • Regular reporting establishes a routine, helping to instill performance measurement into agency culture and daily activities.	• Slow data reporting and processing may limit the value of a quarterly report. • Personnel resources may exceed those available. • Measures driven by data availability may not be suitable for quarterly reporting. • Measures related to critical agency objectives may be difficult to report on frequent basis. • High "yawn" factor if conditions do not change quarterly.
Annually	• Greater ability to track historic trends. • Longer-time period to collect data. • Include comprehensive performance measures. • Formatted for public view – Good public relations and accountability tool. • Able to provide in-depth coverage of agency's performance.	• Data availability and consistency. • Limited personnel resources. • Vulnerable to changes in administration or leadership (if not routinely visible and valued by top-level management). • Lack of frequent coordination between departments (modes) may feel like "reinventing the wheel" for each reporting year.

Source: Working materials from NCHRP Project 8-36 (47), *Effective Organization of Performance Measurement.*

- Stories – Narrative reporting to describe projects and programs in plain language that nontechnical audiences understand.
- Data – Must be credible and form the basis for stories and measures; data sources should be cited and data quality control should be a part of every step of the process.
- Graphics – The design of the document and charts and diagrams should not distract from the content; should both answer and ask questions; use maps to connect what readers are familiar with to the data; colors can be used, but the charts should work in black and white as well; clearly label the axes and use pointers rather than legends where possible.

- Timing – Timely and frequent information.
- Software – Capable of good formats and graphics.
- Include targets for measures where they have been determined.
- Use real-time data as often as possible.
- Measure the causes of the problems. Congestion, safety and other factors have causal factors – many of them are related. Problems with different causes may have different solutions.

9.3.3 Measure Overview – Interpreting and Explaining Performance Measures

The key to any freeway performance measurement program is the ability to document and explain the costs and benefits of improvement programs as they relate to congestion and safety and to detect trends in these effects. Supplemental data, other performance measures, or additional studies can be used to further explain resulting trends or outcomes as required. The measures in Chapter 6 and summarized in Table 9.2 are what a fully functioning reporting system should be capable of producing. These cover the whole range of performance reporting needs, including both national reporting and local needs.

Table 9.2 Performance Measure Considerations for Uses and Audiences

Measure Element	Timeframe for Analysis			
	Real-Time	Operations Planning	Short-Range	Long-Range
Uses	Web sites; 511 service; PDA; Pager; Private sector providers	Allocate staff, equipment, and financial resources; Monitoring; Evaluation of current agency activity operations	Project and program evaluations; Monitoring; Transportation Improvement Plan; Strategic planning	Metropolitan Transportation Plans; Needs studies; Land use and transportation plans
Audience	Travelers; Agency operations	Travelers; Agency operations; Agency Leaders	Citizens; Agency operations and planning; Agency and Community Leaders	Citizens; Agency planning; Agency and Community Leaders
Typical Performance Measures	Travel time; Speed	Travel time; Speed; Buffer time; Delay	Travel time; Buffer time; Delay	Travel time; Delay

The reality is that not all of these measures will be needed for every report. But it is important to think about being able to produce them, because the measures may be needed at some point and flexible systems require more planning. The selection of a set of measures is only partly to define which data should be collected. The process also is designed to identify how the measures should be presented to meet the communication needs of the analysis and the understanding of the audience.

Reporting needs change over time as audience understanding grows. This may appear as a "moving target" problem, but in most cases it is a reaction to the new knowledge and increased interest in understanding the effectiveness of improvement projects and programs. Once an important question has been answered, the public and elected leaders may stop asking about it and either ask for more information or move to another subject. The performance measures used to answer those questions may become less important or the need for reporting may become less frequent. Similarly, when a new issue becomes important, there may be a need to start reporting on that instead, with new performance measures. In some cases, the measure values begin to have less relevance and readers begin to examine the change in measure values or the relationship to targets or goals.

9.3.4 Real-Time Applications

Uses and Audiences

In general there are two types of audiences for real-time transportation information. Most real-time uses are related to either operations within traffic management centers or as communication with the public and businesses using the freeway system. Internal traffic management center operations and the public look for information to make decisions about their next few minutes and hours. While the data are used in preparing all other application time levels, there is much less use of the real-time information at the leadership or decision-maker levels. Emergency, weather, or evacuation operations are exceptions where real-time data are used by higher-level administrators or political leaders for decisions about system configuration, operation, or resource management.

Applications and Typical Measures

When it comes to "freeway performance" it is hard to argue with the use of travel time as an easily understood, very explanatory performance measure. The only problems with travel time as a measure are that it has traditionally been difficult and expensive to collect. Travel time works best when you are using it to refer to a known origin/destination pair, which is why it is frequently used as a real-time measure, or as a trend indicator for illustrative trips.

The specific measure and displays that work for one region may not work well in another region. Generic guidelines are difficult to develop. Travel time and speed are common basic freeway performance measures and most real-time displays include road work, incident and weather information to improve safety and congestion levels and provide trip planning information.

The good news is that modern technology is providing many different ways to collect travel time information and there are several more technologies on the horizon that might make travel time data collection even more common and less expensive. There are data quality issues that must be addressed and the effort to build and maintain a data archive is substantial, but there are substantial benefits for the traffic management center staff and the leaders they support. Planning staff also are becoming frequent users of real-time data to replace or supplement their datasets and to calibrate or fine-tune their models.

Travel times during the peak-periods are typically the performance measure of choice. User-customized maps and information are more frequently available with notable installations in the California PeMS system (http://www.dot.ca.gov/travel/index.php) and web sites from Washington State DOT (http://www.wsdot.wa.gov/traffic/seattle/) and Houston's TranStar (http://www.houstontranstar.org/).

Researchers have developed a number of ways to report travel times without having to deal with specific origins and destinations. These are more appropriate for operations, short- or long-term analyses. When working with the general public in real-time, it is often better to work with specific origin/destination pairs. When reporting areawide statistics, or when reporting statistics that will be used to compare routes/areas/cities/states, more generalized statistics such as the Travel Time Index are better. Indices also are better if the goal is to produce a single number to represent travel performance in an area.

For traveler information purposes, and often for local reporting purposes, agencies tend to use specific trips when they have the data and report travel times for those trips. In Seattle, they are informally called "the 10 famous commutes of the Seattle metropolitan region." Travel times give information to users in a very reader-friendly fashion. A number of urban areas are actively computing this type of information and placing it on their current congestion web sites.

Real-time measure applications are tailored to local issues, tastes, public understanding, and terms. Developing guidelines or frameworks that work in every circumstance are difficult due to the relative "newness" of this situation.

Historical information on travel time and speed is a recent development in many areas. It requires a relatively detailed archived data set and a level of effort beyond posting real-time data. Special circumstances or project implementations are among the situations that may benefit from real-time data. New programs or operations may be planned to have a six-month trial period, but if there may be disagreement over the efficacy or the program benefits are in doubt, the system operators should prepare as though there is a press conference and peer review at the end of each peak-period and at the end of the day.

Real-time performance measures can be used to connect public perception with the traffic data used to manage the system. The data can be used to show the real effects at key points and across the system in a way that may not be understood by anecdotal media coverage. If a radio helicopter hovers over the one problem spot, real-time data can be used to show how well the remainder of the system operates. Even more promising is a strategy that informs media representatives and decision-makers in advance of project opening. Traffic management center staff can use the real-time data to help evaluate projects. Planning staff should be comfortable with how to use real-time data to replace or supplement their data collection.

The graphic in Figure 9.1 illustrates average travel times along I-10 (Katy Freeway) inbound in 15-minute time slices that are color-coded by speed. At a glance the user can discern the effect of changing their trip start time.

Figure 9.1 Average Travel Time Display from Web Site

I- 10 Katy – Inbound

Barker-Cypress to I-610 Loop (13.90 miles)

A.M. Peak			
Departure Time	Travel Time (mm:ss)	Average Speed (mph)	
6:00-6:15	17:20	48.1	
6:15-6:30	22:20	37.3	
6:30-6:45	26:11	31.9	
6:45-7:00	29:23	28.4	
7:00-7:15	32:33	25.6	
7:15-7:30	36:49	22.7	
7:30-7:45	38:16	21.8	
7:45-8:00	35:55	23.2	
8:00-8:15	32:29	25.7	
8:15-8:30	30:41	27.2	
8:30-8:45	27:46	30.0	
8:45-9:00	24:50	33.6	

P.M. Peak			
Departure Time	Travel Time (mm:ss)	Average Speed (mph)	
16:00-16:15	23:29	35.5	
16:15-16:30	23:59	34.8	
16:30-16:45	24:14	34.4	
16:45-17:00	24:39	33.8	
17:00-17:15	26:39	31.3	
17:15-17:30	29:45	28.0	
17:30-17:45	29:44	28.1	
17:45-18:00	28:49	28.9	
18:00-18:15	27:48	30.0	
18:15-18:30	26:47	31.1	
18:30-18:45	24:37	33.9	
18:45-19:00	21:14	39.3	

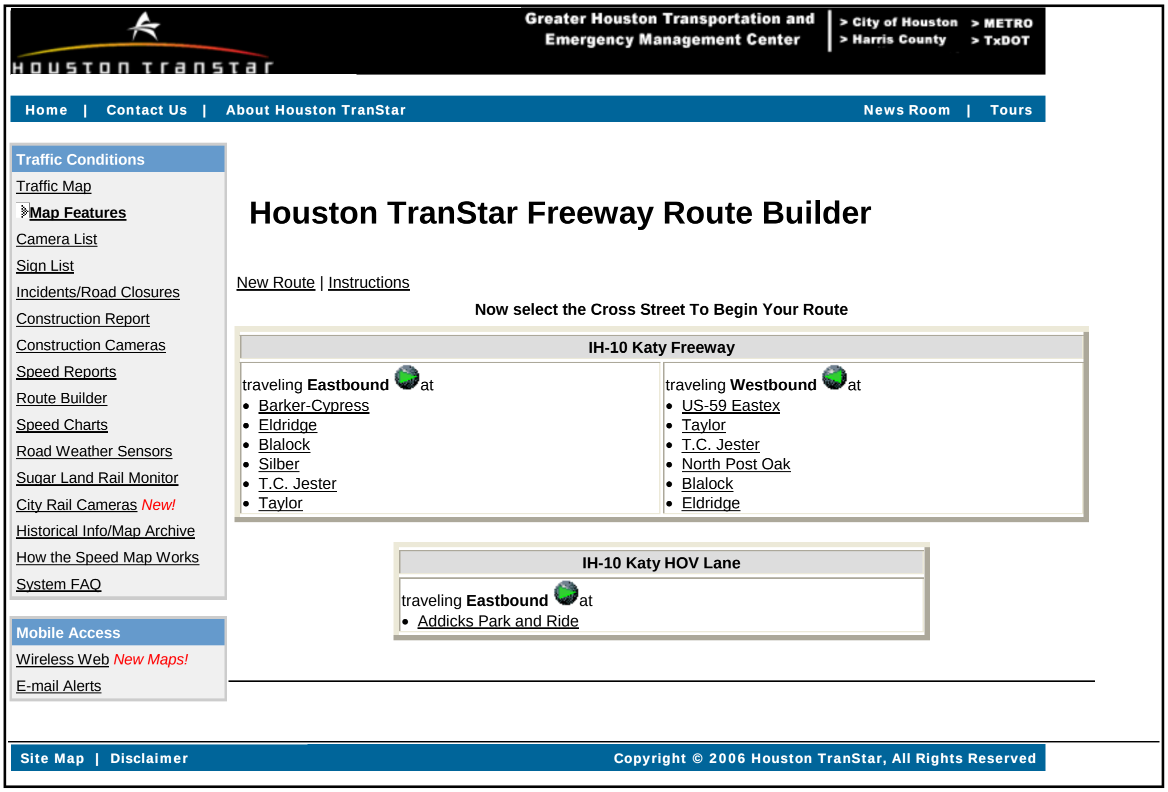
Legend					
< 20 mph	20-29 mph	30-39 mph	40-49 mph	50+ mph	Not Available

Source: Houston TranStar Web Site: http://www.houstontranstar.org/.

Performance Measures Included: Travel time, speed.
Can Also be Used: To present expected travel time.
Measure Category: Quality of service.
Audience: General.
Applications: Real-time.
Use: Monitoring.
Geographic Scale: Corridor, site.
Time Scale: Real-time, period, day, annual.
Strong Points: Easy to understand; "not available" is a good element.
Ways to Improve: Include map, reliability measure.

Travel time between two points is a very important piece of information for travelers. The "route builder" program (Figure 9.2) has been instituted in many ways in different cities to provide users with more detail on typical travel times for trip planning. The user identifies a start point and an endpoint, and often selects route segments as well. The weakness is that the travel times used in the program are usually only for the freeway. The surface streets are not as extensively monitored.

Figure 9.2 Example of Web Site to Provide Customized Travel Time Data to Users

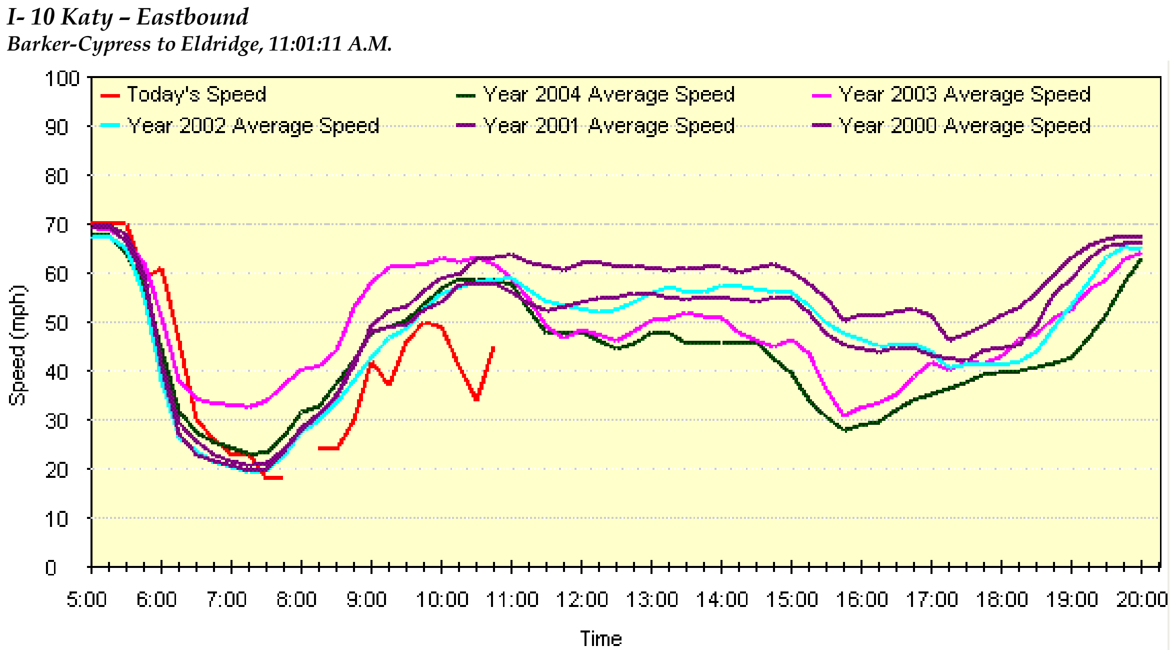


Source: Houston TranStar Web Site: http://www.houstontranstar.org/.

Performance Measures Included: Travel times.
Can Also be Used for: Reliability measures.
Measure Category: Quality of service.
Audience: General.
Applications: Operations planning, short range.
Use: Monitoring.
Geographic Scale: Corridor.
Time Scale: Real-time.
Strong Points: Customized for specific trip.
Ways to Improve: Include map; multiple freeways and streets.

The speed chart in Figure 9.3 provides average speeds in 15-minute time increments. The previous five years are displayed on the graph along with the current day's speed profile up to the current time. The graph shows the trend in change in speeds over the years for a freeway section, as well as the speed variation over the day. Travel time also could be displayed in this format. The longest travel times (for example, the 95th percentile travel time) could be shown in the lines, and then compared to the current travel time to show one aspect of the planning time concept.

Figure 9.3 Example of Speed History Graph for Freeway Section

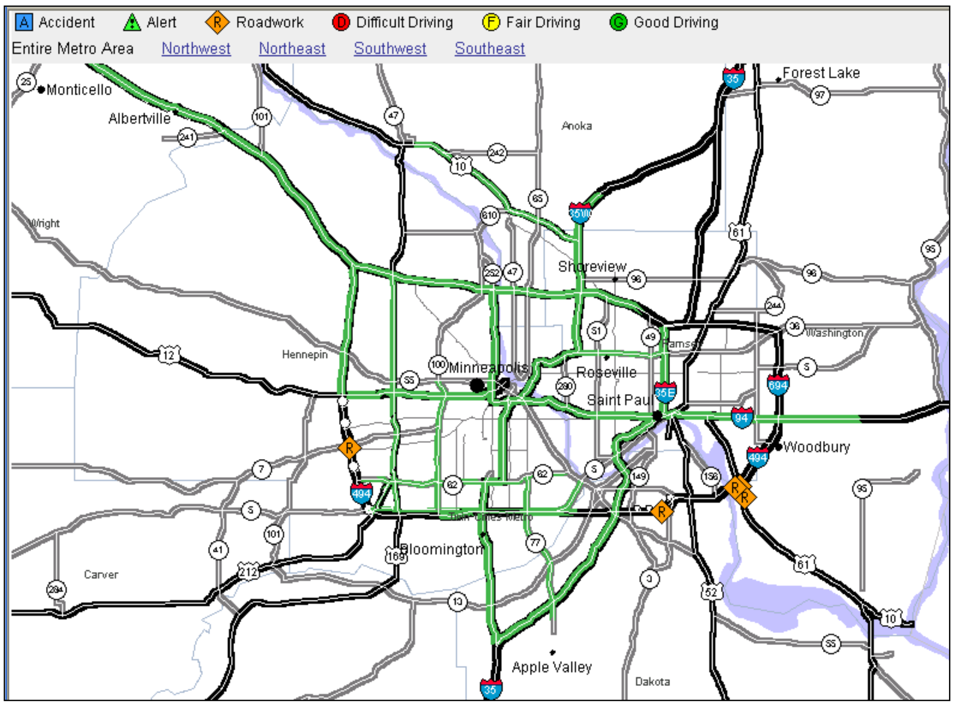


Source: Houston TranStar Web Site: http://www.houstontranstar.org/.

Performance Measures Included: Speed.
Can Also be Used for: Travel time, reliability.
Measure Category: Quality of service.
Audience: Leaders, general, technical.
Applications: Real-time, operations.
Use: Monitoring.
Geographic Scale: Corridor, site.
Time Scale: Real-time, day, annual.
Strong Points: Easy to understand; shows annual trend; allows "rough guess" of conditions over the day.
Ways to Improve: Intuitive color scheme.

Maps have been developed to display travel conditions in most cities. Figure 9.4 shows a map that is generated with the automated data collection devices that also assist operations personnel in their actions on the freeway system in Minneapolis-St. Paul. Color-coding is provided by speed levels. Gray indicates areas where data are not available. Mn/DOT's real-time traveler information system uses a graphic that also includes incidents, work zone, and other unusual events noted on the screen.

Figure 9.4 Traveler Information on the Twin City (Minnesota) Freeway System



Source: Minnesota Department of Transportation Web Site:
http://www.511mn.org/default.asp?display=all&area=TC_Metro&date=&textOnly=False.

Performance Measures Included: Speed.
Can Also be Used for: Incidents, road work.
Measure Category: Quality of service.
Audience: Leaders, general, technical.
Applications: Real-time, operations.
Use: Monitoring.
Geographic Scale: Region, corridor, site.
Time Scale: Real-time, period, day, annual.
Strong Points: Colors, icons and map are easy to understand.
Ways to Improve: Predict conditions in near future; reliability measure.

9.3.5 Operations Planning Applications

Uses and Audiences

Operations planning as used in this *Guidebook* includes the agency operations as well as the planning that travelers and freight shippers do in advance of their trips. With freeway traffic management systems there is more data available and more complicated measures are possible. The key to good planning information is to identify the data that provides the most value and concentrate on providing assessments of data quality that allows the user to know how to regard the certainty of the measures.

Allocating staff and equipment to maintenance and operations activities, identifying shortcomings or needs that might be addressed relatively quickly, identifying problems with the safety and quality of service provided to travelers and shippers are typical agency concerns. Resource allocation decisions can be close to real-time in cases of weather difficulties. Other situations may require an analyst to monitor condition or performance information on a regular basis and adjust operations accordingly such as reassigning law enforcement staff to address a problem with collisions. Before/after studies of new projects or programs may move from short-term to daily reporting in the event of concerns over operations.

Trip planning is improved in many regions with 511 services and web sites that contain not only average travel times, but also document variations in travel times from day-to-day. Customized trip planning where the user can identify an origin and destination are available using web sites, cell phones, and personal digital assistants from public or private sources.

Applications and Typical Measures

Travel time and collisions on freeway sections are excellent measures for identifying the experiences and the effect of agency activity. To be useful for evaluating freeway-related agency performance, however, they must be combined with a size variable. How many people are experiencing that travel time? How much travel delay is caused by this problem? How many collisions and of what type? For many performance reporting needs, delay is more commonly used than travel time. And both collision rate and number of collisions both have a place in freeway analyses.

Volume is probably the most significant measure of use. The growth in data to power the quality of service measures resulted in volume measures falling out of favor. If this were a private business, however, it would be difficult to conceive a management plan that would not include a measure of customers served or units produced.

Vehicle-miles traveled (VMT) is a statistic usually reported at the national or regional level, while trips, persons or vehicles are used in corridor analyses or for presentation to less technical groups. VMT can be used to balance the conditions on sections of different length or volume. These applications may require peak-hour and peak-period volumes, as well as truck, bus, and automobile components. Vehicle-miles traveled also is the measure that will be used in benefit/cost calculations.

When talking "performance" at a local or project specific level, a more detail-oriented volume statistic (peak-period, directional volumes) is typically used as the performance measure. This might include volumes at representative or key locations. Comparative values between urban areas (or nationally) tend to use more aggregated statistics (annual average daily traffic, or road segment/corridor VMT. This is because at the local level the added detail is needed to explain what is going on at the project level and why specific operational or policy decisions are being implemented. At the state or national level, that detail makes the data too voluminous, and too difficult to compare. Aggregated statistics that suppress those details in order to make comparisons over wider geographic/temporal scales are appropriate.

Volumes are often reported in terms of 'people' rather than 'vehicles' when policy issues associated with mobility are addressed, rather than the highway operations issues associated with movement of vehicles on the facility. Both are useful statistics, depending on the audience, situation, and questions that are being analyzed. But volume alone does not tell the performance story.

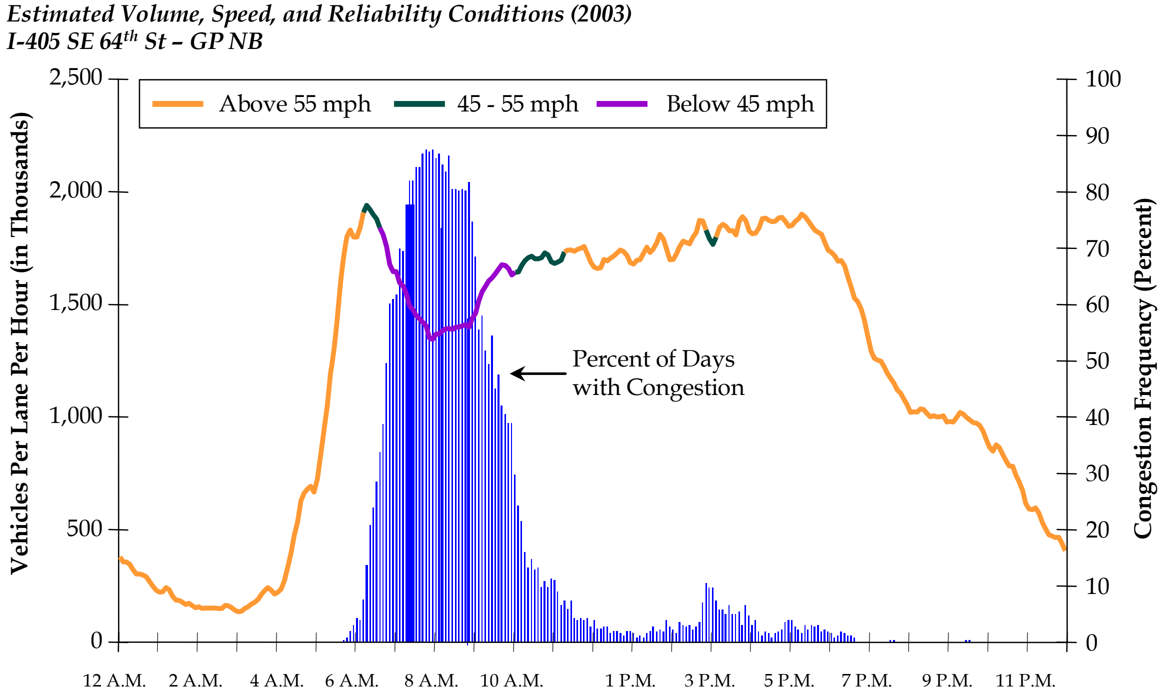
Travel time delay for a trip – defined as the difference between actual travel time and desired travel time – is one measure of congestion. The Travel Time Index is a similar measure that identifies problem areas. Combining volume with these measures allows prioritization of the problems and can be used to calculate total travel delay in person- or vehicle-hours. Delay is easily understood by the public and aggregates to the corridor, area, or regional summary statistics. The numerical units or travel segments used when reporting delay are a function of what is important for the audience and what information is being conveyed.

Similarly, very specific delay statistics (morning peak-period, southbound at Main Street) can be used as input to very specific operational or capital planning studies. These might be either an operational or short-range application. Which measure is used is a matter of what is more effective for describing the results of an analysis. Delay translates easily into dollars and thus it is often used when doing benefit/cost analyses. It is not as descriptive for nontechnical audiences and not as useful in relating the effect of some operational changes. When delay is not removed, sometimes it is better to say "the congestion happens two days a week now instead of five" rather than saying "we saved 230 vehicle-hours of delay."

The decrease in system efficiency is becoming a more significant issue, as agencies try to maximize the use of the existing infrastructure. Performance measures that illustrate this loss of capacity are good, both for instructional purposes to political bodies and the general public, but also serve as an excellent way to measure the performance of operational control efforts. The dramatic effect of incident management is lost when using large data sets such as all weekdays in a year.

The effect of recurring congestion on volume/throughput, however, is clearly visible in Figure 9.5. This type of graphic is one way to show reliability as well as travel time and facility productivity or efficiency measures shown in subsequent graphs. Placing several elements together in one image can provide both the cause and effect, or multiple factors in the same picture. This graph shows a line with the volume plot (volume on the left y-axis) and the speed shown in colors along the line. This identifies the speed decline associated with volume increases and the speed and volume penalty paid when inefficient operation occurs in very congestion conditions (after 6:00 a.m.). The bar graph illustrates the percentage of days (right y-axis) when congested conditions are encountered during each five-minute period.

Figure 9.5 Graph Displaying Traffic Volume, Speed, and Congestion Frequency



Source: Kopf, J., Ishimaru, J.M., Nee, J. and Hallenbeck, M.E. *Central Puget Sound Freeway Network Usage and Performance, 2003 Update*. Seattle, WA: TRAC/University of Washington, 2005.

Performance Measures Included: Traffic volume per lane, traffic speed, congestion frequency.

Can Also be Used for: Travel time, reliability.

Measure Category: Quality of service.

Audience: Leaders, technical.

Applications: Operations, short-term.

Use: Monitoring, Evaluation.

Geographic Scale: Region, corridor.

Time Scale: Annual.

Strong Points: Combines several related elements.

Ways to Improve: Must be explained; can be shown with graphs of the individual elements (3 or 4 graph sequence).

This graph is a great illustration of how volume drops due to congestion. This graphic also shows how peak-period congestion is "spreading" to the shoulders of the peak-period and that congestion happens during the middle of the day. (Note the blue vertical bars are histogram is higher than 10 percent (one day every two weeks) at 3:00 p.m. in the "reverse" commute direction.)

The graph in Figure 9.6 shows the effect of a large truck crash on I-5 in Seattle. The traditional morning congestion can be seen in the slow speeds and the afternoon congestion caused by the collision also is visible. The low vehicle throughput caused by the loss of facility capacity and the duration of the slow speeds for several hours after the accident has been cleared is easily seen. This type of picture is an excellent way to describe to decision-makers and the general public why incident response is needed, as well as an excellent tool for examining the effectiveness of the implemented improvements. (When presenting this to a nontechnical audience, use the term "stop-and-go congestion"; it is easier to understand).

This type of graphic, while not a "performance measure," is an excellent type of "performance report" for local audiences. It explains the nature of travel and congestion. These graphics also can show the effects on volume and congestion caused by changes in operational procedures. (This is good for both engineering purposes, and for public information, for example at open houses where the benefits of ramp metering are explained).

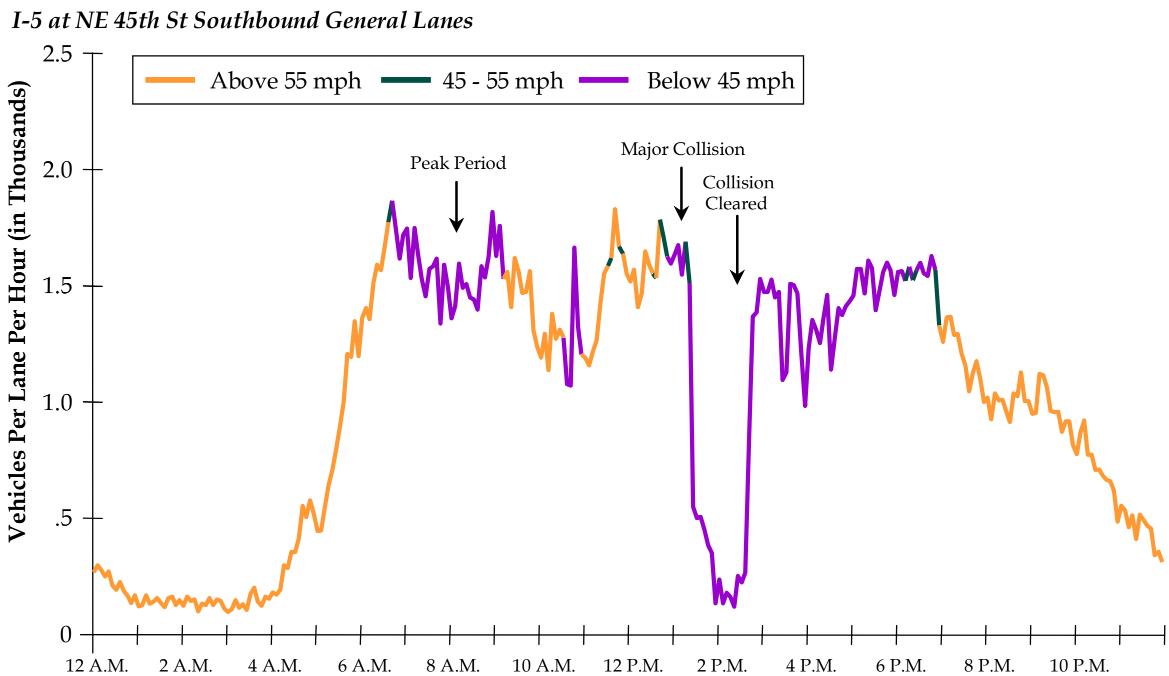
Ramp metering benefits are often difficult to explain before beginning operations, but easy to display afterward. At the location in Figure 9.7, ramp metering already was used in the afternoon. It was then turned on in the morning. It was possible to measure the change in vehicle throughput, and the change in congestion. A graphic like this (with annotations to help explain it) can illustrate those improvements.

The effect of ramp metering is illustrated by combining the percent of congestion and the vehicle flow rate. This graph shows that congestion occurs less often (see the bar graph) and the flow rate increases (the line graph).

Note that the performance measures are still fairly basic. Vehicle volume during the peak-period and in this case, the percentage of days when LOS F takes place. Average speed, or the percentage of time traffic was operating in specific speed ranges, also can be used. The exact units used are a function of operations; in this case, the freeway tends to either work or not work. So a simple measure (like level of service d) is easily measured, presented, and understood.

Another way of describing travel time performance is to compare that performance against an adopted standard. This is how Seattle reports on the performance of their HOV lanes, which are supposed to operate at 45 mph more than 90 percent of the time. This type of graph also allows an analysis of the time of day when problems occur. In this case, the horizontal red line is the speed threshold standard, and the 90th percentile travel time for two different years is plotted by time of day. The percentage of days where the speed falls below 45 mph are the vertical bars in the graph. It is easy to see in Figure 9.8 that this corridor does not meet the performance standard during the evening peak-period.

Figure 9.6 Speed and Volume Characteristics Showing the Effect of a Major Collision



Source: Kopf, J., Ishimaru, J.M., Nee, J. and Hallenbeck, M.E. *Central Puget Sound Freeway Network Usage and Performance, 2003 Update.* Seattle, WA: TRAC/University of Washington, 2005.

Performance Measures Included: Traffic volume per lane, traffic speed, congestion frequency.

Can Also be Used for: Travel time, reliability.

Measure Category: Quality of service.

Audience: Leaders, technical.

Applications: Operations, short-term.

Use: Monitoring, evaluation.

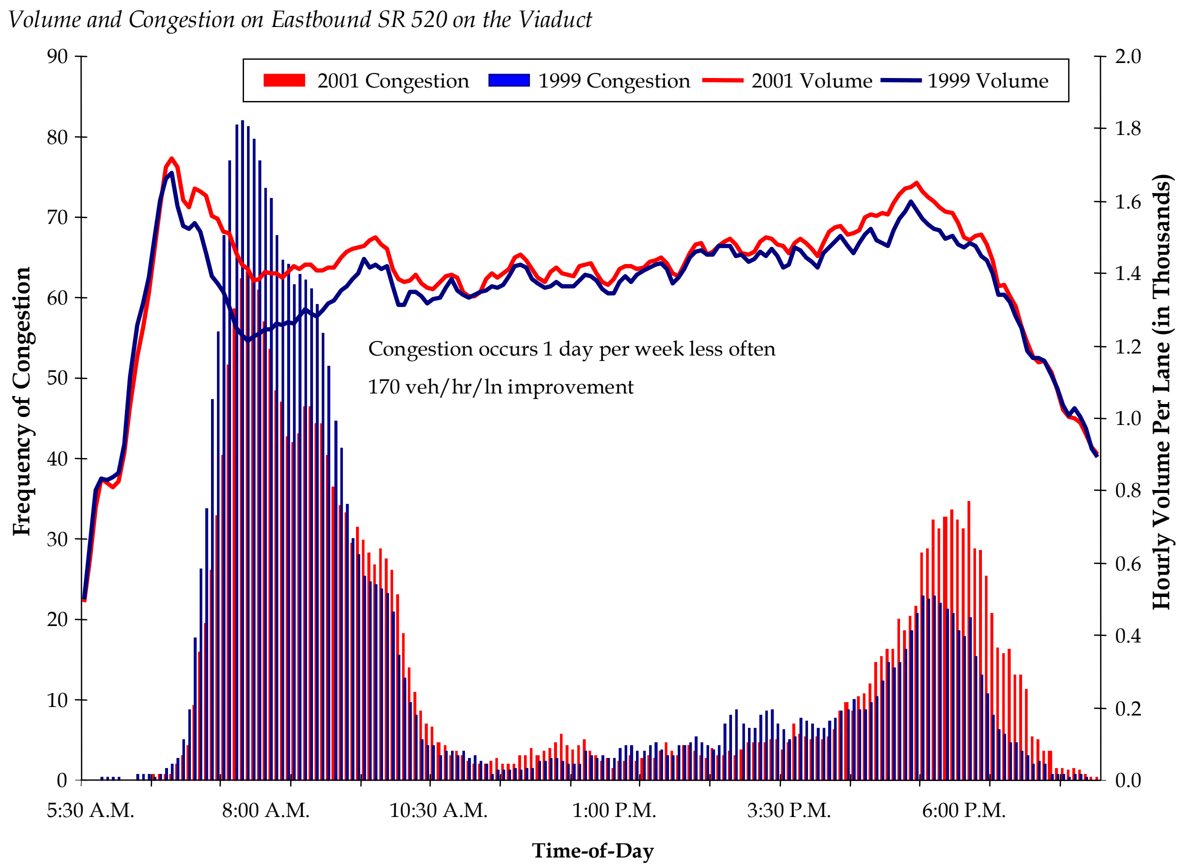
Geographic Scale: Region, corridor.

Time Scale: Annual.

Strong Points: Combines several related elements.

Ways to Improve: Must be explained; can be shown with graphs of the individual elements (3 or 4 graph sequence).

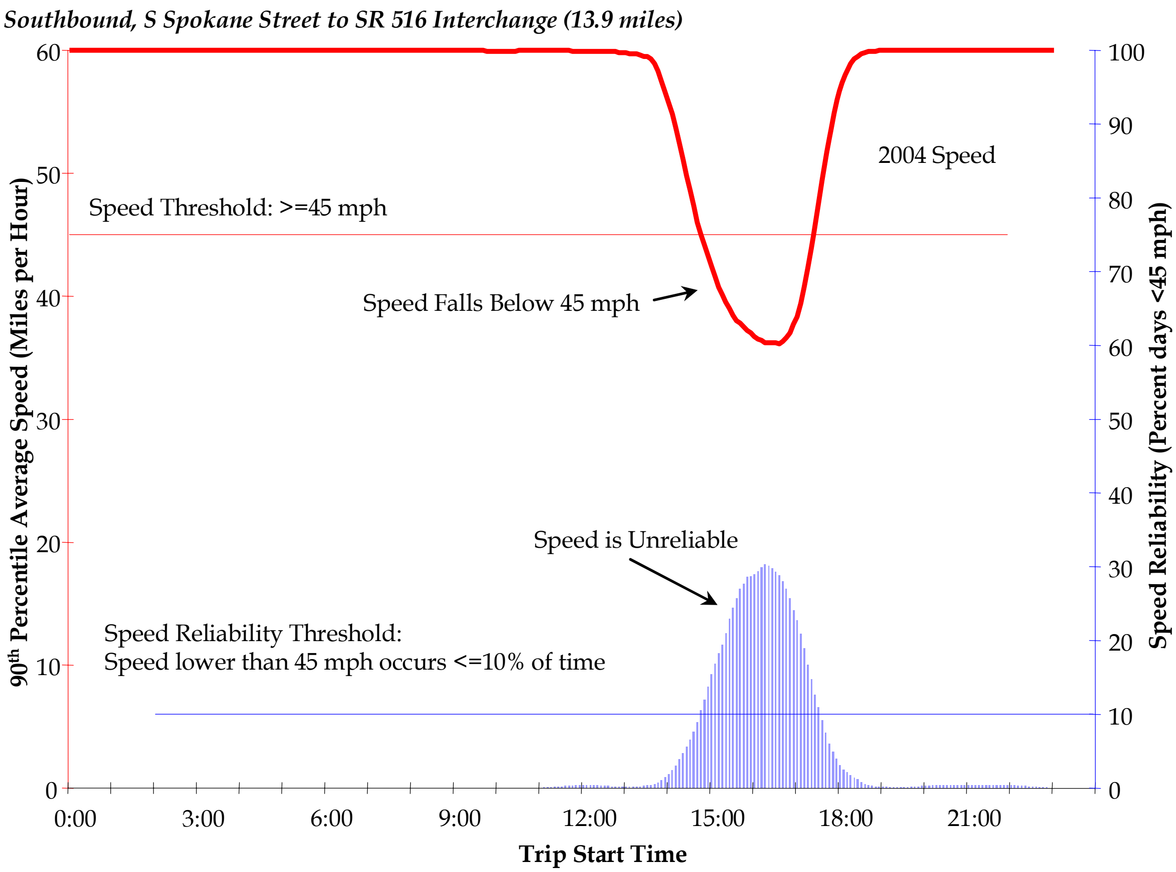
Figure 9.7 Effect of Ramp Metering on Volume and Congestion Frequency



Source: Hallenbeck, M.E., University of Washington Transportation Research Center (TRAC). Supporting Material for *Measuring and Communicating the Effects of Traffic Incident Management Improvements.* NCHRP Research Results Digest Number 289, May 2004.

Performance Measures Included: Change in volume and frequency of congestion.
Can Also be Used for: Speed; travel time.
Measure Category: Quality of service.
Audience: Leaders, technical.
Applications: Operations, short-term.
Use: Monitoring, Evaluation.
Geographic Scale: Corridor.
Time Scale: Day, annual.
Strong Points: Provides direct before/after comparisons.
Ways to Improve: Use multiple graphs that "build-up" to this one.

Figure 9.8 High-Occupancy Vehicle Lane Performance Evaluation Graphic



Source: *HOV Lane Performance Monitoring: 2000 Report.* Seattle, WA: University of Washington Transportation Research Center (TRAC), February 2002.

Performance Measures Included: Speed, reliability.
Can Also be Used for: Most performance measures.
Measure Category: Quality of service.
Audience: Leaders, technical.
Applications: Operations, short-term.
Use: Monitoring, Evaluation.
Geographic Scale: Corridor, site.
Time Scale: Monthly, annual.
Strong Points: Combines average congestion and variation in congestion.
Ways to Improve: --

Activity and Quality Measures Example – Incident Management

Performance measures have been used to track a variety of agency activities; this trend has accelerated with the advent of real-time data collection and presentation systems. Incident management activities are used here as an example of how the same measures and data can be used for agency and quality measures. One benefit of this linkage has been the direct connection between the staff responsible for agency actions (e.g., responding to collisions and stalled vehicles) and the quality measures that are significantly affected by those actions (e.g., delay and travel-time reliability).

Periodic evaluation reports of incident management programs by the operations staff are very effective methods to target problem areas and identify activities. Collecting and using information on response and clearance time provides the kind of information needed to get responding agencies to see the effect of policies and practices. It also provides the material needed for program evaluations and justification for expansion or resource allocation.

It is difficult to directly measure the amount of incident-related congestion, but it is easy to show the effect of specific large incidents (e.g., freeway closures, multiple-lane blockage). Travel-time reliability measures like buffer time, buffer index or planning time will show the effect of improving (or reducing) incident management resources.

Figure 9.9 illustrates one of the many types of agency activity reports that are used to track the performance of incident management staff. These performance measures are used to show both policy-makers and taxpayers what is being done. The measures vary but most efforts look to improve the time it takes to detect, respond to, and clear incidents. The faster the incident is cleared, the less disruptive it is and the higher the safety and congestion benefits. In addition, the public is very aware of the activities and places a high value on the rapid removal of stalled vehicles and collisions.

These types of reports give decision-makers more information about how the systems that have been funded are contributing to smoother operations on the freeway system. Adding statistics such as how often the detection and camera equipment is operating provides a way to show the data and system quality information necessary to communicate periodic problems as well as illustrate the uses of funding.

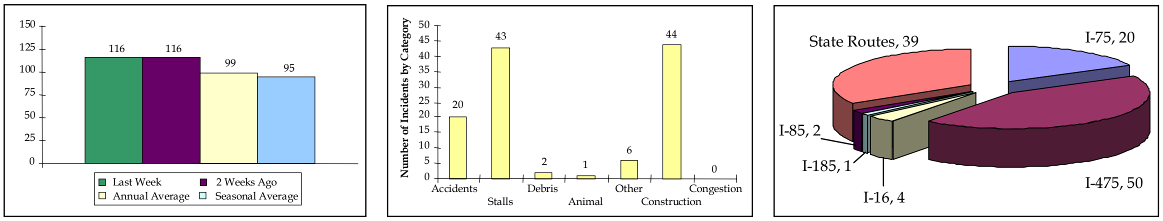
Likewise, current information on work zones and weather that is used for real-time public communication can be combined with traffic condition data to improve descriptions of the congestion problem. The number and type of work zones and days when work zones are active can be correlated with travel delay data to improve predictions and modeling efforts. Work zone reporting also might extend to messages reported and customer and traveler comments. Weather information also can be used in performance evaluations that can provide more information on the effect and frequency of weather difficulties as well as the responses by agencies and travelers.

Traveler information program evaluations can target the access to information and the use of data to make travel plans. Travel operations statistics can monitor the number of incidents that are managed by operators and by type.

Figure 9.9 Incident Management Operations Summary

Macon Statistics

Total Incidents Managed by Operators | Incidents by Category | Number of Incidents by Roadway



Incident Levels		
Level	Number Recorded	Percent of Total
Not Entered	31	26.7%
I	64	55.2%
II	14	12.1%
III	5	43%
IV	2	17%

See Pages 11-14 for the data key on each chart and statistic shown.

Incident Levels		
Incident Impact	Number Recorded	Percent of Total
No Impact	1	0.9%
Low Impact	69	59.5%
Medium Impact	40	34.5%
High Impact	6	5.2%

Weekly Performance Measures *Week Ending: Feb. 3, 2006*

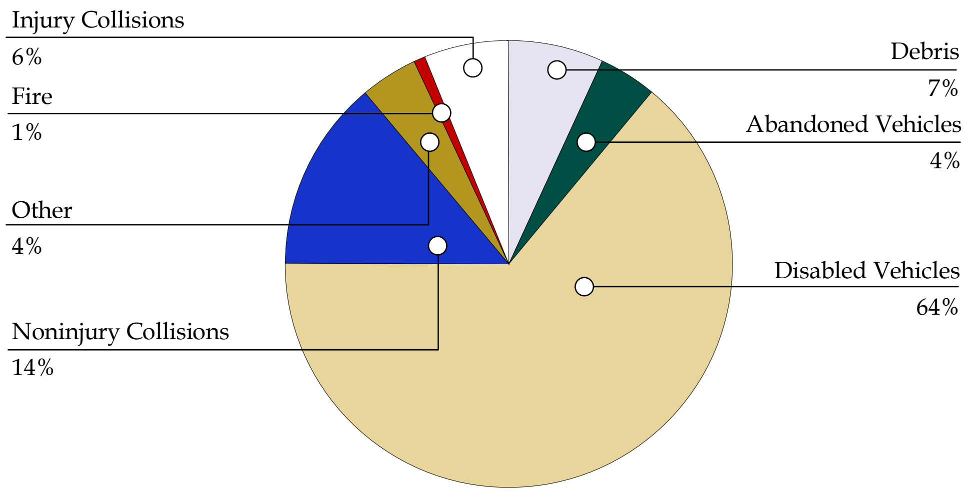
Source: *Weekly NAVIGATOR Performance Measures.* Week ending August 26, 2005.

Performance Measures Included: Regional motorist assistance.
Can Also be Used for: Any operating program.
Measure Category: Agency activity.
Audience: Leaders, Technical.
Applications: Operations, short-term.
Use: Evaluation.
Geographic Scale: Region, corridor.
Time Scale: Monthly, annual.
Strong Points: Intuitive graphics; trends; focus agency actions on elements connected to quality of service.
Ways to Improve: Some graphic changes.

When connected to information about miles covered by operational treatments, equipment used, messages displayed, and equipment reliability, the agency activity can be linked to the congestion experienced. Customer satisfaction surveys and response to agency actions can often provide support for those programs in resource allocation decisions and in budgetary priorities.

Figure 9.10 is an example of a typical agency activity chart. Pie graphs or trend charts can describe many of the actions performed. They can be used to study specific roadways or sectors and can be used as a simple display of before/after experiences. When the incident causes can be correlated with the traffic conditions during that time, there can be more effective use of performance measures for a variety of agency activities.

Figure 9.10 Example of Incident Response Summary



Performance Measures Included: Incident type.

Can Also be Used for: Effect of incident management programs.

Measure Category: Agency activity.

Audience: Leaders, technical.

Applications: Operations, short-term.

Use: Monitoring, evaluation.

Geographic Scale: Region, corridor.

Time Scale: Day, annual.

Strong Points: Clearly relates to both agency activity and evaluation of service.

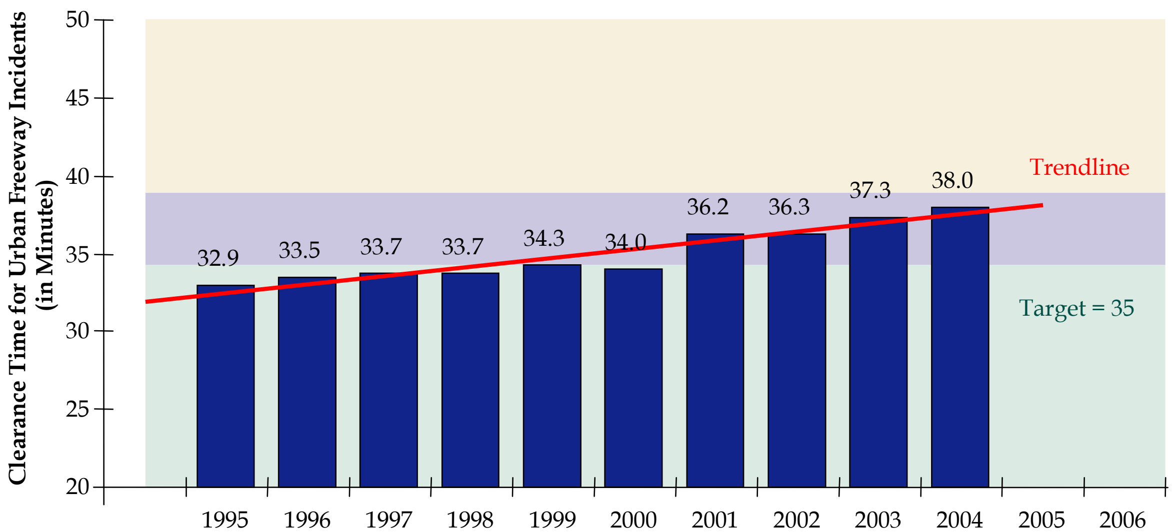
Ways to Improve: Place collision categories adjacent; Relate trends to incident duration; Eliminate legend and label types on chart.

The intent of the overall measurement program is to determine which incident response efforts are improving, which are meeting their goals, and which need improvement. The program evaluation also should estimate the effect those efforts are having on the congestion problem.

The more detailed incident statistics (when the incident occurs, where it occurs, what it does to the roadway, what the response is, how quickly the response arrives, how quickly the response opens the roadway, and how quickly the entire incident scene is back to "normal") also serve as key inputs to the analysis process that generates knowledge about the cause and effect of incidents on freeway performance. The agency activity information can help analyze the amount of delay the incidents cause and how much delay is saved because of the incident response program. These are the ultimate questions that need to be answered for the decision-makers. And they cannot be answered effectively without accurate incident data.

Most of these performance measures and reports are for leaders and technical staff to decide on resource and staff allocation decisions. They can be used for long-term analyses but typically they are used for agency decisions and accountability reports. (The agency activity reports are interesting but not very useful for public readers). Figure 9.11 illustrates one of the basic trend graphs, along with the target clearance time chosen by the Minnesota DOT.

Figure 9.11 Urban Freeway Incident Management Trend and Target

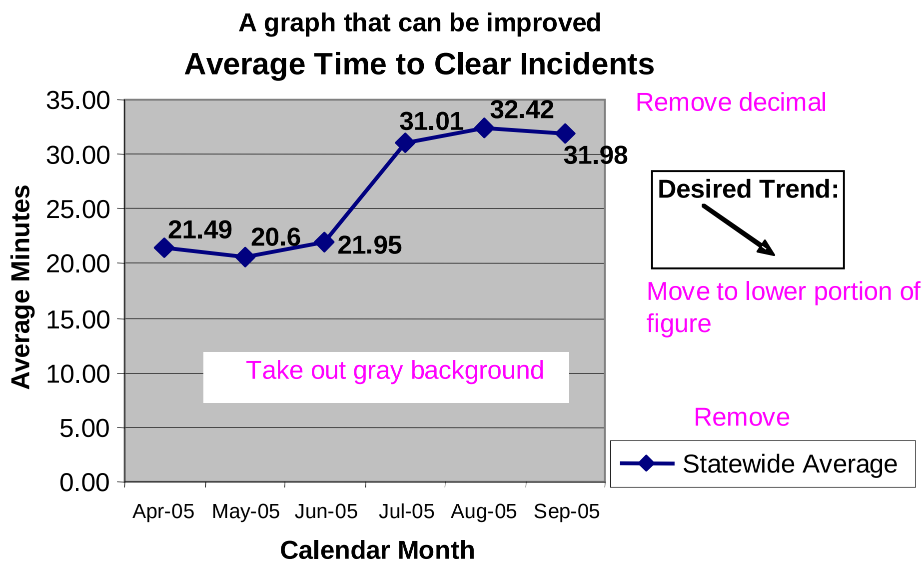


Source: *Moving Minnesota 2003 – Moving People and Freight to 2023.* Minnesota's 20-year Transportation Plan. Minnesota Department of Transportation, Office of Investment Management. July 16, 2002.

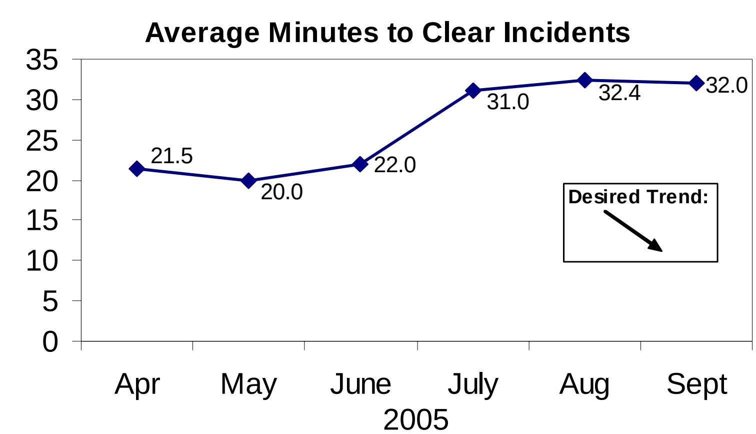
Performance Measures Included: Incident clearance time.
Can Also be Used for: Response, duration time.
Measure Category: Agency activity.
Audience: Leaders, general, technical.
Applications: Real-time, operations, short-term, long-term.
Use: Evaluation.
Geographic Scale: Region, corridor.
Time Scale: Annual.
Strong Points: Also useful for public communication; trend and target.
Ways to Improve: Include number of incidents to display volume of responses.

Figure 9.12 illustrates some improvements that can be made to a typical trend chart generated by generally available software programs. Using the chart design guidelines developed by the Washington State DOT, the lower graph presents a cleaner version of the same information. Similar displays of other time-related trends are very useful for measuring agency activity that is relevant, if not entirely useful, for general audiences.

Figure 9.12 Incident Clearance Time Trends

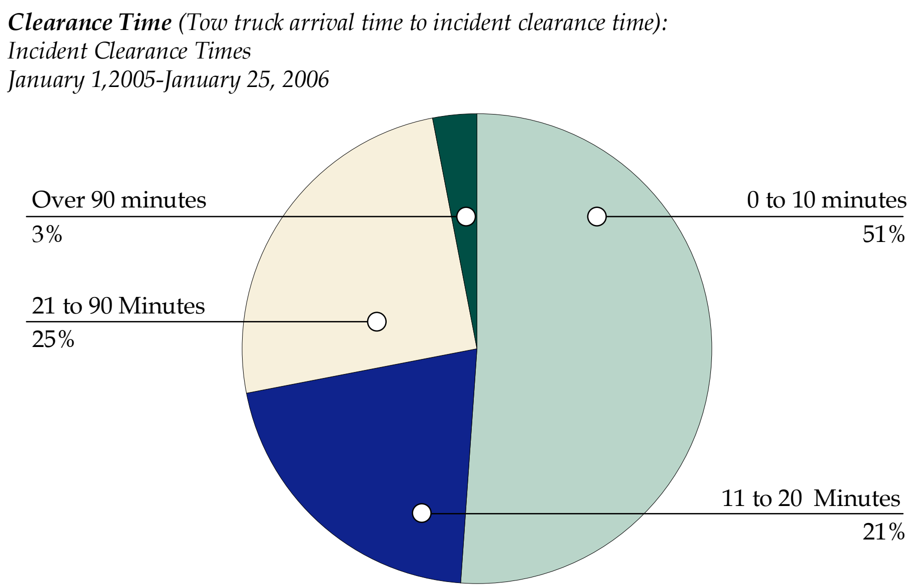


Performance Measures Included: Incident clearance time.
Can Also be Used for: Response, duration time.
Measure Category: Agency activity.
Audience: Leaders, general, technical.
Applications: Real-time, operations, short-term, long-term.
Use: Evaluation.
Geographic Scale: Region, corridor.
Time Scale: Annual.
Strong Points: Also useful for public communication; trend and target.
Ways to Improve: Include number of incidents to display volume of responses.



An important difference between many operational programs and typical freeway widening projects is that the operating schemes often attempt to reduce the frequency and severity of the most severe delay causing events. Averages, in this case, do not tell enough of the story. Distributions, such as shown in Figure 9.13, are one method of illustrating these events.

Figure 9.13 Incident Clearance Time Distribution



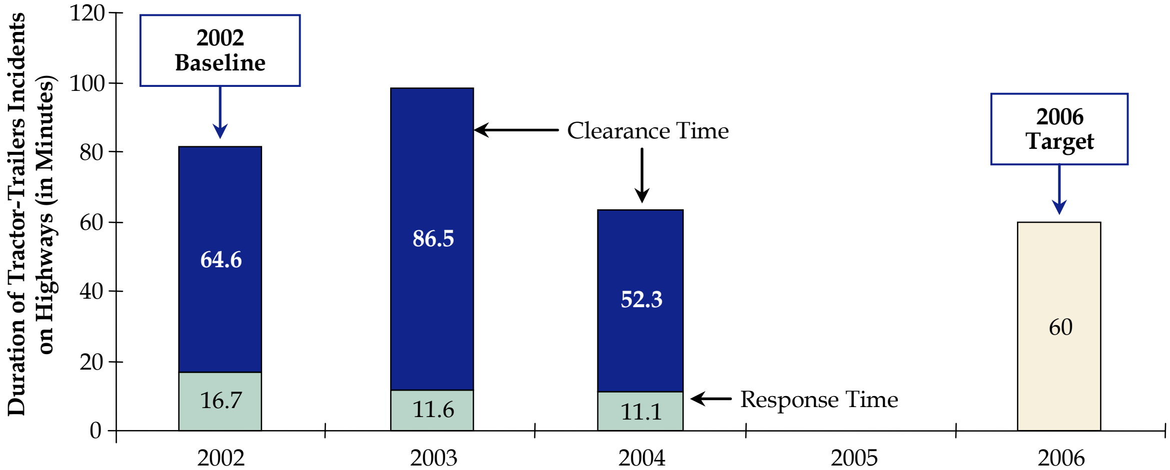
Source: Lomax, T., Stein, R., and Supkis, D. *SAFEclear Program – One-Year Report.* Available: http://www.houstontx.gov/safeclear/oneyear/safeclear-oneyear-report.pdf.

Performance Measures Included: Incident clearance time.
Can Also be Used for: Any operating strategy.
Measure Category: Agency activity.
Audience: Leaders, technical.
Applications: Operations, short-term.
Use: Evaluation, monitoring.
Geographic Scale: Region, corridor.
Time Scale: Annual.
Strong Points: Shows distribution not just average.
Ways to Improve: Show target; Show trend; show number of incidents.

Measuring the response, clearance and duration times for freeway incidents against targets can be a very effective way of relating broad performance measures, such as travel time, to very specific actions by specific individuals or teams. Making performance measures "real" to those most able to affect them is the best way to improve performance, as well as the data needed to create them.

Displays of the components of incident duration – response and clearance time – provides an important element of program evaluation. The two components are often the responsibility of two different groups within an agency. In some cases, such as when the private towing industry responds to incident scenes, the response time can be a performance component of a contractual arrangement. The percentage and number of long duration truck incidents is an important component of an incident management evaluation program (Figures 9.14 and 9.15).

Figure 9.14 Display of Response, Clearance, and Duration Times and Targets



Source: *Moving Minnesota 2003 – Moving People and Freight to 2023.* Minnesota's 20-Year Transportation Pla
Minnesota Department of Transportation, Office of Investment Management. July 16, 2002

Performance Measures Included: Incident duration time.

Can Also be Used for: Any time-related agency statistic.

Measure Category: Agency activity.

Audience: Leaders, technical.

Applications: Operations, Short-term.

Use: Evaluation, monitoring.

Geographic Scale: Region, corridor.

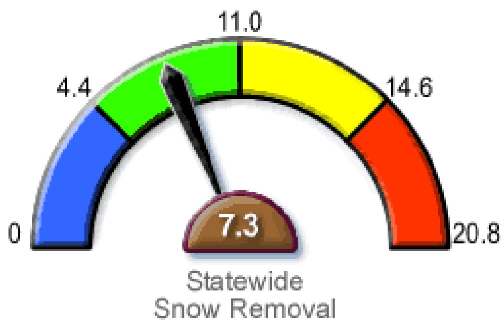
Time Scale: Day, monthly, annual.

Strong Points: Trends and values are intuitive.

Ways to Improve: Compare to same season/month previous year; improve graphics.

Another effective presentation of a performance target is a colored gauge like the one used by Minnesota DOT for measuring the average hours until bare pavement is reached on all state highways after a snowfall.

Figure 9.15 Display of Current Performance Level and Target



Performance Measures Included: Snow removal time.
Can Also be Used for: Any operating strategy.
Measure Category: Agency activity.
Audience: Leaders, general, technical.
Applications: Operations, short-term.
Use: Evaluation, monitoring.
Geographic Scale: Region, corridor.
Time Scale: Day, annual.
Strong Points: Clearly shows performance and target.
Ways to Improve: --

Source: *Moving Minnesota 2003 – Moving People and Freight to 2023.* Minnesota's 20-Year Transportation Plan. Minnesota Department of Transportation, Office of Investment Management. July 16, 2002

9.3.6 Short-Term Planning Applications

Uses and Audiences

Agency uses for information beyond relatively immediate time scales are typically composed of assessments of the quality of service, the trends in both agency and system performance and identification of areas for improvement that might require investment of staff time, equipment, or funding.

Numbers can be important for showing the effect of changes and the need for additional improvement. These are best when done with a few key measures on the "public side" of reporting backed up by more detailed measures for interested parties and for technical analyses.

One aspect of some short-term analyses that may come as a surprise is that if the project or program is significant or controversial, the analysis should be prepared to develop information in a real-time basis. What begins as a before/after assessment of an implementation has often evolved into an analysis of operational options and decision support for any alterations. In these cases, the experienced analyst finds it useful to prepare the data and reporting as though there will be a press conference and peer review at the end of every peak-period or day. This requires real-time data and measures that resonate with the public to show how the condition match or disagree with public perception. If a radio station helicopter hovers over the one problem area in an otherwise successful project, the display that shows how well the rest of the system works may be crucial. Even better, getting civic leaders, media, and decision-makers to understand what you expect before opening.

Applications and Typical Measures

Table 9.3 illustrates one method to compile several performance measures. The graphics below are from the Missouri DOT Tracker information system, but similar "dashboard" programs have been developed by states such as Virginia and Washington. These reports are typically produced quarterly, but the format can be used for semiannual and annual reports as well. The "dashboard" approach to displaying information allows the public or relatively unfamiliar readers to see the status of the performance measures. The red, yellow, green scale is effective and intuitively obvious for most readers. The "comments" section is a vital element giving a place to provide explanations or additional information about the trend, the measure, or the data. Each performance measure has a department staff person who is linked to the measure, improving accountability and accessibility to the information.

Table 9.3 Example of "Dashboard" Performance Measure Display

Performance Measure	Trend	Comments
Take Better Care Of What We Have		
Traffic fatal and injury crash rates compared to national average	Y	Fatal and injury crash rates (2001) – Trend for fatal crash rate is decreasing but rate sill higher than national rate; the injury crash rate is meeting the performance goals (Pages 1 and 2)
State system traffic fatality and injury crash trend	G	Fatality and injury crash totals – Five-year trend for 2001 is decreasing (Pages 3 and 4)
Percent of major highway miles in good or better condition	R	There has been a decrease of major highway miles in good or better condition since 2000 (Pages 5 and 6)
Percent of deficient bridges	Y	Although statistics show a decrease in the percentage of deficient bridges on the state system, there is still a significant gap in the deficiency on the state system compared to all states (Page 8)
Roadway Congestion Index (RCI) for Kansas City and St. Louis compared to national average	Y	We have met the goal of being below the national average but the overall trend in RCI is increasing (Pages 8 and 9)
Percentage of statewide striping program completed	NM	New measure – In the process of gathering data (Page 10)
Moving costs versus herbicide costs	G	Costs were along baseline for the herbicide program and below the baseline for the mowing program (Pages 11 and 12)
Net assets at year end	Y	Preliminary FY2003 financial statements indicate net assets are decreasing (Page 13)

Table 9.3 Example of "Dashboard" Performance Measure Display (continued)

Performance Measure	Trend	Comments
Finish What We've Started		
Percentage of dollars delivered as programmed	G	Result was less than five percent of dollars programmed for SFY 2002 (Page 14)
Percentage of projects delivered as programmed	Y	Deviation was nine percent for SFY 2002 (Page 15)
Percentage of projects delivered on time	R	Target was not met (Page 16)
Percentage of projects delivered within budget	G	Results was less than three percent of programmed dollars (Page 17)
Build Public Trust		
Percent of customer satisfaction	NM	New measure – In the process of gathering data (Page 18)
Percent of funding level target utilized by programmed projects by category for the 2005-2009 STIP	G	(Page 19)

Source: *Dashboard Measurements of Performance,* Missouri Department of Transportation, June 2003.

Key:

- (green) The target was met or exceeded (for the time period in which data is collected).
- (yellow) The trend was positive, but the target was not met (or no target established).
- (red) The trend was negative and the target was not met (or no target established).
- NM – The measure is under development.

Performance Measures Included: Several agency strategies and performance measures.
Can Also be Used for: Quality of service measures.
Measure Category: Agency activity, Quality of service.
Audience: Leaders, Technical.
Applications: Short-term, Long-term.
Use: Monitoring.
Geographic Scale: Region.
Time Scale: Annual.
Strong Points: Comments section; Trend color.
Ways to Improve: Include goals.

Guide to Effective Freeway Performance Measurement

Vehicle and person volume data at multiple locations on a roadway can be presented in a simple table structure. For short-term planning, volume data is a significant element that not only provides a measure of scale, but also allows sections of freeway systems to be combined using the number of customers served as the weighting factor.

Table 9.4 Example of Volume Data Table

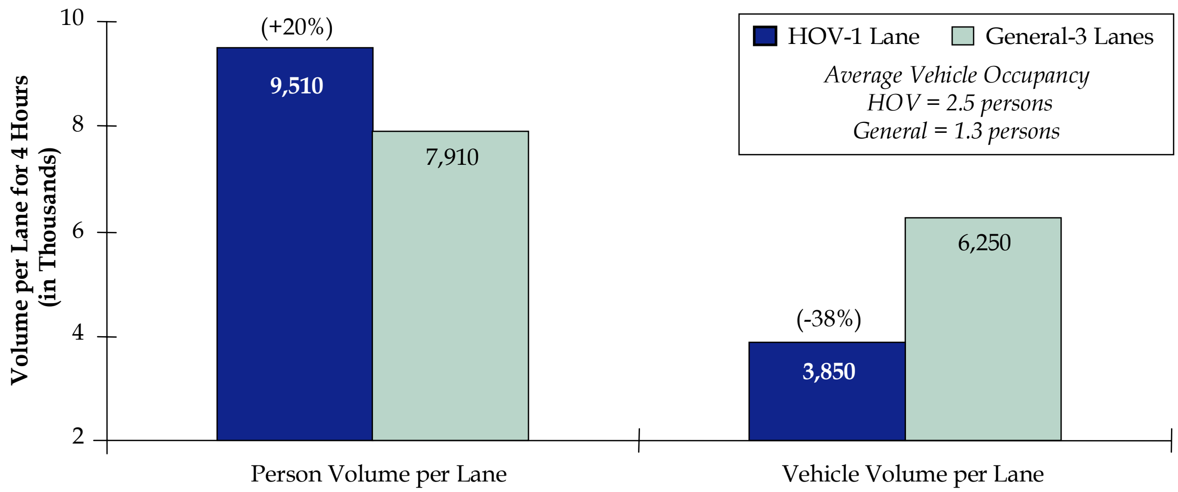
Cabinet	Location On I-5	Daily Vehicle Volume – Lanes – Northbound	Daily Vehicle Volume – Lanes – Southbound	Daily Vehicle Volume – *Total General Purpose*
55	South 184th Street	**110,800**	**102,600**	***213,400***
88	South Pearl Street	**109,700**	**102,100**	***211,800***
111	University Street	**107,700**	**110,400**	***218,100***
130/126	Ship Canal Bridge	**108,600**	**114,100**	***222,700***

Source: Kopf, J., Ishimaru, J.M., Nee, J., and Hallenbeck, M.E. *Central Puget Sound Freeway Network Usage and Performance, 2003 Update.* Seattle, WA: TRAC/University of Washington, 2005.

Performance Measures Included: Volume.
Can Also be Used for: Speed; Travel time between locations; Volume per lane.
Measure Category: Agency activity.
Audience: Leaders, Technical.
Applications: Real-time, short-term, Long-term.
Use: Monitoring.
Geographic Scale: Region, Corridor.
Time Scale: Annual.
Strong Points: Describe as demand.
Ways to Improve: Also include persons.

Graphics and tables can be created to answer specific questions. Figure 9.16 answers the policy question frequently asked, "Are HOV lanes being used?" In this case, the answer is yes they are carrying 20 percent more people than one of the adjacent general freeway lanes.

Figure 9.16 Example of Volume Comparison Chart



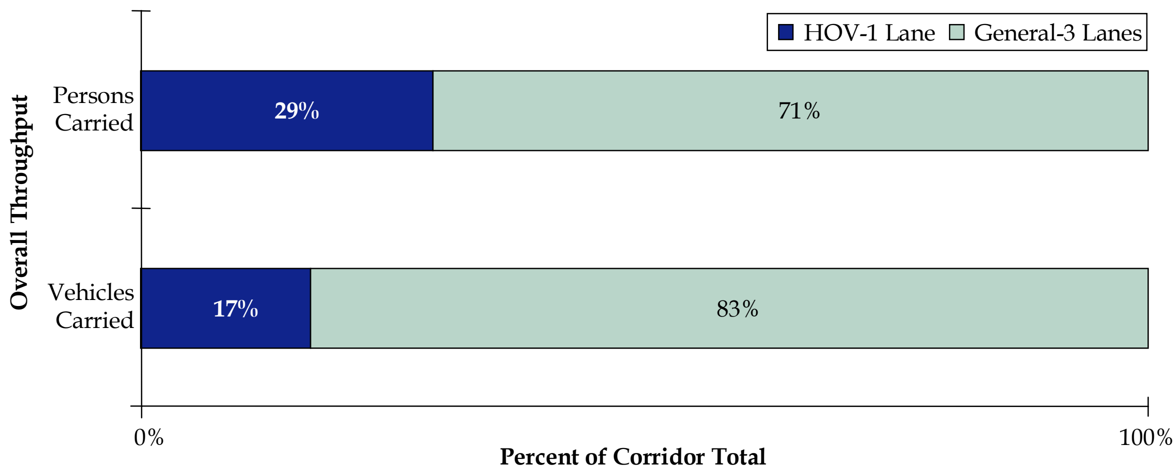
Source: *HOV Lane Performance Monitoring: 2000 Report*. Seattle, WA: University of Washington Transportation Research Center (TRAC). February 2002.

Performance Measures Included: Volume.
Can Also be Used for: Speed.
Measure Category: Agency activity.
Audience: Leaders, general, technical.
Applications: Short-term.
Use: Monitoring, Evaluation.
Geographic Scale: Corridor, site.
Time Scale: Annual.
Strong Points: Related to quality of service compare to before condition.
Ways to Improve:

The numbers are the key data and information element, but the graphical presentation is what makes the numbers stand out. Figure 9.17 takes the same data and presents it differently to answer a different question. In this case, "what is the mode share of general and HOV lanes?"

Both of these cases illustrate the corridor and location type of analysis. They use units that make good sense on a local level. Figure 9.16, however, does not translate well to a broader area analysis. Converting the person travel statistics to mode share allows a broader comparison. Vehicle-miles of travel or person-miles of travel also could be used. However, terms like 'person-miles-of-travel' do not make nearly as much sense to general audiences as 'persons carried.'

Figure 9.17 Mode Share of Corridor Travel



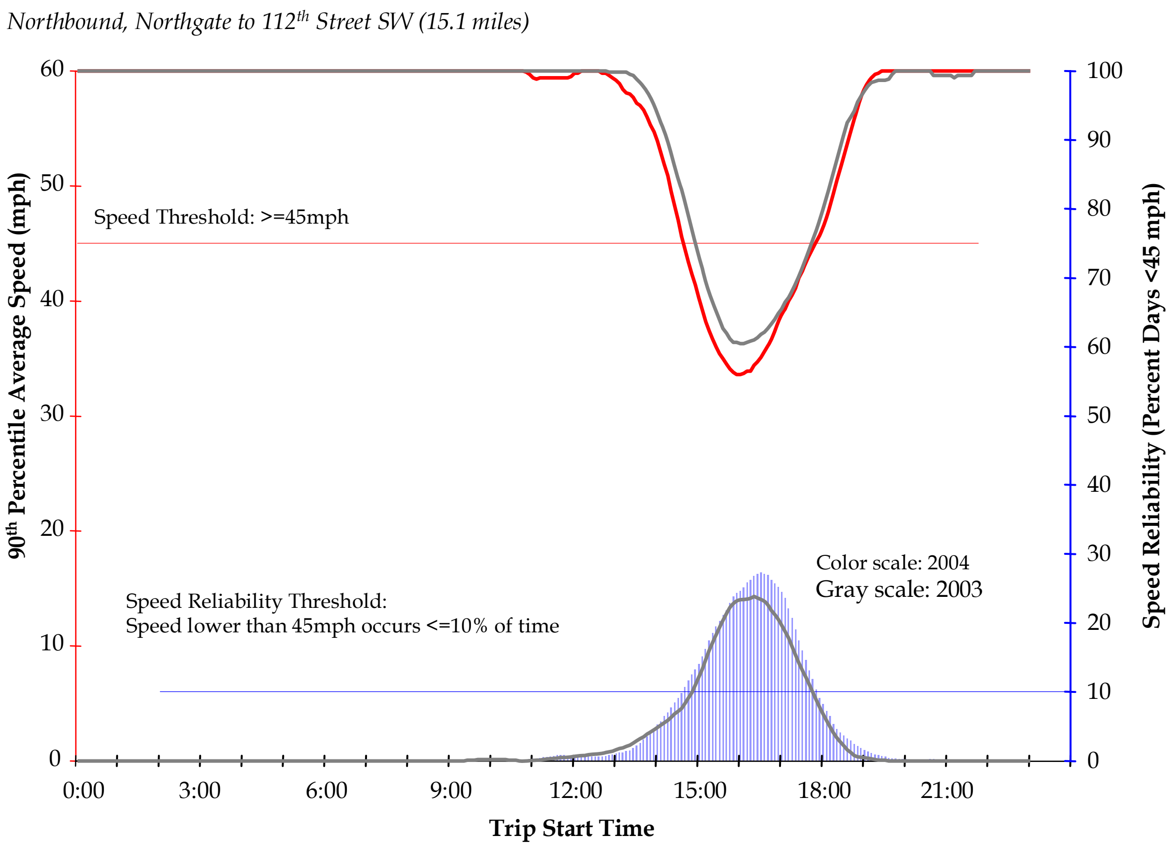
Source: *HOV Lane Performance Monitoring: 2000 Report.* Seattle, WA: University of Washington Transportation Research Center (TRAC). February 2002.

Performance Measures Included: Volume distribution.
Can Also be Used for: Volume.
Measure Category: Agency activity.
Audience: Leaders, technical.
Applications: Real-time, operations, short-term, long-term.
Use: Monitoring, evaluation.
Geographic Scale: Corridor, site.
Time Scale: Annual.
Strong Points: Intuitive.
Ways to Improve: Include total volumes.

Of course, a key part of answering corridor type questions is to have enough data. And the ability to manipulate that data so that you can accurately compute a true corridor statistic. That means having a number of data collection points, and being able to interpolate the holes between those data points.

Annual evaluations that include graphical comparisons are particularly effective in communicating trends. When the data are available to show performance over the day or peak-period, such as the HOV lane evaluation in Figure 9.18, decision-makers and the general public can both connect their concerns with the performance data. Leaders are more concerned with whether the performance targets are being met, while travelers can examine the corridor statistics during their travel period.

Figure 9.18 Comparison of Annual High-Occupancy Vehicle Lane Performance

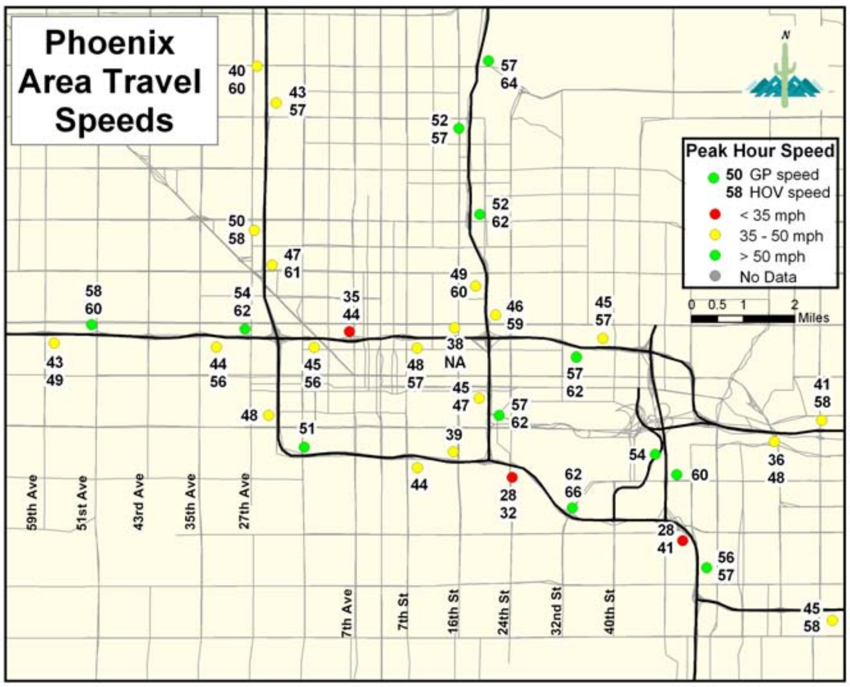


Source: *HOV Lane Performance Monitoring: 2000 Report.* Seattle, WA: University of Washington Transportation Research Center (TRAC). February 2002.

Performance Measures Included: Speed, reliability.
Can Also be Used for: Most performance measures.
Measure Category: Quality of service.
Audience: Leaders, technical, general.
Applications: Short-term, long-term.
Use: Monitoring, Evaluation.
Geographic Scale: Corridor, site.
Time Scale: Monthly, annual.
Strong Points: Combines average congestion and variation in congestion.
Ways to Improve: --

Assessments of information needs often conclude that because travelers are most concerned about travel time and variation in travel time, that the graphical components should include travel time or travel rate, rather than speed. Technically, speed is inversely related to travel time and the variation in the two numerical measures is very nonlinear. Coming down from a speed limit threshold, the speed number declines very sharply, but travel time increases relatively slightly. (The speed change from 60 mph to 30 mph increases travel time by the same amount as a decline from 15 mph to 12 mph). Every car has a speedometer, however, and speed is a powerful performance measure that can be used very successfully on a technical level if only one type of system is being compared (e.g., freeways, major streets). Figure 9.19 shows another method of displaying annual average speeds (in addition to the line colors typically used for real-time displays). This kind of map can be used with a variety of geographically compatible measures.

Figure 9.19 Using Roadway Maps to Present Freeway Speeds
Color Dot Format



Source: *Freeway Traffic Conditions and Trends, 2004: Prototype Annual Report.* Prepared by Texas Transportation Institute for Maricopa Association of Governments. June 15, 2005

Performance Measures Included: Traffic speed.

Can Also be Used for: Almost any quality of service measure; may also be useful to map agency activities.

Measure Category: Quality of service.

Audience: Leaders, general, technical.

Applications: Real-time, operations, short-term.

Use: Monitoring.

Geographic Scale: Region, corridor.

Time Scale: Real-time, period, day, annual.

Strong Points: Easy to understand; relatively easy to produce.

Other Ways to Display: Use colors on roads rather than dots.

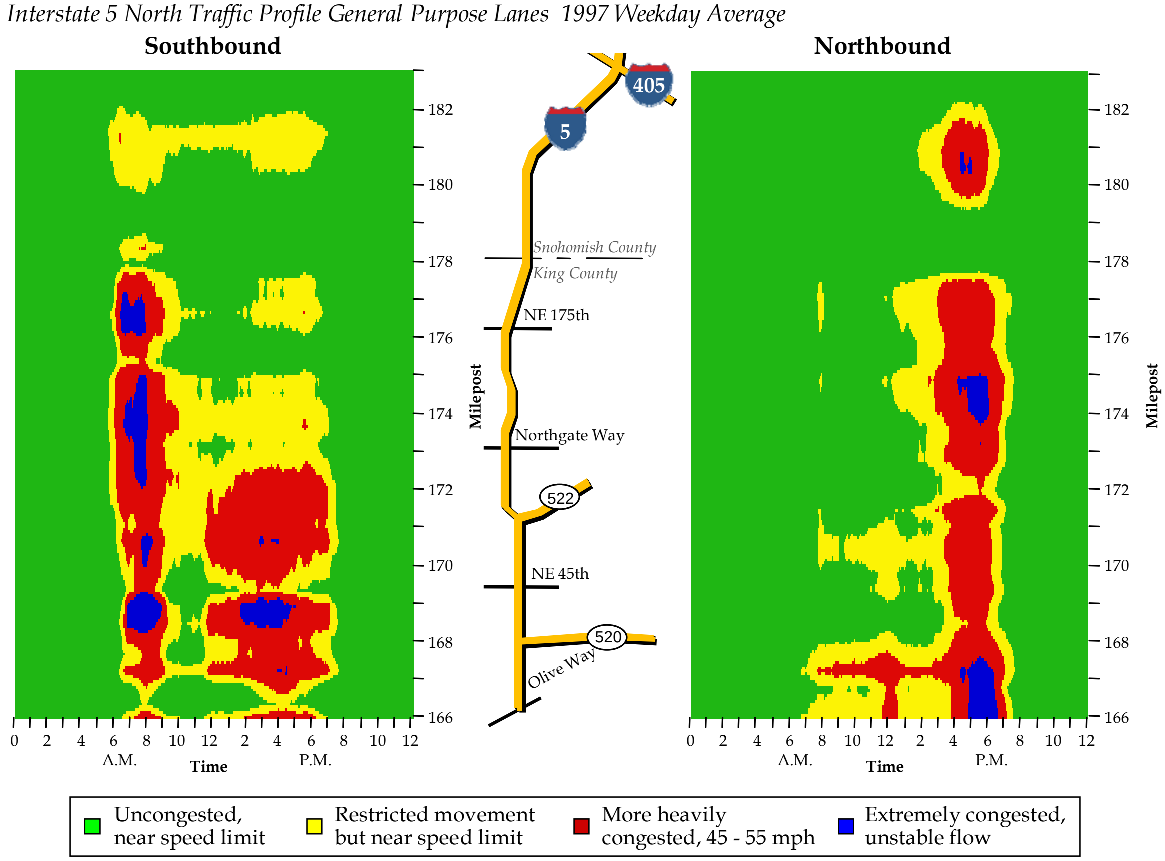
The graphic in Figure 9.20 has a variety of names (e.g., speed contour graph, "the Rorschach graphic"). The diagram shows performance as estimated with average lane occupancy for a freeway corridor for hours of the day. The concept also can be used to show volumes. While complicated to explain, the graph includes all the important components of congestion – timing, intensity, and geographic spread. Technically, the graph is prepared by shading the spreadsheet cells with colors determined by some scheme, removing the numbers, and then setting the "view" to 5 or 10 percent. Copying the resulting image onto one side of a corridor map creates a view that travelers can relate to, even if some explanation is required. The image also helps technical staff understand when and where the problems are occurring.

Trips take place in the direction of travel and time always moves left to right. In Figure 9.20, the southbound movement experiences congestion through much of the day. With the exception of a very congested interchange, the northbound direction has only evening peak-period congestion. These graphics also are good for before/after analyses of improvement projects or route evaluations.

The same style of graphic can be used to display "frequency of congestion" rather than actual conditions. Figure 9.21 shows weekend congestion frequency in terms of the number of weekend days per month that the facility breaks down. It is quite easy to see that there is a weekend problem on I-5 southbound in the early afternoon.

One confounding aspect of a weekend analysis is that if it is based on the traditional definition of "congestion" (e.g., level of service F), the public does not believe congestion is as infrequent as depicted in Figure 9.21. If a lower standard is used (e.g., level of service d) more congestion is displayed and the public's perceptions of weekend congestion is matched.

Figure 9.20 Speed and Time Contour Diagram



Source: Kopf, J., Ishimaru, J.M., Nee, J. and Hallenbeck, M.E. *Central Puget Sound Freeway Network Usage and Performance, 2003 Update*. Seattle, WA: TRAC/University of Washington, 2005.

Performance Measures Included: Traffic speed.

Can Also be Used for: Changes from year-to-year; frequency of congestion.

Measure Category: Quality of service.

Audience: Leaders, general, technical.

Applications: Operations, short-term.

Use: Monitoring, evaluation.

Geographic Scale: Region, corridor, site.

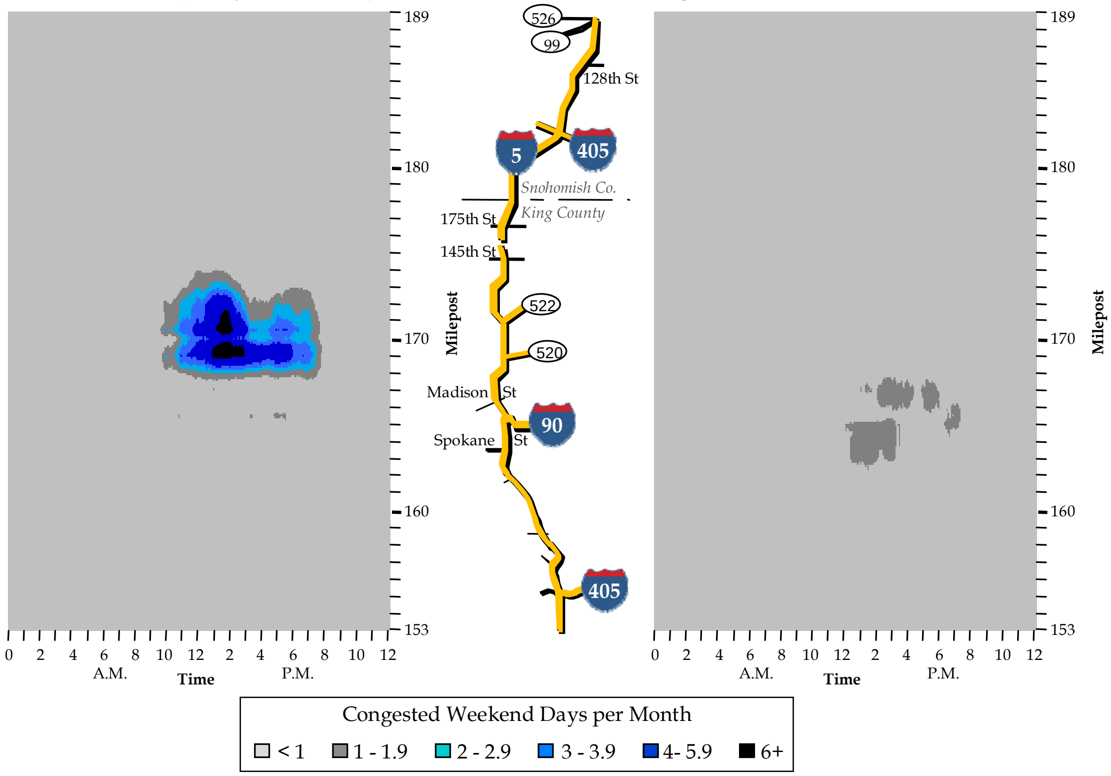
Time Scale: Annual.

Strong Points: Based on real conditions; map and conditions together; intuitive color scheme.

Ways to Improve: The diagram concept can be tough to explain.

Figure 9.21 Weekend Congestion Frequency Contour Diagram

Interstate 5 LOS F Frequency General Purpose Lanes 1999 Weekend Average



Source: Kopf, J., Ishimaru, J.M., Nee, J. and Hallenbeck, M.E. *Central Puget Sound Freeway Network Usage and Performance, 2003 Update.* Seattle, WA: TRAC/University of Washington, 2005.

Performance Measures Included: Frequency of congestion on weekends.

Can Also be Used for: Traffic speed.

Measure Category: Quality of service.

Audience: Leaders, general, technical.

Applications: Operations, short-term.

Use: Monitoring, evaluation.

Geographic Scale: Corridor.

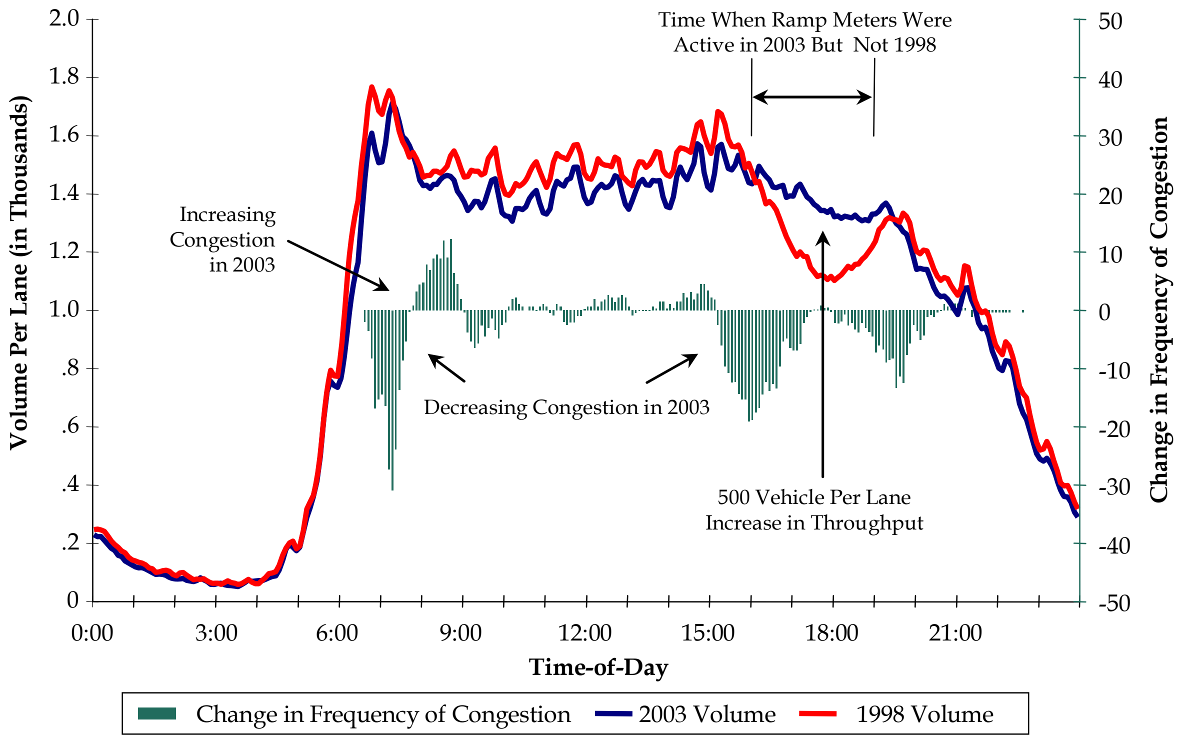
Time **Scale:** Annual.

Strong Points: Based on actual conditions; Intuitive color scheme; map and conditions together.

Ways to Improve: Both the diagram concept and the “frequency of congestion” can be tough to explain.

The effect of ramp metering is not typically shown in removal of congestion, but rather in the volume of travelers served by the freeway and the frequency of time and days that congestion occurs. The line graphs in Figure 9.22 show volume per lane in a before and after period. The bar graphs illustrate the change in frequency (number of days) that congestion occurs. The graphic shows the higher volumes handled and lower congestion in the 4:00 p.m. to 7:00 p.m. period when metering changes were implemented.

Figure 9.22 Display of Volume and Congestion Frequency Changes Due to Ramp Metering

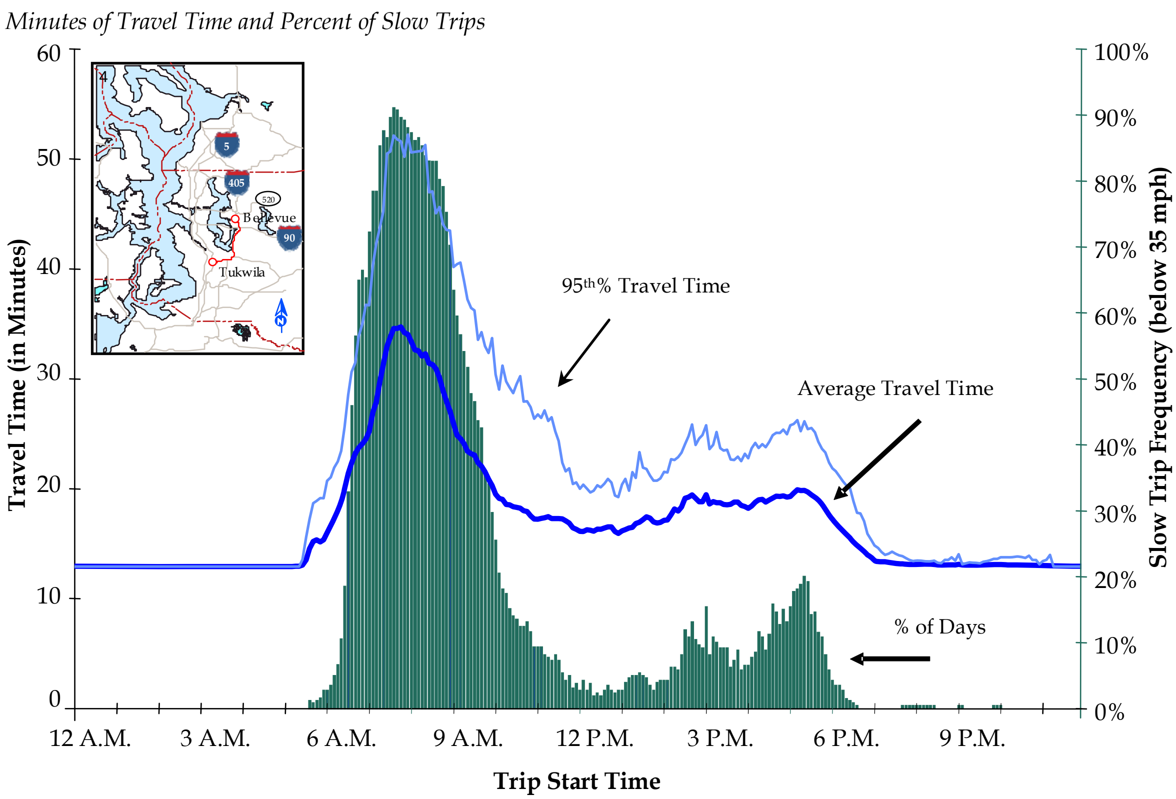


Source: Hallenbeck, M.E., University of Washington Transportation Research Center (TRAC). Supporting Material for *Measuring and Communicating the Effects of Traffic Incident Management Improvements.* NCHRP Research Digest Number 289, May 2004.

Performance Measures Included: Volume and frequency of congestion.
Can Also be Used for: Speed; travel time.
Measure Category: Quality of service.
Audience: Leaders, technical.
Applications: Operations, short-term.
Use: Evaluation.
Geographic Scale: Corridor.
Time Scale: Day, annual.
Strong Points: Provides direct before/after comparisons.
Ways to Improve: Use multiple graphs that "build-up" to this one.

Figure 9.23 shows how travel times vary over the course of a day, as well as from day-to-day. The green line gives average travel time for the trip shown in the inset map if the trip starts at any time during the day. The red line shows the 95th percentile travel time for that same trip (the red line can be explained as the slowest trip home from work each month.) The blue vertical bars show the percentage of time this trip operates below a set performance standard – in this case, the trip is slower than an average of 35 mph.

Figure 9.23 Average and Extreme Travel Time and Frequency of Slow Trips



Source: Hallenbeck, M.E., University of Washington Transportation Research Center (TRAC). Supporting Material for *Measuring and Communicating the Effects of Traffic Incident Management Improvements*. NCHRP Research Digest Number 289, May 2004.

Performance Measures Included: Average and 95th percentile travel time; percent of days with congestion.

Can Also be Used for: Evaluating operations and capacity changes.

Measure Category: Quality of service.

Audience: Leaders, general, technical.

Applications: Operations, Short-term.

Use: Monitoring, evaluation.

Geographic Scale: Corridor.

Time Scale: Period, day, annual.

Strong Points: Shows average conditions and variation; includes map of trip.

Ways to Improve: May be too complicated (use 2 or 3 graphs in sequence).

By computing this type of graph for several different years, it is possible to report on the trends occurring in the region. Are the average travel times changing? Are trips becoming more or less reliable? (Are the red and green lines getting closer to each other or farther away?)

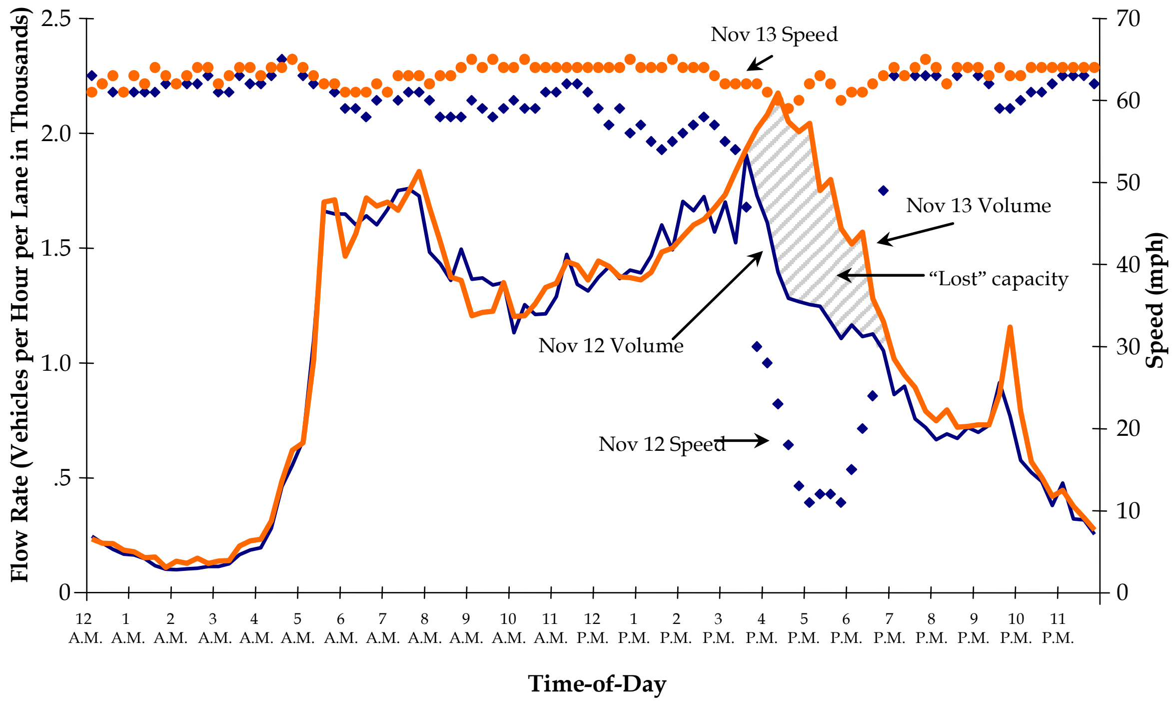
Combinations of the time of average travel time, significantly bad travel times, and the frequency of days with congestion provide important explanations for the unreliable travel times. The connection between frequent congestion and unreliability is evident in Figure 9.24.

The computation of delay rarely takes into account the loss of volume caused by the congestion.

Loss of productivity or efficiency is a new measure being used in at least two ways. Caltrans and WSDOT compare volume for each five-minute period to the highest five-minute volume – illustrating the penalty for not maintaining the best condition achieved. Arizona DOT and Maricopa Association of Governments examine the differences between 'usual' conditions and the volume/speed on incident or weather days. The intent is to show decision-makers that if the agencies are not allowed to effectively manage the existing roadway, not only does it result in delay, but fewer people and vehicles are served than the roadway was designed for. Not only are people served poorly, but fewer people are served more poorly.

Figure 9.24 Presentation of "Lost Capacity" Concept

Station 40: I-10 EB at 25th Street Illustrating the Concept of "Lost" Capacity



Source: *Freeway Traffic Conditions and Trends, 2004: Prototype Annual Report.* Prepared by Texas Transportation Institute for Maricopa Association of Governments, June 15, 2005.

Performance Measures Included: Speed and volume.
Can Also be Used for: Travel time and volume.
Measure Category: Quality of service.
Audience: Leaders, technical.
Applications: Short-term.
Use: Monitoring, evaluation.
Geographic Scale: Site.
Time Scale: Annual.
Strong Points: Relates both volume and speed to a performance measure with an inherent target-maximum productivity.
Ways to Improve: Requires reader to understand "maximum productivity"; Fewer hour labels.

The graphic illustrates the realities of the effects of traffic congestion on vehicle throughput. When speeds drop, volume drops. The cars are packed on the freeway, but they are not moving past any point on the road very rapidly. Thus, if the speeds could be maintained (by instituting better ramp metering or other controls) not only would the people using the road move more quickly, but more people could use that road (without building more lanes). Computing this statistic regionwide allows it to be reported on a map to indicate the locations with the most significant loss of capacity. This could be used for prioritizing operational improvements or used in describing regional operational performance.

The comparison of traffic flow rate and speed can show the volume throughput lost due to inefficient operation. When speed declines due to congested operation, the traffic volume per lane also decreases. “Lost productivity” is the term used to describe this loss of both speed and traffic volume.

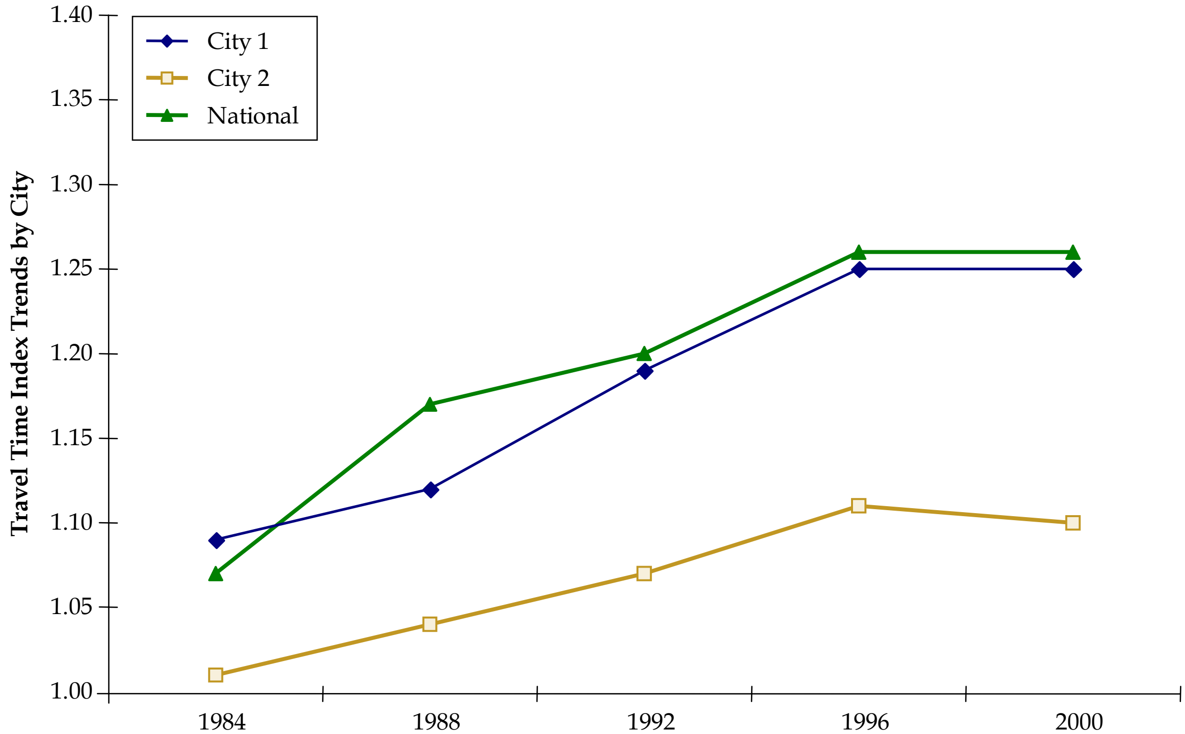
The Travel Time Index (TTI) is a comparison of peak-period conditions (including incident caused congestion) versus free flow conditions. It is unit less, so it allows comparisons involving different trip lengths, roadway types, or geographic areas. It describes the “expected conditions” of trips, relative to free flow conditions. This makes it particularly good for national or regional comparisons or comparisons between unlike corridors (i.e., corridors of different lengths.)

The Buffer Index is the other emerging national comparison statistics. It too is unitless, so it allows comparisons between corridors and/or urban areas. The Buffer Index gets back to the issue of reliability. It says “how much extra time to do I need to add to my expected trip time, if I absolutely HAVE to get there on time?” (It is the FedEx of travel time performance measures).

Basically, the more unreliable a trip is (i.e., the more variable the travel times are), the greater the value of the Buffer Index. The measure does not focus on the relatively minor day-to-day variation; it measures the number and time delay of very slow trips.

Another of the uses of the Travel Time Index or Buffer Index is that they allow fairly straight forward trend analysis, therefore answering key questions such as, “Are things getting better, or worse?” and “By how much?” The TTI and BI translate easily from place to place, and from trip to trip. But they work less well for questions such as “how long is it going to take me to make MY trip?”

Figure 9.25 Example of Peer City Comparison



Source: Texas Transportation Institute.

Performance Measures Included: Travel time index.
Can Also be Used for: Almost any performance measure.
Measure Category: Quality of service.
Audience: Leaders, general.
Applications: Short-term, long-term.
Use: Monitoring.
Geographic Scale: Region, corridor.
Time Scale: Annual.
Strong Points: Compare to trend, peer region and national average for similar sized regions.
Ways to Improve: "Peer" comparisons should include consideration of size, growth, community goals, etc.; include more years.

Communicating and Understanding Reliability for Professionals: The "Reliability Profile"

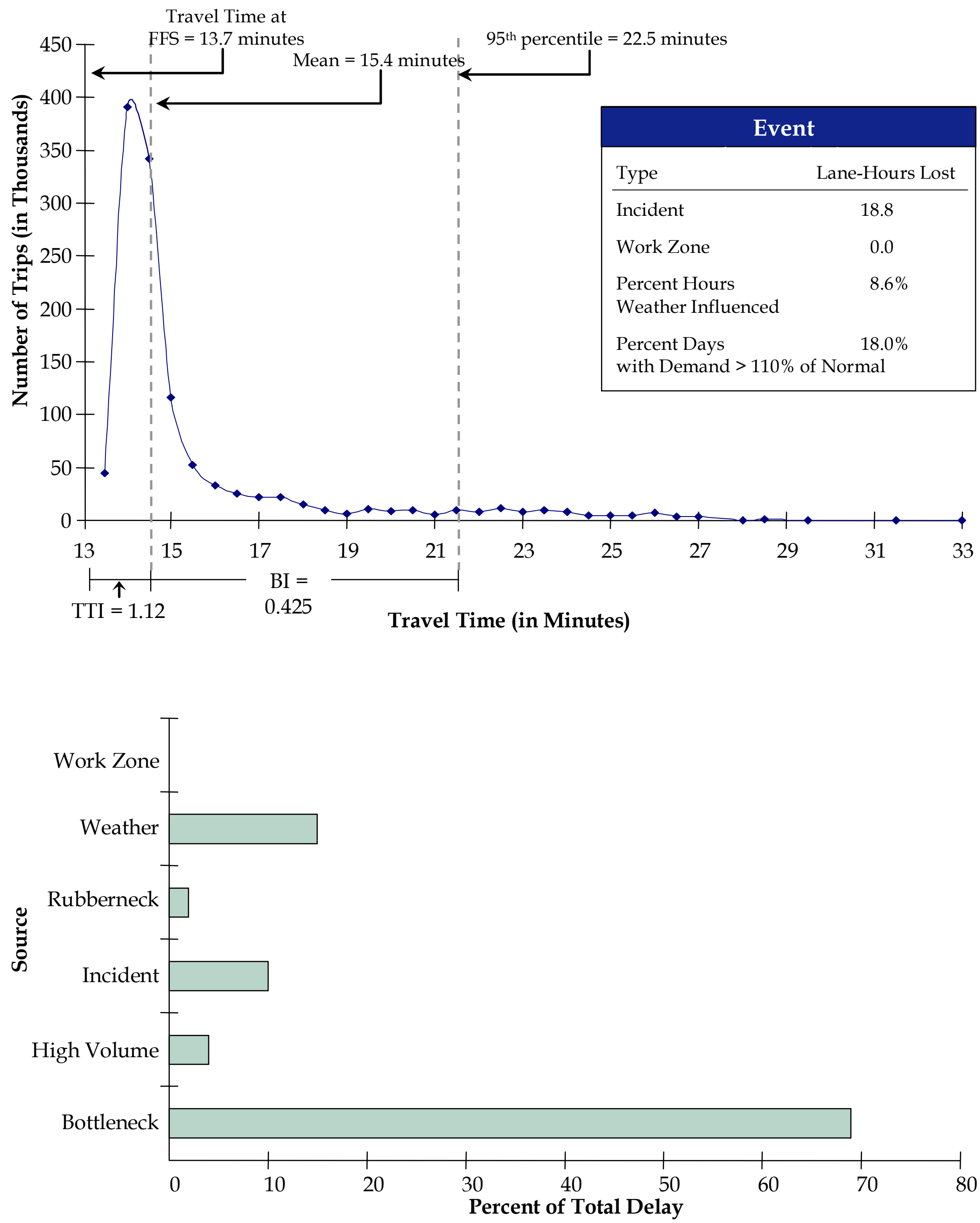
Travel time reliability is a difficult concept to communicate and present because it relates to a history of travel time experience. Still, it is important that professionals understand the nature of reliability on the freeways they manage. A method for doing this is to produce one-page summaries – ***the Reliability Profile*** – that display reliability patterns and the underlying causes of unreliable travel. Figures 9.26 and 9.27 show complete Reliability Profiles for two freeways in Seattle. The characteristics of the graphic are:

- Information is compiled for individual sections – one page per section per time period (usually one year, though only four months are shown for Seattle).
- The actual distribution of travel times is shown, with reliability performance measures superimposed on it. The Travel Time Index (TTI), Buffer Index (BI), and 95th percentile travel time are shown, but others can be used.
- A synopsis of event-related performance measures are displayed as way of explaining the reliability pattern.
- Delay by source is depicted as a further way of explaining the reliability pattern.

The Reliability Profile has the advantage of displaying multiple performance metrics on a single page along with a visual representation of the travel time history (distribution). Note that congestion and reliability on these sections are quite different. Average congestion on this section of I-90 is only moderate, but during the four-month study period, several events caused several travel times to be excessive, resulting in a high Buffer Index. On I-405, average congestion is much higher, but the impact of extreme events is less pronounced, at least for the four-month time period covered.

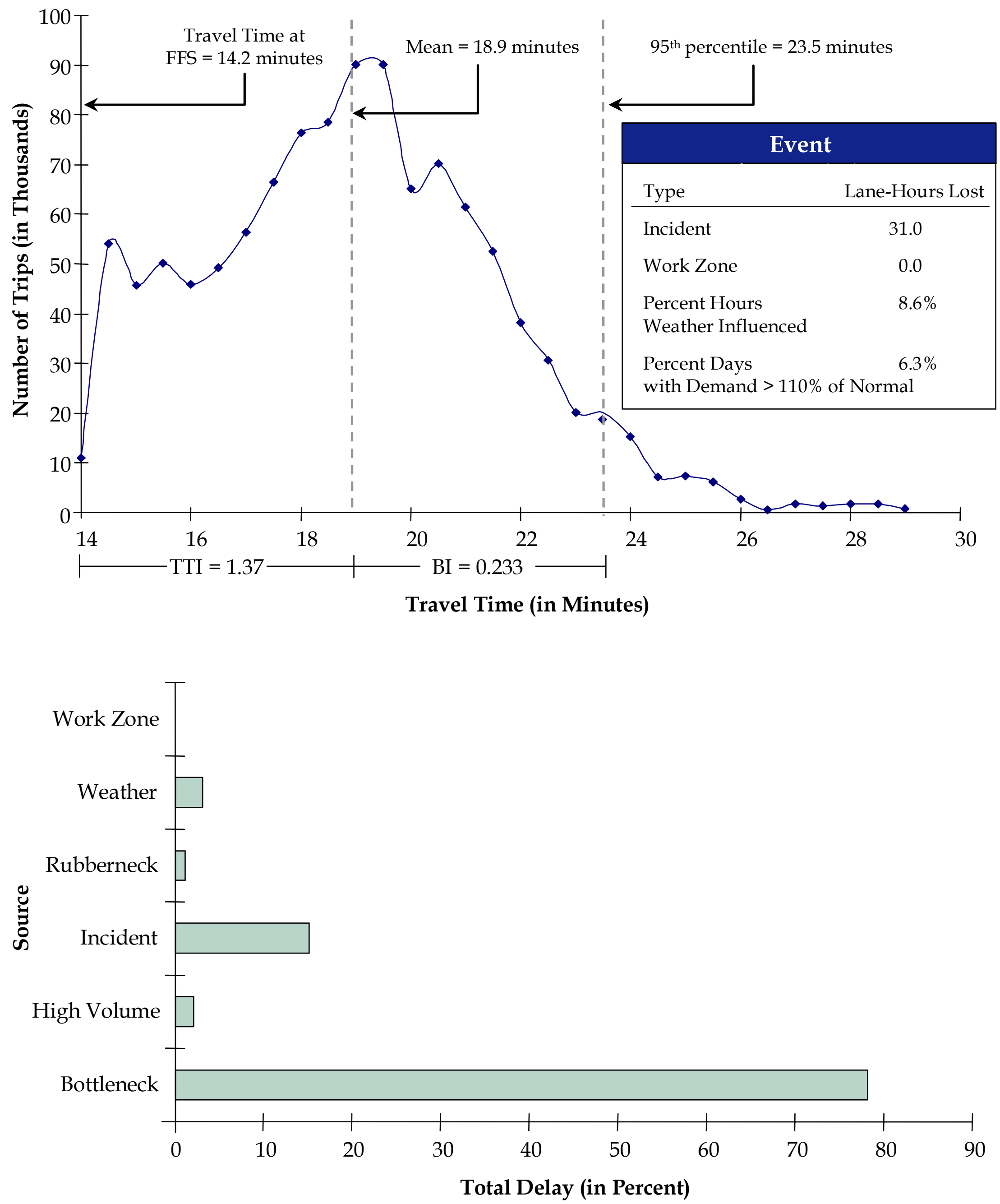
Additional partial Reliability Profiles are shown for freeways in Atlanta (Figures 9.28 through 9.30). Note that these do not have the event characteristics and congestion by source displays, because data were not available to compute these performance measures. Still, the size and shape of the distributions along with the graphic display of congestion and reliability performance measures are still revealing. By producing these graphics and routinely comparing freeway section performance side-by-side, professionals can gain additional insight into how their freeways are performing.

Figure 9.26 Reliability Profile: I-90 Seattle, EB
4-7 P.M. Weekdays, January-April 2003



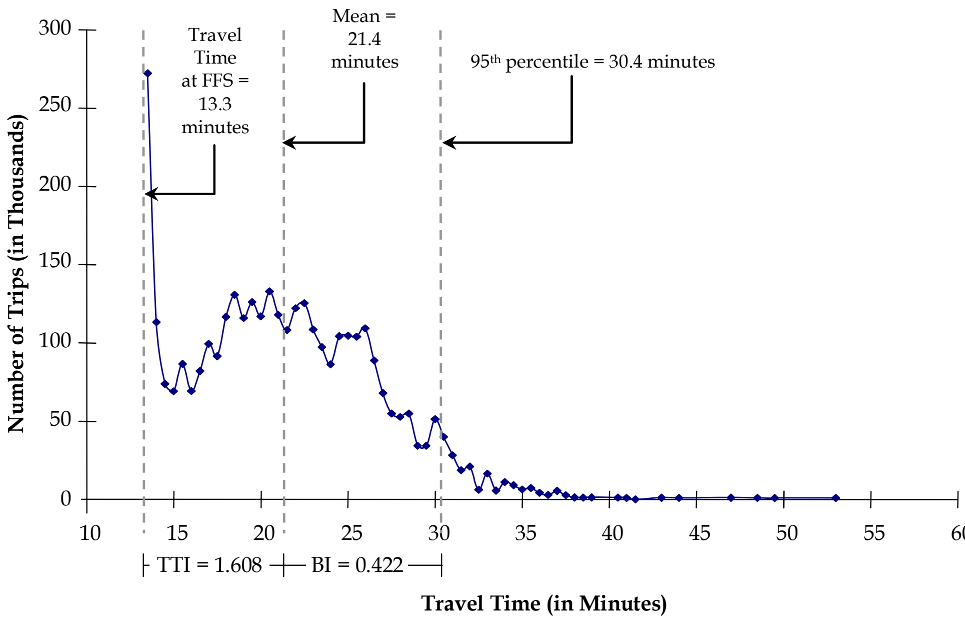
Source: Analysis of WSDOT data.

Figure 9.27 Reliability Profile: I-405 Seattle, SB
4-7 P.M. Weekdays, January-April 2003



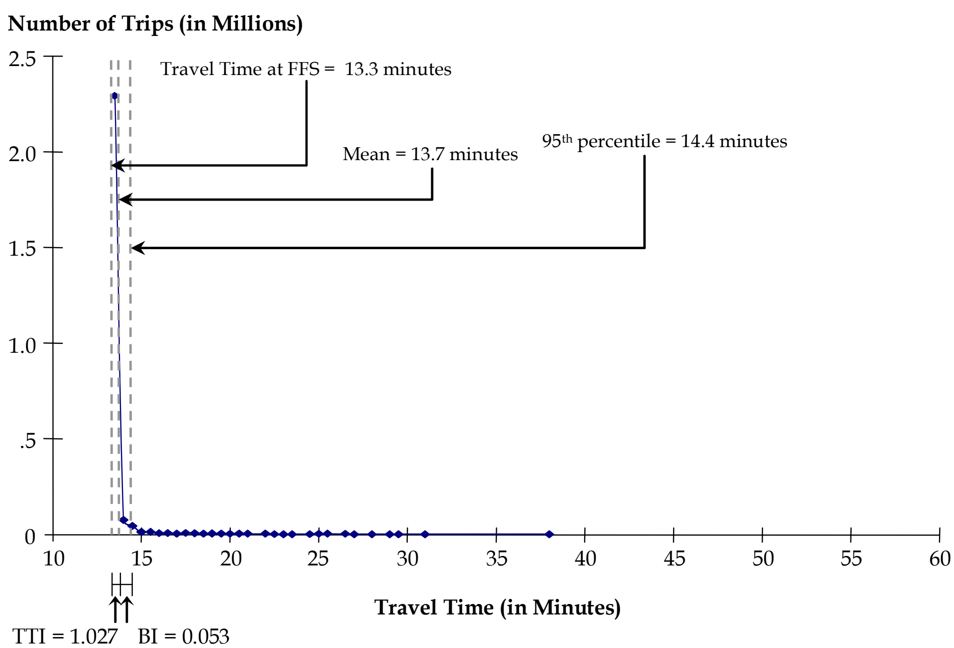
Source: Analysis of WSDOT data.

Figure 9.28 Reliability Profile: I-75 Atlanta – I-285 to North Suburbs, NB
5-7 P.M. Weekdays, 2004



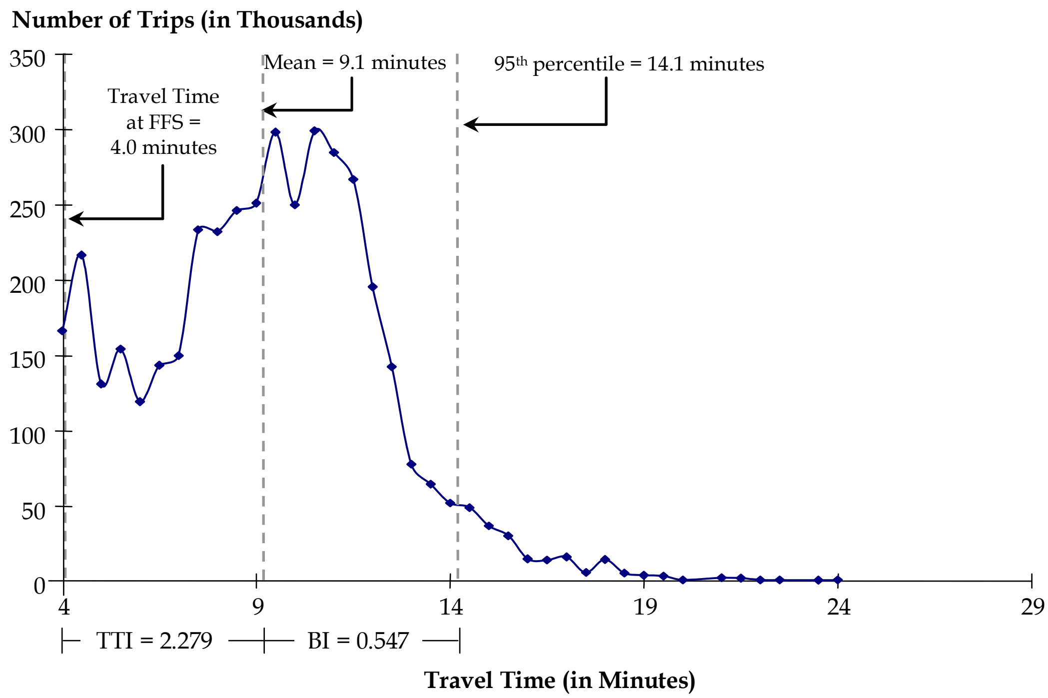
Source: Analysis of NaviGAtor data.

Figure 9.29 Reliability Profile: I-75 Atlanta – I-285 to North Suburbs, SB
5-7 P.M. Weekdays, 2004



Source: Analysis of NaviGAtor data.

Figure 9.30 Reliability Profile: I-75 Central Atlanta, SB
5-7 P.M. Weekdays, 2004



Source: Analysis of NaviGAtor data.

9.3.7 Long-Term Planning Applications

Uses and Audiences

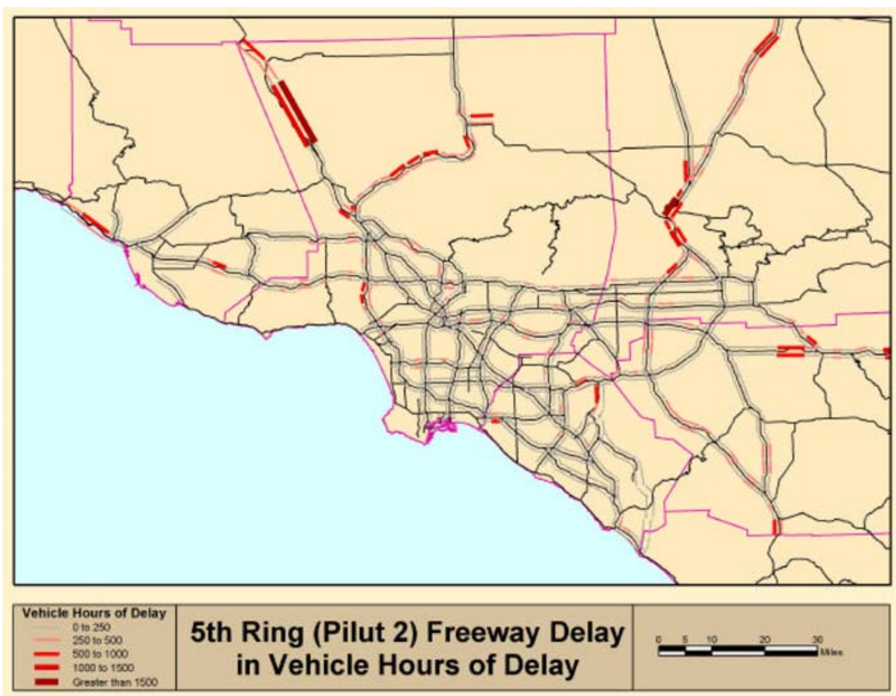
Many of the long-term planning applications are evolutions or variations on short-term planning ideas. Trends and evaluations of large-scale improvement scenarios are the most frequent applications. While all long-range metropolitan transportation plans include a financially constrained plan scenario, regions are increasingly investigating the benefits from additional expenditures. Developing mobility targets and identifying the improvement needed to achieve them use any of the same performance measures that are used in operations and short-term planning efforts.

Peer group comparisons and regional averages also have a place in long-term planning efforts. The population and employment projections used in the long-range modeling can be used to identify peer cities and explain some of the growth of congestion. Information and measures can be developed to show the effect of roadway and public transportation service growth and the role of operational strategies.

Applications and Typical Measures

Congestion maps such as in Figure 9.31 provide an easy method of illustrating the congestion on major roads. Using intuitive colors to show intensity of congestion and width to indicate magnitude of total travel delay provides a method to relate the familiar geography to the performance measures. The maps of freeway delay can be used to target funding and studies on the most significant problem areas.

Figure 9.31 Map Display of Travel Delay



Source: Southern California Association of Governments, Regional Transportation Plan, 2004. http://www.scag.ca.gov/rtp2004/2004draft/FinalPlan.htm.

Performance Measures Included: Traffic delay

Can Also be Used for: Most performance measures that can be aggregated and mapped

Measure Category: Quality of service

Audience: Leaders, technical

Applications: Short-term, long-term

Use: Monitoring, evaluation

Geographic Scale: Region, corridor

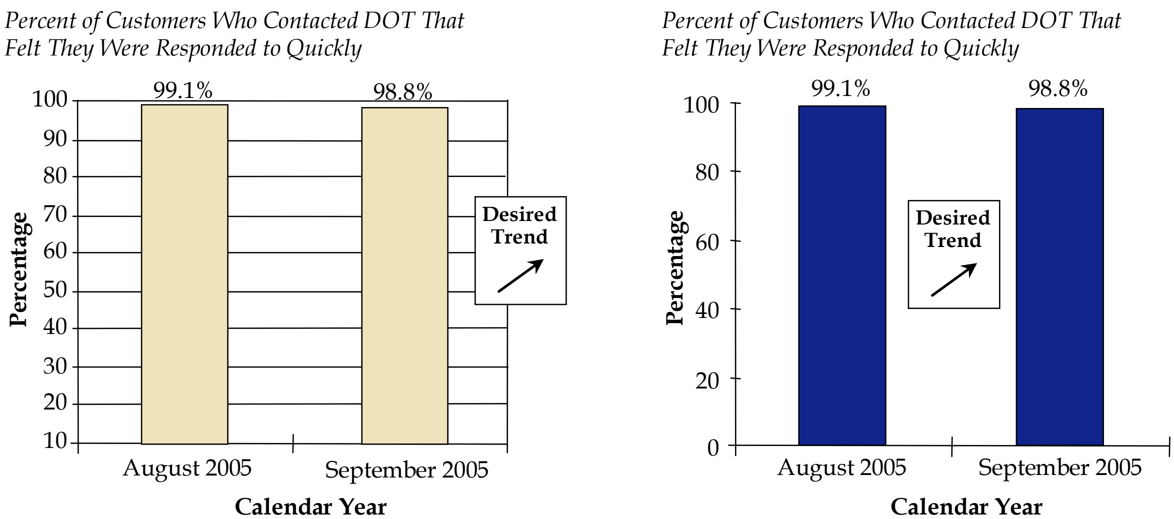
Time Scale: Annual

Strong Points: Graphic comparison of problem areas

Ways to Improve: Some comparisons are best done with some normalizing value (e.g., per mile, per person) to show intensity

Customer satisfaction measures can illustrate both short- and long-term trends in overall quality of service. Surveys of satisfaction can be tied to more objective performance measures as a way to "calibrate" the measures and data that are routinely collected about the transportation system. Figure 9.32 illustrates a typical graphic and measure. The revised version of the graph is cleaner and has the trend arrow placed in a logical part of the graph.

Figure 9.32 Customer Satisfaction Responses and Trend



Source: Texas Transportation Institute.

Performance Measures Included: Customer satisfaction.

Can Also be Used for: Most performance attributes that public finds important.

Measure Category: Quality of service.

Audience: Leaders, general, technical.

Applications: Short-term, long-term.

Use: Monitoring, evaluation.

Geographic Scale: Region, corridor.

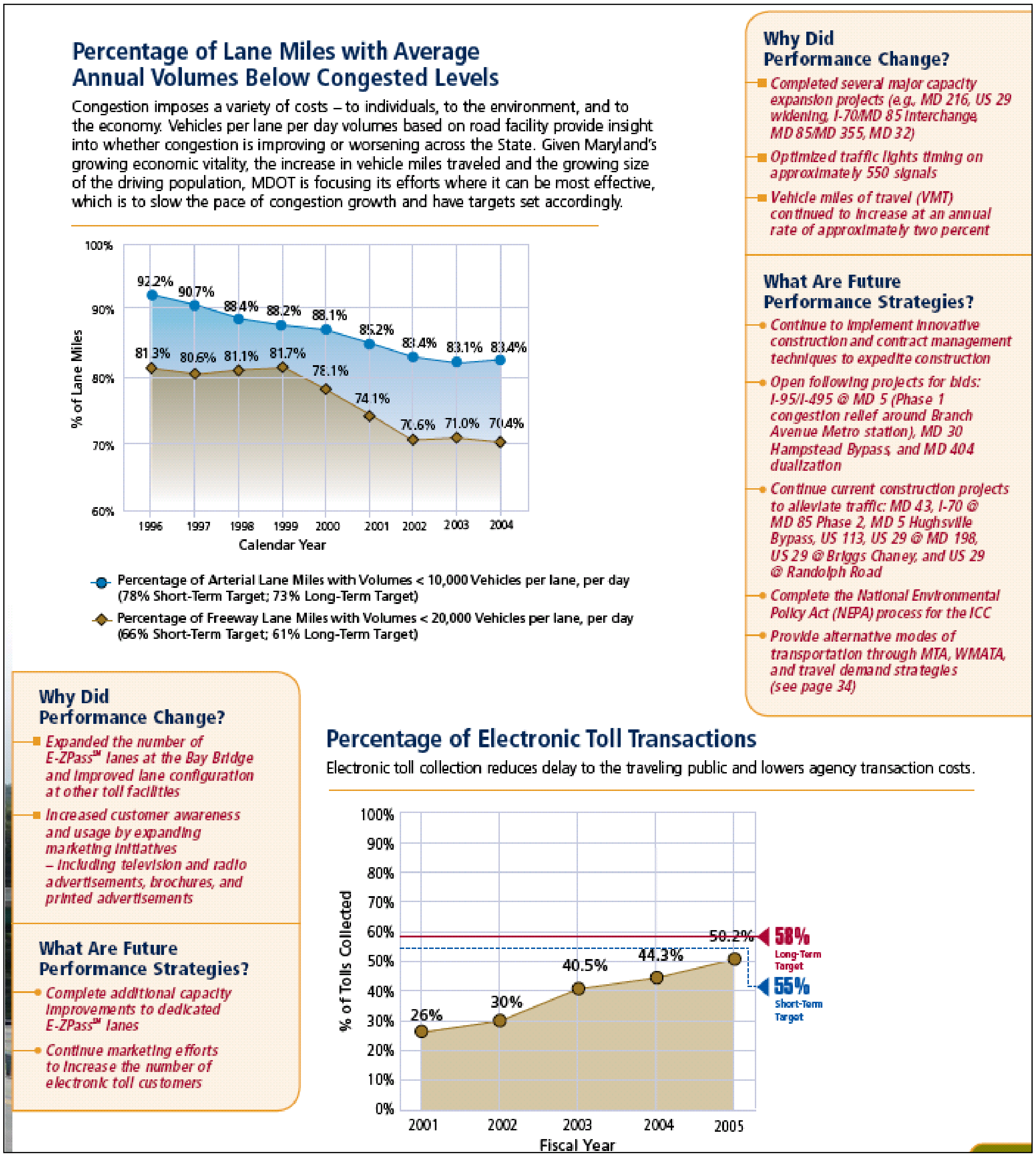
Time Scale: Monthly, annual.

Strong Points: Graphic comparison of topic trend.

Ways to Improve: Compare both recent and longer term trends.

Reporting methods are evolving but some sort of performance measure summary is being prepared in many state DOTs and metropolitan planning organizations on at least an annual basis. Maryland Department of Transportation submits an annual performance report (Attainment Report) that includes a multimodal set of performance measures as part of the annual budget submission process (Figure 9.33 illustrates one page of the report). Explanations for performance changes and future strategies to improve performance are included along with historic trends and performance targets.

Figure 9.33 Example of Annual Performance Report Elements



Source: Ehrlich, R.L. and Flanagan, R.L. *Performance Progress – Implementing the MTP & CTP.* 2005 Annual Attainment Report on Transportation System Performance. Maryland Department of Transportation. Available: http://www.e-mdot.com/Planning/Plans%20Programs%20Reports/Reports/Attainment%20Reports/2005%20MDOT%20Annual%20Attainment%20Report.pdf.

While too complicated to explain each line, there are several key elements in the general layout of the "one-page" graphic in Figure 9.34. A summary box in the upper left provides an "at-a-glance" summary of the key measures. The body of the table provides detail for each city; at a regional level, the cities could be replaced by freeway corridors or subareas. The "commentary" box provides a text summary and explanation of key trends or explanatory elements.

Figure 9.34 Example of Performance Measure Summary Report with Explanatory Factors

DRAFT

URBAN CONGESTION REPORT
October-December 2005

NATIONAL EXECUTIVE SUMMARY

UCR NATIONAL COMPOSITE INDICATORS			
YEAR	Congested Hours ↑ 2.2%	Travel Time Index ↑ 1.2%	Planning Time Index ↓ 0.2%
2005	5.663	1.366	1.829
2004	5.539	1.350	1.832

City	Congested Hours (6 Cities DOWN>5%; 8 Cities UP>5%): This Quarter	Congested Hours: (%) Change vs. Year Ago	Travel Time Index (1 Cities DOWN>5%; 3 Cities UP>5%): This Quarter	Travel Time Index: (%) Change vs. Year Ago	Planning Time Index (3 Cities DOWN>5%; 5 Cities UP>5%): This Quarter	Planning Time Index: (%) Change vs. Year Ago	% Usable Data: 94%	Contributing Factors Compared to Previous Year (Peak Period): Bad Weather	Work Zones	Incidents	VMT Served
Riverside-San Bernardino	2.3	128.9%	1.21	4.5%	1.45	7.0%	99%	-5%	N/A	N/A	3%
San Francisco, CA	3.1	49.1%	1.30	5.3%	1.62	6.0%	99%	6%	N/A	N/A	-5%
Providence, RI	3.3	10.5%	1.22	0.0%	1.65	4.7%	99%	-2%	N/A	N/A	-2%
Houston, TX	5.5	9.2%	1.42	-0.6%	2.09	-4.4%	47%	0%	N/A	11%	N/A
Orange County, CA	4.5	9.0%	1.37	5.7%	1.75	4.1%	99%	-12%	N/A	N/A	1%
Seattle,WA	8.3	8.7%	1.46	3.7%	2.07	6.1%	87%	22%	N/A	14%	-1%
San Diego, CA	4.3	7.1%	1.42	2.4%	1.92	-1.8%	99%	-6%	N/A	N/A	3%
Portland,OR	6.8	6.3%	1.35	-0.8%	1.91	0.6%	92%	16%	N/A	N/A	-7%
Philadelphia, PA	6.4	4.7%	1.30	1.2%	1.78	-2.9%	98%	1%	N/A	-14%	2%
Chicago, IL	13.3	3.8%	1.59	4.4%	2.31	5.3%	95%	8%	N/A	1%	-1%
Phoenix, AZ	4.9	1.4%	1.30	0.4%	1.66	-0.4%	100%	-4%	N/A	N/A	-4%
Los Angeles, CA	8.3	0.6%	1.49	-1.1%	2.00	-1.5%	99%	-11%	N/A	-18%	1%
Minneapolis-St. Paul, MN	5.1	-1.7%	1.41	1.5%	1.97	1.8%	100%	1%	N/A	N/A	-1%
Hampton Roads, VA	1.8	-12.8%	1.09	-5.4%	1.31	-13.3%	100%	4%	N/A	N/A	-18%
Pittsburgh, PA	5.4	-14.4%	1.22	1.0%	1.61	0.2%	97%	-1%	N/A	-20%	-1%
Detroit, TX	2.8	-17.8%	1.24	-3.2%	1.64	-11.6%	98%	0%	N/A	N/A	0%
San Antonio, TX	2.1	-24.5%	1.17	-0.9%	1.48	1.2%	99%	-6%	N/A	-1%	7%
Sacramento, CA	6.7	-27.7%	1.38	8.5%	1.72	10.5%	98%	7%	N/A	N/A	0%
Salt Lake City, UT	0.3	-83.3%	1.09	-4.6%	1.30	-15.0%	87%	10%	N/A	N/A	18%
Tampa, FL	1.9	N/A	1.19	N/A	1.53	N/A	99%	N/A	N/A	N/A	N/A

For three months ending December 2005, the three national composite congestion measures posted mixed results compared to the same period in 2004. Composite hours of congestion per day increased 2.2%, led by increases in eight cities. Of the three measures, congested hours continues to exhibit the largest month-to-month variation, particularly in smaller, less congested networks where small variations can result in large percentage changes (e.g., Hampton Roads, Portland, Providence, Riverside, San Antonio, and Salt Lake City). Also, sharp drops in hours of congestion in four California cities experiencing system-wide updates in October 2005 contributed to the national composite's decline. National composite travel time index also increased, but less sharply (1.2%). Composite planning time index fell 0.2% to 1.829 from 2004. Data quality was acceptable overall except three cities (Houston, Salt Lake City, and Seattle) which fell below our 90% usability target.

24 January 2006 — For more information, contact: (rich.taylor@fhwa.dot.gov)

Source: Urban Congestion Report, Monthly Summary. Federal Highway Administration, Office of Operatic
Prepared by Mitretek Systems, Cambridge Systematics and Texas transportation Institute, 2006.

Performance Measures Included: Congested hours, travel time index, buffer index, vehicle-miles of travel.

Can Also be Used for: Most performance measures.

Measure Category: Quality of service.

Audience: Leaders, technical.

Applications: Short-term, long-term.

Use: Monitoring.

Geographic Scale: Region, corridor.

Time Scale: Annual.

Strong Points: Includes explanatory factor information and a comment section; color to highlight changes; data quality statistics.

Ways to Improve: This is complicated!

Annual reports may have a limited effect on decision-making. If the data are not "in front" of managers or the public very often they become an element of interest rather than a call to action. Maryland DOT has strengthened the connection between performance and budget decisions by listing statewide transportation improvement plan projects in the Attainment Report along with the quality of service measures. In addition, each modal group is asked to include reasons for performance change in historic data and future strategies. These "reasons" typically refer to projects or programs.

Asset management is another emerging decision-making process that uses performance measures for long-term decisions. The Transportation Asset Management Tradeoff Model from the New York State Department of Transportation draws on economic and performance data from approximately 2,000 investment candidates, which are identified by four classes of assets – pavements, bridges, safety, and mobility. These management systems provide input into the TAM Tradeoff model for investment decisions at the program level.

The Model ranks these projects both within and among program areas using benefit/cost ratios with the common measure being "excess user cost." New York State DOT defines excess user cost as the cost to travelers (traveler and freight delay, accident costs and vehicle operating costs) that exceeds a reasonable level/threshold according to NYSDOT. These avoided excess user costs (i.e., benefits) can be calculated for investments in individual assets or facilities for entire corridors.

The General Accountability Office has found that the environment that these decisions are made, however, is not conducive to these kinds of broad investment analyses. The Federal program and many states have separations between funding programs, including some state Constitutional restrictions on the spending of certain funds.[2] Cross-modal or public/private investment decisions also are not a part of the typical operating strategies used in most state or regional programs.[3]

With greater emphasis on involving the private sector in funding and operating traditional public sector transportation systems, however, it would seem that performance measurement will play a much more important role in these cross-program and multimodal investment decisions. Decision support systems, executive information systems, and public accountability reporting efforts will draw on a wide range of data that have been prepared and used by agency operators. This mix of data and reporting will continue to blur the lines between real-time, operations, short-range, and long-term performance measures and will expand the usefulness of the information systems.

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[2] Highway and Transit Investments: Options for Improving Information on Projects' Benefits and Costs and Increasing Accountability for Results. Washington, D.C.: U.S. Government Accounting Office, Report GAO-05-172. January 24, 2005.

[3] Surface Transportation: Many Factors Affect Investment Decisions. Washington, D.C.: U.S. Government Accounting Office, Report GAO-04-744. June 30, 2004.

9.4 Freeway Performance Measurement Self-Assessment

The purpose of this section is to provide practitioners with a way of knowing how fully developed their freeway performance measures program is. No attempt is made at scoring each item, but once the scorecard is completed, a cursory glance will indicate which areas needs to have attention focused on them. Table 9.5 provides the scorecard.

Table 9.5 Freeway Performance Measurement Program Self-Assessment Scorecard

Freeway Performance Measurement Program Characteristic	Not Planned	Planned to Be Undertaken	Under Development	Fully Executed
Policy				
Are performance measures linked to an overall vision, goal, and/or objectives for managing the freeway system?				
Have performance targets for the core set of performance measures been established?				
Do agencies that have a stake in freeway performance within an area use the same performance measures?				
Are the same performance measures used across all applications, from current tracking of trends to long-range planning?				
Performance Measures (Metrics)				
What aspects of freeway performance are measured routinely?				
Congestion				
Reliability				
Safety				
Operational Efficiency				
Ride Quality				
Emissions				
Customer Satisfaction				
Are congestion measures based on travel time?				
Are both quality of service (outcome) and activity-based (output) measures been established for each performance category?				
Have multiple measures (metrics) been established for quality of service and activity-based measures within each performance category?				
Development Methods (Congestion/Mobility)				
For what percent of freeway directional miles are continuously collected travel time or speed data used to support performance measurement?				
For what percent of freeway directional miles are sampled travel time or speed data used to support performance measurement?				
For what percent of freeway directional miles are performance measures developed using models without any kind of observed travel times or speeds?				
Archived Operations Data				
What types of data from operations are available in an archive?				
Speed or Travel Time Data				
Volumes				
Lane Occupancies				

Table 9.5 Freeway Performance Measurement Program Self-Assessment Scorecard (continued)

Freeway Performance Measurement Program Characteristic	Not Planned	Planned to Be Undertaken	Under Development	Fully Executed
Archived Operations Data (continued)				
Incident Characteristics				
Incident "Timeline"				
Work Zone Characteristics				
Weather Events				
Special Events				
Ramp Queues (applicable only if ramp metering exists)				
Detector "Health"				
Camera "Health"				
VMS "Health"				
Are archived data subjected to quality control?				
Are the results of quality control available to operations personnel?				
Performance Measure Publications				
Is an annual report on freeway performance produced?				
Are weekly, monthly, or quarterly freeway performance reports produced?				
Are trends shown in performance reports?				
Are graphics and maps used to convey information in the performance reports?				
Use of Performance Measures[a]				
Short-Term Use:				
Are performance measures used to make decisions about which projects get funded in a given year?				
Are performance measures a factor in establishing program area budgets?				
Are travel time-based congestion performance measures used in alternatives analysis?				
Are travel time-based congestion performance measures used in evaluation of existing projects and policies?				
Has the use of performance measures led to changes in policy or operational procedures?				
Long-Term Use:				
Are performance measures used in alternatives analysis at the design stage?				
Are performance measures used in alternatives analysis at the preliminary engineering stage?				
Are performance measures used in alternatives analysis at the design stage?				
Are performance measures used in alternatives analysis for the long-range transportation plan?				

[a] Local agencies may decide that some of these features are not applicable to their situation.

10.0 Application Scenarios

10.1 Introduction

The purpose of this section is to demonstrate how the freeway performance measurement program specified in previous sections can be implemented by transportation agencies under different conditions. The approach taken to developing these scenarios is similar to that taken is "Concept of Operations" documents for operational strategies – hypothetical situations are established and steps outlining how operations will respond to these situations are detailed. For each one of the scenarios, it is shown how performance measures can be used for both project evaluation and ongoing monitoring. Where appropriate, both operations and planning applications are explored.

10.2 Case 1 – Medium-Sized Urban Area, New TMC Deployment

10.2.1 Situation

A metropolitan area with an urbanized area population of 400,000 has just had a new freeway TMC deployed by the State DOT. A total of 60 centerline miles of freeway lies within the urbanized area boundary, and 25 miles of the most congested mileage has had ITS technologies deployed, including:

- Roadway traffic sensors collecting volume, speed, and occupancy approximately every half-mile. The TMC software aggregates the data to five-minute increments and the data are saved but are simply written to a flat file on one of the TMC servers.
- CCTV cameras capable of viewing the entire 25 miles of core freeways.
- Service patrols that focus on the 25-mile core freeways but will venture onto other freeway segments on an as-needed basis.
- Dynamic message signs that display incident messages and estimated travel times (using the roadway traffic sensor data) to major destinations.

10.2.2 Performance Measurement Initiatives

Two events are driving the establishment of a performance measurement process in the area:

1. The State DOT has recently embarked on an agencywide performance measurement initiative whereby all major functions are responsible for reporting summary performance measures to DOT headquarters; and

2. The MPO has decided to take a more aggressive performance-based planning approach to its activities.

10.2.3 Sequence of Events

- MPO, TMC, and representatives from the central DOT planning and operations offices met to discuss how to proceed. Selection of the performance measures for the freeway was relatively easy; the Core Measures plus the "operating efficiency" measures from the Supplemental measures were selected.

- However, there was concern that data to support the measures would be a problem:

  – Traffic data was simply being "spooled off" to the server and had not been checked for data quality other than a few rudimentary checks done by the TMC software;

  – Data on events – traffic incident, weather, and work zones – was nonexistent; and

  – The MPO was concerned that the models they were using for estimating congestion on the freeway sections without surveillance would not match up with the directly measured data from the sections under surveillance.

- As a result of the meeting, two actions were taken. First, the MPO agreed to take on the task of managing the data through the development of a formal data archive. The TMC would send data directly to the MPO once per week for processing. The MPO added this activity to their Unified Planning Work Program so it could be eligible for funding. Second, the TMC agreed to make modifications to its operating software to allow the collection of event data; pull down menus were constructed for the TMC operating software and operators were instructed to enter the required data. In addition, it agreed to automate the service patrol logs.

- The MPO agreed to be in charge of the analysis of the data as one function of the central archive. A series of prototype reports were developed:

  – Monthly and quarterly reporting on congestion, incident characteristics, and incident management activities by individual corridor; and

  – Annual reporting on the full range of freeway performance measures.

- The MPO decided that it should adopt the freeway congestion performance measures for all of its planning activities, including using them on nonfreeways.

- The first six monthly reports were kept in house as analysis procedures and graphics were refined. It was decided to publicly release the second quarterly report to the public.

- At first, the TMC had deployed its service patrol assignments equally across the coverage area. However, by examining the monthly performance reports, it was determined that one five-mile segment had many more incidents occurring during peak periods than the other segments. As a result, the service patrol schedules and routes were adjusted to deploy more service patrols.

- In the annual report, the TMC also noticed that although the clearance time for incidents seemed to be similar to other TMCs around the country, they thought that incident delay still was too high. (Note: they had not adopted the “delay by source” metrics because it was felt that the analytics behind their calculation had not yet matured. Their judgment of incident delay was subjective.) By comparing the various incident component times, they determined that although the first responder response time seemed reasonable, the total response time seemed high. Further investigation revealed that there were communication breakdowns among the agencies who were involved in getting the appropriate equipment to the scene. As a result, a coordination meeting was held the problems were resolved.

- During the second year, a major reconstruction project (addition of a fourth through lane in each direction on the median side; three through lanes already existed) was to take place on the most congested 10 miles of freeways over a period of 12 months. Original deployment of traffic sensors in this corridor included both in-pavement loops and nonintrusive (roadside) radar detectors (five miles each). The TMC did not want to “go dark” during rehabilitation when in-pavement sensors would be removed, so it decided to deploy portable radar devices on the sections as they were reconstructed. This provided valuable real-time data that was used for traveler information purposes by the TMC. However, the monthly reports revealed a dramatic increase in peak-period congestion. The “Lane-Hours Lost Due to Work Zones” measure seemed to be in a reasonable range (compared to peer TMCs). Further investigation revealed that the contractors were closing one and two lanes routinely during the three-hour a.m. and p.m. peak periods. The original contract had specified that all through lanes must be kept open during the ***peak hour***. DOT construction personnel felt that the current contract could not be modified within reason, so construction practices on this project were not changed. However, this information was used to develop subsequent construction contracts in the State. The TMC also notified travelers of this situation. Finally, the TMC decided to add one of the supplemental work zone measures, “Average Work Zone Duration by Work Zone Type by Lanes Lost” to track what was occurring.

- Based on the success of using the new performance measures at the TMC, DOT headquarters decided to use them in the evaluation of project alternatives. While delay was already routinely used and estimated via simulation models, it was now noted that this was recurring (bottleneck) delay, not total delay. Also the inclusion of the Travel Time Index allowed comparisons to current conditions and to corridors and projects in other areas.

10.3 Case 2 – Medium-Sized Urban Area, No Freeway TMC, MPO Instituting a Regionwide Congestion Management System

10.3.1 Situation

A similarly sized urban area to the previous example is used for this case, but TMC deployment is several years away. However, the MPO wanted to define a more comprehensive congestion management system (CMS) than the one in existence, which was based on HCM methods using the State's and MPO's traffic counts.

10.3.2 Performance Measure Initiative

The MPO wanted to start planning for the eventual data the TMC would give them by defining a CMS that would use the same performance measures as the TMC would use for operations. It had further decided that the same set of congestion-based performance measures should be used for all its activities, including project evaluations.

10.3.3 Sequence of Events

- The MPO decided to measure travel times directly using floating cars for several representative commuter trips in the region. The trips were identified using the Census journey-to-work data: several of the highest inter-Census tract flows were identified and staff identified the routes most likely taken between them. Emphasis was given to higher-order highways in selecting the routes – in this way, staff could keep track of congestion on individual segments as well as for the entire trip. The data collection plan was developed in accordance with FHWA's *Travel Time Data Collection Handbook.*[1]

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[1] Texas Transportation Institute, *Travel Time Data Collection Handbook*, Report FHWA-PL-98-035, March 1998, http://www.fhwa.dot.gov/ohim/start.pdf.

- The performance measures, tabulated for the entire trip (from origin to destination and for selected highways segments covered by the trip, selected were:
  - Travel Time;
  - Travel Time Index; and
  - Total Delay.
- Once the CMS program got underway, the MPO turned its attention to modifying performance measures in its other applications. The first of these was the reporting on corridor and areawide performance from their travel demand forecasting (TDF) model. Although the model gave delay and V/C ratio statistics as output, it was felt that the capacities and free flow speeds used in the model were too crude to provide reliable speed and delay statistics. Also, the internal speed function, a locally developed variant of the Bureau of Public Roads function,[2] was not deemed to give reliable results under queuing (oversaturated) conditions. The MPO developed a simple program that used volumes and basic link information (for freeways and major arterials) from the TDF model output along with:
  - Improved capacity and free flow speed estimates for each link; and
  - The queuing-based delay estimation procedure from NCHRP 387.[3]
- The update to the Long-Range Transportation Plan incorporated the new performance measures, replacing level-of-service and V/C ratio which had been used in the past. The areawide Travel Time Index for current and future conditions on freeways was compared to current values for other cities to provide a sense of scale and also as an aid in developing a performance target for areawide investments. The improved delay estimates provided the ability to provide rough estimates of user costs in the Plan.
- The MPO extended its use of the congestion performance measures into other activities. While additional performance measures beyond the three mentioned above were used on individual studies, all congestion-related studies were required to report the three measures as a minimum:
  - All consultant contracts were now required to produce the three congestion performance measures, where appropriate, using procedures in the NCHRP 3-68 report.
  - All internal evaluations of completed projects as well as backup information included in the Transportation Improvement Program (TIP) now used the three measures.

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[2] An equation that relates travel time to free flow speed and V/C ratio.

[3] NCHRP Report 387, *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications,* Transportation Research Board, Washington, D.C., 1997.

Appendix A

Library of Potential Freeway Performance Measures

Performance Measure						Data Needs			
Measure	**Definition**	**Reported By (As Available)**	**Units**	**Reporting Frequency**	**Formula**	**Data Required**	**Status**	**Source**	**Use of Measure**
Outcome Measures									
Congestion									
Travel Time Index	The ratio of average travel time to a free flow travel time.	Roadway, time period, system	None	Monthly	(1)	Actual travel time Speed (from detectors)	New	SunGuide	Indicates congestion level. Reporting is required by FHWA and FDOT Central Office. Planners travel time as alternative to level of service.
						Free flow travel time Free flow speed – Actual speeds for each road segment	New	SunGuide	
						Distance	Existing	SunGuide	
Total Delay	The additional time that is incurred when actual travel times are greater than free-flow travel times.	Roadway, time period, system	Vehicle-hours	Annually	(2)	Actual travel time	New	SunGuide	Indicates congestion level. Alternate indicator to Travel Time Index. Should be calculated monthly and summed for annual reporting.
						Free flow travel time	New	SunGuide	
Percent of Congested Traffic	The ratio of congested VMT to total VMT. VMT is the sum of distances traveled by all motor vehicles in a specified highway system for a given period of time.	Roadway, time period, system	Percentage	Annually	(3)	Total VMT = Total traffic volume x the length of the road section (for the time period of interest)	Existing	SunGuide	Indicates congestion level. Alternate indicator to Travel Time Index. Should be calculated monthly and summed for annual reporting.
						Congested VMT = Traffic volume x the length of the road section that occurs below a preset threshold (for the time period of interest)	Existing	SunGuide	
Queue Length	The average length of queues within the corridor.	Roadway, time period, system	Feet	Monthly					
Throughput	Number of vehicles served through the corridor.	Roadway, time period, system	Vehicles per hour	Monthly					
Percent of Day with Average Speeds < 45 mph	Total time (minutes) that traffic travels at speeds < 45 mph (freeways) divided by 1,440 minutes per day.	Roadway	Percentage	Annually					
Percent of Day with Average Speeds < 30 mph	Total time (minutes) that traffic travels at speeds < 30 mph (freeways) divided by 1,440 minutes per day.	Roadway	Percentage	Annually					
Investment	Total investment cost compared to results.	PMT, VMT, lane-miles	Dollar	Annually					
Operations and Maintenance Costs	Total O&M cost compared to results.	PMT, VMT, lane-miles	Dollar	Annually					
Construction Cost	Total construction costs.	Roadway, type, lane-miles	Dollar	Annually					
Future Projects	Number of freeway projects identified, planned, or programmed.	Project type, status	Projects	Annually					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Travel Time Reliability									
Planning Time Index	The 95th percentile travel time index.	Roadway, time period, system	None	Annually	(4)	Travel time index	New	SunGuide	Indicates variability of roadway congestion. Alternate indicator to Buffer Index. Should be calculated monthly and summed for annual reporting.
Buffer Index	The extra time most travelers add to their average travel time when planning trips.	Roadway, time period, system	Percentage	Monthly	(5)	Actual travel time: • Volume; • Speed; • Free flow speed; and • Distance.	New	SunGuide	Indicates variability of roadway congestion. In urban areas travel time reliability provides a customer experience indication of freeway performance. Reporting is required by FHWA and FDOT Central Office.
Accuracy of Congestion (Travel Time) Information	Difference between predicted travel time information presented to public and the actual travel time experienced.	Roadway, time period, system, evacuation	Minutes, Percentage	Annually	(6) Under development	Actual travel time: • Volume; • Speed; • Free flow speed; and • Distance. Predicted travel time	New New	TMC Operators TMC Operators	Indicates validity of the travel time algorithm and accuracy of system detectors. Should be calculated monthly and summed for annual reporting.
On-Time Performance	Percentage of on-time performance.	Roadway, time period, system	Percentage	Annually					
Incident Duration									
Incident Prediction	Incident vulnerability index.	Roadway	None	Annually					
Total Incident Duration	Difference in time from when first agency is notified until all evidence of the incident is removed.	Roadway, a.m./p.m. peak, and off-peak time period, incident severity, incident type	Minutes	Weekly	(7)	Time of incident occurrence Time of return to normal traffic flow (if not possible, time when Road Ranger leaves site)	Existing Existing	SMART SMART	Indicates the total time of incident impact. Measures overall efficiency of TIM activities by partnering agencies.
TMC Detection Time Period	The difference between when the TMC is notified and when any agency is notified.	Roadway, a.m./p.m. peak, and off-peak time periods	Minutes	Weekly	(8)	Time of incident occurrence Time of initial notification	Existing Existing	SMART SMART	Measures the time it takes other agencies to notify the TMC. Value is zero when TMC detects the incident. A measure of agency coordination.
TMC Verification Time Period	The difference between the initial TMC notification time and when the incident is verified.	Roadway, a.m./p.m. peak, and off-peak time periods	Minutes	Weekly	(9)	Time of initial notification Time of verification	Existing Existing	SMART SMART	Measures camera coverage and Road Ranger coverage, which are the primary factors in reducing verification time.
TMC Response Time Period	The difference between the initial TMC notification time and the time Road Rangers/SIRV arrive.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Weekly	(10)	Track Road Rangers and SIRV separately: Time of initial notification Time of Road Ranger (RR) arrival	Existing Existing	SMART SMART	Measures time for Road Rangers/SIRV to arrive on the incident scene. Provides an indication of Road Ranger routes and coverage areas.
Road Ranger Dispatch Time Period	The difference between initial TMC notification and when a Road Ranger is contacted for dispatch to an incident.	Roadway, a.m./p.m. peak, and off-peak time periods	Minutes	Weekly	(11)	Time of initial notification Time of Road Ranger (RR) dispatch	Existing	SMART	Component of TMC response time.
Road Ranger Response Time Period	The difference between when a Road is dispatched and when that Road Ranger arrives at the incident scene.	Roadway, a.m./p.m. peak, and off-peak time periods	Minutes	Weekly	(12)	Time of dispatch Time of Road Ranger (RR) arrival	Existing	SMART	Component of TMC response time.

Performance Measure						Data Needs			
Measure	**Definition**	**Reported By (As Available)**	**Units**	**Reporting Frequency**	**Formula**	**Data Required**	**Status**	**Source**	**Use of Measure**
Incident Clearance Time Period	The difference between the time Road Rangers/SIRV arrives and the lanes are cleared.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity, lane	Minutes	Weekly	(13)	Track Road Rangers and SIRV separately Time of Road Ranger (RR) arrival	Existing	SMART	A measure of interagency coordination since vehicle removal is primarily the responsibility of other agencies. Measures adherence to "Open Roads Policy."
						Time that the lanes are cleared	Existing	SMART	
Incident Delay	Total delay per lane-mile.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Vehicle-Hours	Annually	(14)	Incident duration Volumes Speeds	Under Development	SMART	Provides a quantitative measure of the congestion impacts of an incident.
						Queue length	Needed	SMART	
						Number of blocked lanes	Existing	SMART	
Number of Secondary Incidents	The number of events that occur due to the congestion from the primary event (designated as secondary incident by TMC).	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Incidents	Annually	(15)	Number of secondary crashes	New	SMART	Provides an indication of reduced crashes, an important public benefit of Incident management.
Verification Time in Areas without CCTV Coverage	Verification time in areas without CCTV coverage.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per week					
Dispatch Time	Dispatch time.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per week					
Interval Response Time Times as Blocked Lanes Are Opened during Incident	Interval response time times as blocked lanes are opened during incident.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per week					
Return to Normal Traffic Flow Time	Return to normal traffic flow time.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per week					
Automated Response Implementation Time	Automated response implementation time.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per week					
Tow Truck Response Time	Tow truck response time.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per week					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Customer Satisfaction									
Satisfaction with ITS Program	Percentage of respondents satisfied with overall ITS program.	Annual survey	Percentage	Annually	Percentage responses from survey	Random public survey results	New	Central Office/ District 4 Annual survey	Provides a qualitative measure of public satisfaction of the ITS program.
Satisfaction with DMS	Percentage of respondents satisfied with DMS usage and performance.	Annual survey	Percentage	Annually	Percentage responses from survey	Random public survey results	New	Central Office/ District 4 Annual survey	Provides a qualitative measure of public satisfaction of the ITS program.
Satisfaction with Traveler Information SMART SunGuide and ITMS Web Site	Percentage of respondents satisfied with the traveler information web site.	Annual survey	Percentage	Annually	Percentage responses from survey	Random public survey results	New	Central Office/ District 4 Annual survey	Provides a qualitative measure of public satisfaction of the ITS program.
Satisfaction with Road Rangers	Percentage of respondents satisfied with Road Rangers service.	Annual survey	Percentage	Annually	Percentage responses from survey	Random public survey results	New	Central Office/ District 4 Annual survey	Provides a qualitative measure of public satisfaction of the ITS program.
Satisfaction with Work Zone Program	Percentage of respondents satisfied with WZ program.	Annual survey	Percentage	Annually					
Satisfaction with Road Weather Management Program	Percentage of respondents satisfied with the road weather management program.	Annual survey	Percentage	Annually					
Satisfaction with Overall Commute	Percentage of respondents satisfied with their overall commute and noncommute times.	Annual survey	Percentage	Annually					
Congestion Tolerance	Surveys commuter perception on congestion.	Roadway, time period, system	Rating	Annually					
Satisfaction with Project Delivery	Percentage of respondents satisfied with their perception of project timeliness and quality.	Annual survey	Percentage	Annually					
Ease of Database Accessibility	Percentage of partnering agencies satisfied with database accessibility.	User feedback/survey	Percentage	Annually	Percentage responses from survey	User survey results	New	District 4 Annual survey	Provides a qualitative measure of system usability and indicates any user problems with the database and its accessibility.
Individuals Receiving Traveler Information	Number of individuals receiving traveler information.	Source type	Persons	Annually					
Individuals Acting on Traveler Information	Number of times route, time, mode, or destination change after receiving traveler information.	Source type, information type	Event	Annually					
Benefit/Cost Measures									
ITS Program Benefit/Cost Ratio	Total ITS program benefits divided by total program cost.	Program	Ratio	Annually	Benefits/Cost	Estimates of ITS benefits, including travelers' time saved, freight time saved, crashes reduced, and secondary crashes reduced. Total District ITS programs costs	New	FDOT District 4	Provides an overall indication of the effectiveness of the District's ITS program.

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Output Measures									
System Coverage									
ITS Miles Managed	Number of centerline miles covered/managed by ITS equipment in the network, (as defined in the 2004 Statewide ITS Performance Measures report).	Roadway	Miles	Annually	(16)	ITS roadway coverage	Existing	FDOT District 4	Measures ITS geographical coverage. Required by FDOT Central Office.
Percent Centerline Miles Managed	Percent of centerline miles covered/managed by ITS equipment in the network.	Roadway type	Percentage	Annually	(17)	ITS roadway coverage	Existing	FDOT District 4	Indicates the portion of the roadway system covered by ITS.
Number of ITS Devices	Number of ITS devices.	Type, roadway	Devices	Annually	(18)	Number of ITS devices	Existing	FDOT District 4	Indicates total number of ITS devices.
Traffic Flow									
Average Volume	The average number of vehicles.	Roadway, a.m./p.m./off-peak periods/weekend/nighttime, daily total.	Vehicles	Annually	(19)	Traffic count (detectors)	New	SunGuide	Traffic volumes are used by FDOT Planning.
Average Occupancy	The average percentage of time, during the sample period, that the detector sensed a vehicle.	Roadway, time period	Percentage	Annually	(20)	Traffic occupancy (detectors)	New	SunGuide	Vehicle occupancy measures traffic density. Occupancy is used in some traffic algorithms.
Average Travel Time	The average time to traverse a given highway segment.	Roadway, time period	Minutes	Monthly	(21)	Actual travel time	New	SunGuide	Travel time is the basic measure of congestion and reliability.
Average Density	The average number of vehicles that occupy one mile of road space.	Roadway, time period	Vehicles-Miles (all lanes in a direction)	Annually	(22)	Traffic flow (vph) – Hourly equivalent of count volumes: count, speed, distance	New	SunGuide	Density is used in some traffic algorithms. An alternate to occupancy measure.
Total volumes	Freeway total volume from all lanes.	Roadway, a.m./p.m./off-peak	Vehicles	Weekly					
AADT	Average annual daily traffic.	Roadway, a.m./p.m./off-peak	Vehicles	Weekly					
Volume/Capacity Ratio	Ratio between corridor's volume and capacity.	Roadway, a.m./p.m./off-peak	None	Weekly					
Percent Trucks	Percent trucks in a given corridor.	Roadway, a.m./p.m./off-peak	Percentage	Weekly					
Bottlenecks	Number of bottlenecks in system.	Roadway, a.m./p.m./off-peak	Bottlenecks	Annually					
Flow Management	Percent of lane-miles that are managed.	Roadway, a.m./p.m./off-peak	Percentage	Annually					
Bus Shoulders	Miles of shoulders built or rebuilt annually.	Roadway, a.m./p.m./off-peak	Miles	Annually					
Usage of Bus Shoulders	Miles of bus lane utilizing hardened shoulders.	Roadway, a.m./p.m./off-peak	Miles	Annually					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Incident Management									
Total Number of Incidents	Number of incidents managed.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity, incident type, vehicle type, pavement type, or day of week	Incidents	Weekly	(23)	Incident type	Existing	SMART	Indicates level of TMC activity, used in managing resource needs and benefit calculations.
						Incident severity	Existing	SMART	
TMC Incident Detection Method	System by which the TMC was notified.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	None	Weekly	(24)	Incident detection Incident type Incident severity	Existing	SMART	Provides indication of the portion of incidents detected by TMC or Road Rangers.
Incident Level	Severity of lane blockage incidents.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity, lane blockage duration	None	Monthly	(25)	Incident detection Incident type Incident severity	Existing	SMART	Tracking incident severity provides stratification of incidents for incident duration calculations.
Incident Delay Reduction	Estimated reduction in delay due to incident management.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Hours	Annually					
Incident Fuel Consumption	Estimated reduction in fuel consumption due to incident management.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Gallons	Annually					
Incident Emissions Reduction	Estimated reduction in emissions (HC, CO, and NO) due to incident management.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Tons	Annually					
Incident Management System Coverage	Percentage of freeway system instrumented with cameras and sensors.	County, roadway, direction	Percentage	Annually					
Incident Management Dollars Spent Per Incident Response	Incident management program annual cost divided by annual number of incident responses.	Program	Cost	Annually	(26)	Incident detection Incident type Incident severity	Existing	SMART	Provides an indication of the cost-effectiveness of the incident management program.
						Cost of incident management program	Existing	FDOT District 4	
Total Number of Requests for Road Ranger/SIRV Response	Number of requests for Road Ranger response.	Roadway, time period, incident type, county, truck, beat, zone, source	Calls	Monthly	(27)	Track Road Rangers and SIRV separately: Call type	Existing	SMART	Indicates level of Road Ranger/SIRV activity. Difference between requests and responses indicates gaps in Road Ranger coverage.
Total Number of Road Ranger/SIRV Responses	Number of Road Ranger responses logged.	Roadway, time period, incident type, county, truck, beat, zone, source	Responses	Monthly	(28)	Track Road Rangers and SIRV separately: Response type	Existing	SMART	Indicates level of Road Ranger/SIRV activity. It will assist in Road Ranger resource allocation.
Total Number of Road Ranger/SIRV Events	Number of Road Ranger events logged.	Roadway, time period, incident type, county, truck, beat, zone, source	Events	Monthly	(29)	Track Road Rangers and SIRV separately: Event type	Existing	SMART	Indicates level of Road Ranger activity and service performed. It will assist in Road Ranger resource allocation.

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Total Number of Road Ranger/SIRV Activities	Number of Road Ranger activities logged.	Roadway, time period, incident type, county, truck, beat, zone, source	Activities	Monthly	(30)	Track Road Rangers and SIRV separately: Activity type	Existing	SMART	Indicates the type of service performed. It will assist in Road Ranger resource allocation.
Average Road Ranger/ SIRV Assisting Time	Average length of a Road Ranger assist.	Roadway, time period, incident type, county, truck, beat, zone, source	Minutes	Monthly	(31)	Track Road Rangers and SIRV separately: Road Ranger activity log Emergency management timeline	Existing	SMART	Indicates the service time of Road Rangers. It will assist in Road Ranger resource allocation.
Average Road Ranger/ SIRV In-Service Time	Average length of Road Ranger service – time the Road Ranger is available to provide assists or be dispatched.	Roadway, time period, incident type, county, truck, beat, zone, source	Minutes	Monthly	Total time Road Rangers are in service/number of RR vehicles	Track Road Rangers and SIRV separately: Road Ranger activity log	Existing	SMART	Indicates the service time of Road Rangers. It will assist in Road Ranger resource allocation.
Average Road Ranger Billable Time	Average length of Road Ranger billable time.	County, truck, beat, zone	Hours	Monthly	Total Road Ranger billable time/ number of RR vehicles	Road Ranger activity log	Existing	SMART	Indicates the service time of Road Rangers. It will assist in Road Ranger resource allocation.
Number of Outgoing TMC Calls	Number of outgoing TMC calls.	Type	Calls	Monthly	(32)	Number of calls	Existing	TMC Operators	Measures number of times other agencies are contacted by the TMC.
Number of Incoming TMC Calls	Number of incoming TMC calls.	Type	Calls	Monthly	(33)	Number of calls	Existing	TMC Operators	Indicates number of times other agencies contact the TMC.
Detection Method by Type	Percent of incidents detected by type.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Percentage	Per week					
Reliability of PDS Detectors	Ratio of positive detections to false detections.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	None	Per month					
Number of Towing Dispatches	Number of towing dispatches.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Dispatches	Per week					
Freeway Service Patrol									
Number of FPS Assists	Number of FPS assists.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Assists	Per week					
FPS Assistance Duration	FPS assistance duration.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per month					
FPS Response Time	FPS response time.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Minutes	Per month					

Performance Measure						Data Needs			
Measure	**Definition**	**Reported By (As Available)**	**Units**	**Reporting Frequency**	**Formula**	**Data Required**	**Status**	**Source**	**Use of Measure**
Number of Incidents Cleared by FSP without Other Agency Assistance	Number of incidents cleared by FSP without other agency assistance.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity, VMT	Incidents	Per month					
Number of Potential Incidents Not Confirmed	Number of potential incidents not confirmed.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Incidents	Per month					
Tasks Accomplished by Automated Process Versus Manual Process	Ratio of automated tasks to manual tasks.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	None	Per year					
Utilization of Cameras for Security Surveillance by External Agencies	Percent of time CCTV is used for security surveillance.	County, Agency type	Percentage	Per year					
Utilization of Cameras for Incident Management by External Agencies	Percent of time CCTV is used for incident management.	County, Agency type	Percentage	Per year					
Effectiveness of TIME Program	Effectiveness of the program.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Rating	Per year					
Number of Assists without Dispatch	Number of assists without dispatch.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Assists	Per month					
Number of Times FSP Is First Responder	Number of times FSP is first responder.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Assists	Per month					
Number of Incidents FSP Are Unable to Respond	Number of incidents FSP are unable to respond.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Incidents	Per month					
Number of Incidents with FSP Route Call-Off	Number of incidents with FSP route call-off.	Roadway, a.m./p.m. peak, and off-peak time periods, incident severity	Incidents	Per month					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
System Performance									
ITS Field Equipment and Communications Equipment									
Operational Field Equipment Percentage	Percent time equipment is operational, in "good" or better conditions.	Device type, roadway	Percentage	Monthly	(34)	Equipment uptime Time of equipment failure	Existing	TMC Operators	Indicates ITS field equipment and systems reliability and efficiency of the ITS maintenance program.
						Time of equipment replacement/ repair/resolution	Existing	TMC Operators	
Mean Time to Repair	Average downtime per preventative or emergency repair/failure.	Device	Hours	Annually	(35)	Equipment downtime Time of equipment failure Time of equipment replacement/ repair/resolution	Existing	SMART	Indicates time needed to detect and repair equipment. Measures efficiency of maintenance program.
Mean Time Between Failures	Average time between equipment failure.	Device	Days	Annually	(36)	Time of equipment failure Time of equipment replacement/ repair/resolution	Existing	SMART	Indicates how often a piece of equipment fails. Provides information on equipment quality and the manufacturer's warranty.
Cost per Equipment Repair/ Failure	Cost of repair and impacts on a system due to an equipment failure.	Device	Cost	Annually	(37)	Cost of repair	Existing	FDOT District 4	Indicates cost of maintaining a piece of equipment. Provides information on equipment quality and the manufacturer's warranty.
Number of Centerline Miles Instrumented	Number of centerline miles instrumented.	Roadway, a.m./p.m./ off-peak periods	Lane-miles	Annually					
Number of Devices in Failure by Type	Number of devices in failure by type.	Roadway, a.m./p.m./ off-peak periods	Device	Weekly					
Number of Routine Maintenance Jobs	Number of routine maintenance jobs.	Roadway, a.m./p.m./ off-peak periods	Tasks	Weekly					
Number of Nonroutine Jobs	Number of nonroutine jobs.	Roadway, a.m./p.m./ off-peak periods	Tasks	Weekly					
Number of Lanes Restricted Due to Routine Maintenance	Number of lanes restricted due to routine maintenance.	Roadway, a.m./p.m./ off-peak periods	Lanes	Weekly					
Number of Lanes Restricted Due to Nonroutine Maintenance	Number of lanes restricted due to nonroutine maintenance.	Roadway, a.m./p.m./ off-peak periods	Lanes	Weekly					
Number of Hours Lanes Restricted Due to Routine Maintenance	Number of hours lanes are restricted due to routine maintenance.	Roadway, a.m./p.m./ off-peak periods	Hours	Weekly					
Number of Hours Lanes Restricted Due to Nonroutine Maintenance	Number of hours lanes are restricted due to nonroutine maintenance.	Roadway, a.m./p.m./ off-peak periods	Hours	Weekly					
Device Down Time	Device down time.	Device	Hours	Weekly					
Device Exceeding Expected Use	Number of devices exceeding expected design life.	Type	Device	Annually					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
TMC Software and Hardware									
Device/Module Uptime Percentage	Percentage of time a TMC device or software module is operational.	Software module, server, switch, firewall, and video wall controller	Percentage	Monthly	(38)	TMC hardware device uptime: Time of module failure, time of module replacement/repair/resolution	Existing	TMC IT	Indicates TMC equipment and systems reliability and efficiency of the TMC maintenance program.
Calls Sent to IT Helpdesk	Number of requests sent the District IT Helpdesk.	Category	Calls	Monthly	(39)	Calls	Existing	TMC IT	Indicates the total number of requests for IT assistance. Used to manage IT resource needs.
Helpdesk Calls Outstanding	Number of unresolved Helpdesk request at the end of the reporting period.	Category	Calls	Monthly	(40)	Call unresolved	Existing	TMC IT	Indicates calls that still need to be resolved. Used to manage IT resource needs.
Helpdesk Calls Closed	Number of Helpdesk requests that were completed.	Category	Calls	Monthly	(41)	Calls resolved	Existing	TMC IT	Indicates progress in completing requests for IT assistance.
Helpdesk Call Close Time	Time period from when a call was received by the Helpdesk until it was closed.	Category	Days	Monthly	(42)	Call resolve time	Existing	TMC IT	Indicates time needed to complete a request for IT assistance. Used to manage IT resource needs.
TMC On-Line Time	Time required to bring TMC systems on-line.	Type	Hours	Monthly					
Number of Devices in System by Type	Number of devices in system by type.	Type	Devices	Weekly					
Number of Devices Operating	Number of devices operating.	Type	Devices	Weekly					
System Software Module Failures	System software module failures.	Type, Module	Failure	Weekly					
System Hardware Failures	System hardware failures.	Type	Failure	Weekly					
Subsystem Software Module Failures	Subsystem software module failures.	Type, Module	Failure	Weekly					
Subsystem Hardware Failures	Subsystem hardware failures.	Type	Failure	Weekly					
Freeway Service Patrol Dispatch and Management									
Operator Man-Hours	Operator man-hours.	Division, Staff	Man-hours	Weekly					
FSP Dispatch Man-Hours	FSP dispatch man-hours.	Division, Staff	Man-hours	Weekly					
FSP Operator Man-Hours	FSP operator man-hours.	Division, Staff	Man-hours	Weekly					
CSR Man-Hours	CSR man-hours.	Division, Staff	Man-hours	Weekly					
Maintenance Technician Man-Hours	Maintenance technician man-hours.	Division, Staff	Man-hours	Weekly					
Employee Turnover	Percentage of employees leaving.	Division, Staff	Percentage	Annually					
Vehicles in Operation per Shift	Vehicles in operation per shift.	Division, Shift	Vehicles per shift	Monthly					
VMT by Vehicle	VMT by vehicle.	Division, Shift	Vehicle-miles	Monthly					
VHT per Vehicle	VHT per vehicle.	Division, Shift	Vehicle-hours	Monthly					
Vehicle Fluids Used	Vehicle fluids used.	Vehicle	Gallons	Monthly					
Vehicle Maintenance Required	Vehicle maintenance required.	Vehicle	Event	Monthly					
Supplies Used	Supplies used.	Vehicle	Item	Monthly					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Work Zone Management									
Average Volume	The average number of vehicles.	Roadway, a.m./p.m./ off-peak periods/ weekend/nighttime, daily	Vehicles	Annually					
Maximum Hourly Volume	The maximum hourly volume through the work zone.	Roadway, a.m./p.m./ off-peak periods/ weekend/nighttime, daily	Vehicles	Annually					
Capacity Loss	The difference between maximum hourly volumes before and after the work zone project.	Roadway, a.m./p.m./ off-peak periods/ weekend/nighttime, daily, lane-miles	Vehicles	Annually					
Percent VMT through WZ	Percentage of VMT through the work zone compared to total VMT for region.	Roadway, WZ type, vehicle type, a.m./p.m./ off-peak periods	Percentage	Annually					
VMT through WZ	The vehicle miles of travel through the work zone.	Roadway, WZ type, vehicle type, a.m./p.m./ off-peak periods	VMT	Annually					
VHT through WZ	The vehicle hours of travel through the work zone.	Roadway, WZ type, vehicle type, a.m./p.m./ off-peak periods	VHT	Annually					
Queue Length through WZ	The queue length due to the work zone.	Roadway, WZ type, vehicle type, a.m./p.m./ off-peak periods	Feet	Annually					
Number of Work Zones Planned	Number of work zones planned.	County, Roadway, Type, a.m./p.m./off-peak periods	Work zones	Monthly					
Number of Work Zones	Number of work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Work zones	Monthly					
Lane-Miles of Work Zones	Lane-miles of work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Lane-miles	Monthly					
Duration of Work Zone	Average duration of work zone activity.	County, Roadway, Type, a.m./p.m./off-peak periods	Days	Monthly					
Time between Work Zone Activities	Average time between work zone activities.	County, Roadway, WZ Type, activity	Days	Monthly					
Hours of Work Zone Activity	Hours of WZ activity by number of lanes lost.	Number of lanes lost	Hours	Monthly					
Reliability of Work Zone Reports	Reliability of work zone reports.	County, Roadway, Type, a.m./p.m./off-peak periods	None	Monthly					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Incidents Reported in Work Zones	Incidents reported in work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Incidents	Monthly					
WZ versus Preconstruction Crash Ratio	Ratio between crash rates in work zones versus preconstruction crash rates.	County, Roadway, Type, a.m./p.m./off-peak periods	None	Annually					
Number of DOT/Contractors Injuries in Work Zones	Number of DOT/contractors injuries in work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Injuries	Monthly					
Enforcement Personnel Presence	Percent of time active work zones have enforcement personnel present.	County, Roadway, Type, a.m./p.m./off-peak periods	Persons	Monthly					
Traffic Citations Given in Work Zones	Number of traffic citations given in work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Citations	Monthly					
Lanes Closures Due to Work Zones	Lanes closures due to work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Closures	Monthly					
Lane-Miles Lost Due to Work Zones	Lane-miles lost due to work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Lane-miles	Monthly					
Shoulder Miles Lost Due to Work Zones	Shoulder miles lost due to work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Shoulder-miles	Monthly					
Congestion Due to Work Zones	Percent change in delay caused by work zones.	County, Roadway, Type, a.m./p.m./off-peak periods	Percentage	Monthly					
Road Closure Announcements	Percent of road closures announced within 1 hour of closing.	County, Roadway, Type, a.m./p.m./off-peak periods	Percentage	Monthly					
Lane Changes per Work Zone	Average number of times the number of through lanes changes per work zone.	County, Roadway, Type, a.m./p.m./off-peak periods	Lane changes	Annually					
Time between Lane Change and Dissemination	Average length of time between changes in the number of through lanes and communication to public.	County, Roadway, WZ Type, a.m./p.m./off-peak periods, dissemination type	Hours	Annually					
Inactive/Active Days Ratio	Ratio of inactive days to active days.	County, Roadway, Type, a.m./p.m./off-peak periods	None	Annually					
Number of Traffic Control Plans per Work Zone	Number of traffic control plans per work zone.	County, Roadway, Type, a.m./p.m./off-peak periods	Plans	Annually					
Night Activity to Daylight Activity Ratio	Night activity to daylight activity ratio.	County, Roadway, Type, a.m./p.m./off-peak periods	None	Annually					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Traffic Control Plan Changes	Average number of times traffic control plans change per work zone.	County, Roadway, Type, a.m./p.m./off-peak periods	Changes	Annually					
Percent of Work Zones That Are Formally Evaluated for Mobility and Safety Impacts	Evaluated after implementation, not part of Transportation Management Plans.	County, Roadway, Type, a.m./p.m./off-peak periods	Percentage	Annually					
Percent of Work Zone Employees and Managers Who Have Completed Work Zone Safety Training	Separate for all employees and managers; separate for state personnel and contractors.	County, Division	Percentage	Annually					
On-Time Performance Ratio by Type of Incentive	On-time performance ratio by type of incentive.	County, Roadway, Type, a.m./p.m./off-peak periods	Percentage	Annually					
Average Number of On-Site Workers per Day by Work Zone Type	Average number of on-site workers per day by work zone type.	County, Roadway, Type, a.m./p.m./off-peak periods	Workers	Annually					
Average Number of Days between Contract Award and Start of Work	Average number of days between contract award and start of work.	County, Roadway, Type, a.m./p.m./off-peak periods	Days	Annually					
Average Cost by Work Zone Type	Average cost by work zone type.	Roadway, WZ Type, Activity	Dollar	Annually					
Lane-Miles Paved per Work Zone Duration	Lane-miles paved per work zone duration.	County, Roadway, Type, a.m./p.m./off-peak periods	Lane-miles	Annually					
Percent of Projects Finished Early by Type of Incentive	Percentage of projects finished early by type of incentive.	County, Roadway, Type, a.m./p.m./off-peak periods	Percentage	Annually					
Road Weather Management									
Number of Weather Stations Deployed	Number of weather stations deployed.	County, Roadway, Type	Stations	Annually					
Number of Responses Due to Weather Detection	Number of responses due to weather detection.	County, Roadway, Type	Responses	Monthly					
Lane-Miles Affected	Lane-miles affected by severe weather conditions (rain, snow, ice, winds, fog, dust, or smoke).	County, Roadway, Type	Lane-miles	Monthly					
Lane-Miles Treated	Lane-miles treated due to severe weather conditions (pre-treatment, post-treatment, or plowing).	County, Roadway, Type	Lane-miles	Monthly					
Road Closure Announcements	Percent of road closures announced within 1 hour of closing.	County, Roadway, Type	Percentage	Monthly					
Weather Events Measure	Hours of rainfall, snow, or fog conditions.	County, Roadway, Type	Hours	Monthly					
Hours between Start of Frozen Precipitation and Deicing/Plowing	Hours between start of frozen precipitation and deicing/plowing.	County, Roadway, Type	Hours	Monthly					

Performance Measure						Data Needs			
Measure	**Definition**	**Reported By (As Available)**	**Units**	**Reporting Frequency**	**Formula**	**Data Required**	**Status**	**Source**	**Use of Measure**
Traveler Information									
Web Site Operations									
Number of TMC Web Site Visits	Number of web site visits.	Time period, event	Hits	Monthly	(43)	Web site hits	Existing	TMC IT	Indicates how often the web site is used by the public. Also, indicates effective-ness of ITS marketing program.
TMC Web Pages Visited	Web page hits.	Page	Hits	Monthly	(43)	Web site hits	Existing	TMC IT	Indicates which pages are viewed most. Unused pages may be deleted or combined.
Referring Web Sites	Referring web sites.	Site	Sites	Monthly	(44)	Referring web pages	Existing	TMC IT	Indicates where users found reference to FDOT web site.
TMC Web Site Visit Data	Average web site visit data transmitted.	Site	Bytes of data	Monthly	(45)	Data transmitted per visit	Existing	TMC IT	Indicates how visitors use the web site and provides indications of bandwidth needs.
Session Duration	Average visit duration.	Site	Minutes	Weekly					
Referring Web Sites	Originating web site prior to visit.	Site	Sites	Monthly					
Page Load Time	Amount of time needed to load web page.	Page	Seconds	Monthly					
Top 5 Pages Visited	Top 5 web pages visited.	Site	Page	Weekly					
Top 10 Cameras Viewed	Top 10 cameras viewed, if available.	Site	Page	Weekly					
Top 10 DMS Viewed	Top 10 DMS viewed, if available.	Site	Page	Weekly					
Dynamic Message Signs									
Number of DMS Systems	Number of DMS systems deployed.	County, Roadway, Type	Units	Annually					
Lane-miles of DMS Coverage	Lane-miles of DMS coverage.	County, Roadway, Type	Lane-miles	Annually					
Percent DMS Operational	Percent of DMS that are fully operational.	Device type	Percentage	Monthly					
Hours of DMS Operations	Total number of DMS operational hours.	Roadway, a.m./p.m./ off-peak periods, device type	Hours	Monthly					
Number of DMS Messages	Number of DMS messages.	a.m./p.m. peak and off-peak time period, type, event	Messages	Monthly	(46)	Message type	Existing	SMART	Indicates how often DMS are used.
DMS Message Duration	Average length of time a message is displayed.	a.m./p.m. peak and off-peak time period, type, event	Messages	Monthly	(47)	Message duration	Existing	SMART	Indicates how long DMS are used.
Diversions Due to DMS Messages	Average increase in detector (ramp) volumes when an incident message is displayed.	a.m./p.m. peak and off-peak time period, type, event	Vehicles	Monthly	(48)	Vehicle counts	New	SunGuide	Indicates how many vehicles change behavior due to DMS.
Number of DMS Messages Posted in Response Another Agency Request	Number of DMS messages requested by a different agency (i.e., neighboring district, central office).	a.m./p.m. peak and off-peak time period, type, event	Messages	Monthly	(46)	Message type	Existing	SMART	Indicates how often other agencies need to utilize DMS infrastructure.
						Message owner	Existing	SMART	
Diversions Due to DMS Messages	Average increase in detector (ramp) volumes when an incident message is displayed.	a.m./p.m. peak and off-peak time period, type, event	Vehicles	Monthly	(48)	Vehicle counts	New	SunGuide	Indicates how many vehicles change behavior due to DMS.

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
DMS Message Posting Time	Difference in time from incident verification to when the first DMS message is posted on a sign.	a.m./p.m. peak and off-peak time period, type, event	Minutes	Monthly	(49)	Incident verification time Time when first message is posted	Existing	SMART	Indicates operator time needed to post a message, measures operator efficiency, and ease of software use.
Percent Display Time	Percent time messages are displayed by message type.	Message type	Messages per sign	Per month					
Reliability of Travel Time Messages	Variability of travel time, defined as one standard deviation away from the average.	Message type	Minutes	Per week					
DMS Readability	Percent signs with acceptable brightness, working pixels, etc.	System	Percentage	Per month					
DMS Message Usefulness	Message usefulness.	Message type	None	Per year					
Number of System Generated Messages That Are Operator Modified	Number of messages modified.	System, Roadway, a.m./p.m./off-peak	Messages	Per month					
Number of False Alarms	Number of false alarms.	Roadway, a.m./p.m./off-peak	Messages	Per month					
Call Center Operations									
Call Duration	Call duration.	Call type	Seconds	Weekly					
Call Answer Time	Call answer time.	Call type, a.m./p.m./off-peak periods	Seconds	Weekly					
Number of Calls Taken	Number of calls taken.	Call type, a.m./p.m./off-peak periods	Calls	Weekly					
Number of Call Abandoned/Overflow	Number of call abandoned/overflow.	Call type, a.m./p.m./off-peak periods	Calls	Weekly					
Type of Info Requested	Type of info requested.	Call type	None	Weekly					
Customer Satisfaction	Customer satisfaction.	Call type, a.m./p.m./off-peak periods	Rating	Annually					
CSR Man-Hours Per Shift	CSR man-hours per shift.	Call type, a.m./p.m./off-peak periods	Man-hours	Weekly					
Broadcast Media Operations									
Number of Radio, TV Stations Broadcasting Information	Number of radio, TV stations broadcasting information.	Station, City, County, a.m./p.m./off-peak periods	Stations	Annually					
Number of Broadcasters Using Media Room during Peak Hours	Number of broadcasters using media room during peak hours.	Station, City, County, a.m./p.m./off-peak periods	Broadcasters	Monthly					
Utilization of CCTV Images	Utilization of CCTV images.	Image Type	Stations	Annually					
Number of Users through Broadcast Media Proxy	Number of users through broadcast media proxy.	Station, City, County, a.m./p.m./off-peak periods	Audience	Annually					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Call Box Usage									
Number of Call Boxes	Number of call boxes deployed.	Roadway, direction, county	Unit	Per year					
Call Box Usage	Call box usage.	Roadway, a.m./p.m./ off-peak, Call type	Call	Per year					
Freeway Management									
Ramp Meters									
Number of Ramps Metered	Number of ramps metered.	Roadway	Ramps	Per year					
Number of Ramp Meters	Number of ramp meters.	Type	Device	Per year					
Percent of Time Meters Are Operational	Average length of operational hours in terms of percentage over a 24-hour day.	Site, Roadway, control type	Percentage	Per month					
Number of Vehicles Metered	Number of vehicles metered.	Roadway, a.m./p.m./ off-peak	Vehicles	Per month					
Average Vehicle Delay	The average additional time that is incurred when actual travel times are greater than free-flow travel times.	Roadway, a.m./p.m./ off-peak	Hours	Per month					
Increase in Travel Time Reliability in Metered Corridors	Percent change in buffer index versus normal flow.	Roadway, a.m./p.m./ off-peak	Percentage	Per month					
Decrease in Incidents in Metered Corridors	Percent change in incidents per VMT versus unmetered corridors.	Roadway, a.m./p.m./ off-peak	Percentage	Per month					
HOV Management									
HOV Lane-Miles	Total length of the HOV facility, including all lanes.	Roadway	Miles	Per year					
HOV Lane Volume	Number of vehicles served by the HOV lane.	Roadway, a.m./p.m./ off-peak	Vehicles	Per month					
HOV Lane Speed versus SOV Lane Speed	HOV/SOV vehicle speed comparisons.	Roadway, a.m./p.m./ off-peak	Mph	Per month					
HOV Lane Occupancy versus SOV Lane Occupancy	Percent of time detector zone is occupied.	Roadway, a.m./p.m./ off-peak	Percentage	Per month					
HOV Lane Throughput	Number of passengers per hour.	Roadway, a.m./p.m./ off-peak	Passengers per hour	Per month					
Special Events Management									
Assistance to Police Managing Special Events	Number of assistance given to local police.	Event, Event type	Assistance	Per month					

Performance Measure						Data Needs			
Measure	Definition	Reported By (As Available)	Units	Reporting Frequency	Formula	Data Required	Status	Source	Use of Measure
Other Systems									
Electronic Payment									
Traffic Volume through Toll Booth	Traffic volume through toll booth.	a.m./p.m./off-peak periods, vehicle type	Vehicles	Weekly					
Number of Cruise Card Tolls	Number of cruise card tolls.	a.m./p.m./off-peak periods, vehicle type	Vehicles	Weekly					
Number of Cruise Card Lane Violations	Number of cruise card lane violations.	a.m./p.m./off-peak periods, vehicle type	Vehicles	Weekly					
ITS or CVO Operations									
Number Trucks Bypassing Weigh Stations Using Electronic Tags	Number trucks bypassing weigh stations using electronic tags.	a.m./p.m./off-peak periods	Trucks	Annually					
Number Trucking Companies Using Electronic Credentialing	Number trucking companies using electronic credentialing.	a.m./p.m./off-peak periods	Companies	Annually					
Number of Trucks Utilizing Enhanced Truck Stops and Incentives	Number of trucks utilizing enhanced truck stops and incentives.	a.m./p.m./off-peak periods	Trucks	Monthly					
Reduction in the Truck Percentage on Interstates during Peak Periods	Reduction in the truck percentage on interstates during peak periods.	Interstate corridor	Percentage	Monthly					

Appendix B

Benchmarking Interview Results

Introduction

A major part of this research effort was to ascertain what the more progressive agencies are doing in the area of freeway performance measures. The original scope for the project stated that agencies in three to five areas be interviewed. However, we determined that it was possible to interview more than five areas for the project, because of the geographic spread of the Research Team and by combining visits on other Operations-related projects. Therefore, the team interviewed agencies in 11 areas (described below), five of which involved multiple agencies (at least operations and planning) in freeway performance measurement and the remainder involved operations personnel only.[1]

To prepare for the interviews, the Team assembled a notebook that depicts what various states are doing in the area of performance measurement, with a focus on freeways where applicable. These materials were meant to show interviewees what other areas are doing and what is possible.

Interview Plan

Approach

To help frame the questions for the interviews, the Research Team conducted a pilot interview with Georgia NaviGAtor personnel. After this interview, the Team constructed two interview guides, one for operations agencies, and one for planning agencies.

Areas Selected and Why

Table B.1 shows the areas that were selected for interviews along with the justification for selecting these areas. Also shown are the agencies interviewed in each area. Note that the agencies were selected primarily because they were believed to have "exemplary" performance measure programs. Therefore, these are the agencies that are probably in the forefront of the field. While by no means comprehensive, several other areas are probably at least as well progressed in performance measurement, many transportation agencies are not as advanced in the performance measurement programs.

[1] One of the areas, San Antonio, did not have an appreciable performance measures program as of this writing. Therefore, the information summarized here are derived from the remaining 10 areas.

Table B.1 Agencies Participating in the Benchmarking Interviews

Metro Area	Reasons for Selection	Agencies Interviewed
Multiple Agency Interviews		
1. Minneapolis-St. Paul, MN	MnDOT has been collecting and using performance and efficiency data for many years – they were an early leader in performance measures, earning themselves the title of "Land of 10,000 performance measures." MnDOT Ops aggressive at using operations data and information for decision-making. Long history of active freeway management and data collection. Location of high-profile public debate on operational policy (ramp metering), and location of significant transit technology test (buses on narrow shoulders).	Metro District Operations, MnDOT Center for Transportation Studies, University of Minnesota Metro Council
2. Seattle, WA	WSDOT very actively pursuing performance measures as a means of selling O&M program. Very active public reporting process, active experimentation in performance measure development, and freeway performance is a key subject in proposed ballot initiatives.	WSDOT HQ Traffic Office WSDOT NW Region WSDOT HQ Strategic Planning and Programming Puget Sound Regional Council
3. Hampton Roads, VA	Field Operational Test aimed at developing a comprehensive archive data management system (ADMS) being conducted here. Multiple stakeholder groups actively engaged in use of the archive; performance measurement at different levels a major thrust. Cambridge Systematics is leading the evaluation.	Hampton Roads STC, VDOT Hampton Roads Planning District Commission
4. Milwaukee, WI	WisDOT embarked on aggressive use of information for operations and planning.	WisDOT District 2 Operations WisDOT Central Office University of Wisconsin-Madison WisDOT District 2 Planning
5. Phoenix, AZ	MAG beginning a performance measurement program (planning); Maricopa County DOT also interested in warehousing data and providing performance reports. MAG has recently provided significant funding for improved data collection for performance reporting. Arizona DOT Traffic Operations Center currently monitors 50 percent of freeways in Phoenix and Tucson metro areas (100 centerline miles).	ADOT/Intermodal Transportation Division ADOT/Transportation Planning Division Maricopa Association of Governments

Table B.1 Agencies Participating in the Benchmarking Interviews (continued)

Metro Area	Reasons for Selection	Agencies Interviewed
Multiple Agency Interviews		
5. Phoenix, AZ (continued)	Real-time information is provided to web site and 511. A quarterly report is published internally on freeway congestion in the Phoenix area and how well departmental objectives are being met. ADOT currently spends $2.25 million a year on its Traffic Operations Center plus $1.25 million a year on detector maintenance.	
6. Los Angeles, CA	Caltrans HQ actively involved in performance measurement for both operations and planning activities. Caltrans currently is funding development of an arterial monitoring system to supplement the freeway monitoring system. Real-time freeway congestion information currently is posted to the web.	Caltrans, Freeway Operations, District 7 Southern California Association of Governments Caltrans, Planning
Operations Interviews Only		
7. Portland, OR	Portland has a very active freeway management effort, an ongoing performance measure development effort with Portland State University, and considerable public pressure to improve roadway performance.	See Note (a)
8. Houston, TX	TxDOT/TRANSTAR currently prepares an annual performance report.	Houston TRANSTAR
9. San Antonio, TX	TxDOT Operations has shown interest in better exploiting their data resources.	See Note (b)
10. Washington, D.C.	CHART very active in incident management performance measures; expansion of Hampton Roads ADMS being planned for Northern Virginia.	CHART (Maryland) VDOT Northern Virginia District
11. Atlanta, GA	NaviGAtor actively using incident management performance measures. Business Plan being developed tied to multiple performance measures.	GDOT, Office of Traffic Operations

[a] No formal interviews were conducted as part of NCHRP 3-68. Rather, the team relied on other work conducted by TTI on performance measures. As part of this effort ODOT assembled a Technical Advisory Committee (TAC) made up of individuals from ODOT sections of traffic management, transportation planning and analysis, transportation data, traffic operations, and internal audit/performance measures. The TAC also included individuals from the metropolitan planning organization (MPO) in Portland (Metro) and the Eugene/Springfield area (Lane Council of Governments), academia, and the local Federal Highway Administration (FHWA) office.

[b] Initial conversations with TransGuide indicated that they currently are not using performance measures nor are they planning on developing them in the near future. TransGuide does have an extensive sensor system (485 lane-miles) and a formal incident management program from which detailed performance measures could be developed, however.

Summary and Analysis of Benchmarking Interviews

Tables B.2 through B.6 summarize the interviews by the major topics covered in the interview guides. From these interviews, several themes and trends can be observed, as discussed below.

Motivations for Undertaking Freeway Performance Measurement

Four motivations exist for agencies to undertake freeway performance measurement.

1. **Legislative Mandates**. State legislatures may require transportation, as well as other state agencies to engage in a formal performance measurement and reporting process. Washington State is an example of this case. Freeway performance measures are undertaken initially primarily to feed the mandated reporting process, at least in Washington State's case, managers learn that there is intrinsic value in conducting freeway performance measurement for their own purposes (see reasons 3 and 4 below).

2. **Agencywide Performance Measurement Initiatives.** Even in the absence of legislative intervention, DOTs and MPOs often initiate department-wide performance measurement programs for a variety of reasons. Usually these are ostensibly linked to the notion of "customer focus" and improved public relations and involvement. Like legislative mandates, these efforts result in Annual Performance Reports. Freeway performance is usually couched in terms of congestion/mobility in these reports and are usually summarized at the State or major metropolitan area level.

3. **Formal Business Plan Linkage, Particularly for Operations.** Several agencies have taken a formal business plan approach to the actions. Most of these follow the process previously shown in Figure 3.2 and found in the private sector scan of performance measurement, i.e., the Vision-Goals-Objectives-Performance Measures-Targets-Actions sequence. The undertaking of Business Plan can be dictated by DOT upper management or self initiated by a champion.

4. **Quantification of Benefits for Freeway Programs, Particularly for Operations.** Operations personnel are discovering that when it comes to competing for internal resources and visibility, they are at a disadvantage compared to other functional areas. Infrastructure programs have a long history of documenting the effects their program have users, as embodied in pavement, bridge, and maintenance management systems. "Not having the numbers" makes it hard to argue in favor of programs when others do have the numbers. Maryland SHA and Wisconsin DOT are two examples of this.

In two of the interview cities, San Antonio and Houston, freeway performance measurement has not yet been undertaken, though there are signs that this may change (i.e., they may just be "late adopters"). None of the four motivations currently are present in these cities and local managers are not convinced of the cost-effectiveness of implementing performance measurement. In this sense, they are no different from the other cities, without strategic, legislative, or top management mandates/initiatives, it is doubtful that the other areas would have undertaken performance measurement.

In applying performance measurement concepts, it appears that public agencies mirror those in the private sector. Implementation of the concepts are the difficult part for public agencies. Once the institutional hurdle of establishing a performance measurement program is passed, many technical difficulties still lie ahead, as discussed below.

Types of Performance Measures Used by Agencies

- Both outcome and output measures are used by agencies. It is clear that agencies who have undertaken freeway performance measurement have accessed the literature on performance measurement because they use the outcome/output terminology.
- For outcome measures, derivatives of speed and delay are commonly used by both operating and planning agencies. The Travel-Time Index is a popular metric. Level of service as a metric is still in use in both planning and operations agencies, though it is not as widespread as it might have been 10 years ago. Reliability metrics have not yet found their way into widespread use. (Seattle and Minneapolis are exceptions.) These metrics are usually formulated for short segments or at key locations. An exception is Seattle where a series of defined "freeway trips" have been defined, these can involve travel over multiple freeway routes for extended lengths.
- Some of the more interesting metrics used by agencies include:
  - The number of very slow trips (half of free flow speed) that occurs each year by time of day and major trip (Seattle);
  - Percentage of reduction in incident congestion delay; and
  - Percent of freeway lane-miles below congested volumes (based on volume per lane).
- Output measures are used primarily by operating agencies, and then primarily for incident management activities and the operation of field equipment (e.g., sensors, cameras).
- Many areas are beginning to define more sophisticated measures for measuring congestion/mobility performance but have not yet implemented them. Overall, there appears to be a trend away from the general categories of performance (LOS) and toward continuous measures that are based on delay and travel time. Further, consideration of travel-time reliability is growing in acceptance, though its implementation is still problematic, primarily due to data requirements.
- Customer satisfaction measures, where collected, are not used specifically for freeway performance measurement. Rather, they are instituted to gauge overall opinions about how well an agency is dealing with congestion.

Use of Performance Measures

- Development of performance reports appears to be the major use right now for outcome-related freeway performance measures. The frequency of publication varies from weekly to annually, but annual reports are the most common. The existence of dashboards was not found in any of the areas, though MNDOT is in the development phase.

- The linking of performance measures (more specifically, changes in them over time or their level relative to preset targets) and investment decisions is not well established. The best examples of actions taken based on performance measures is the tracking of detailed output measures for incident management programs, there is evidence that agencies act on these to modify activities such as service patrol routing and schedules. However, a linkage between major freeway investments and outcome measures (e.g., freeway delay) was not found. Washington State seems to be farthest along on this matter, but even there the correlation is not direct. This may be due to the lack of experience with developing and applying the measures rather than with an unwillingness to use them to support investment decisions. It is true, however, that having better information on the scope and causes of congestion tends to lead towards more open thinking about what to fund to improve the situation (at least in the case of Washington State). What it doesn't solve is the fact that the State and MPO planning processes choose large investments that are based on long-range needs rather than on short-term changes in performance measures (or the failure to meet current performance targets).

- State DOTs and MPOs do not directly collaborate in joint efforts in developing freeway performance measurement programs. There seems to be a split of responsibility along traditional lines – DOTs tend to handle construction and operations while MPOs handle planning activities. Some MPOs and DOTs use common measures, but also develop measures unique to their applications.

Data Collection and Analysis

- Metrics are developed through a variety of methods – operations agencies (whose focus is primarily freeways) rely heavily on archived roadway surveillance data; the development of formal data archive management systems is on the rise. Planning agencies (whose purview includes all roadways in an area) use a mix of methods, including travel demand forecasting and other models (e.g., HERS); sample-based travel time runs from floating cars; and overlapping aerial photography. Planning agencies are just now starting to tap ITS data archives as a source of data for performance measures; this occurrence is not very widespread.

- Universities within a state are commonly used to at least initially set up performance measurement programs and data archives. Sometimes these functions are passed on to the DOT, sometimes the universities retain control.

- Integration of the various data sources available (ITS roadway surveillance, events (incidents, weather, work zones), and sample-based data) is not well very well advanced. However, there is recognition that this must occur, especially in areas that consider delay by congestion source (e.g., incidents) as an important measure.

- Collection and use of incident data is becoming more common among freeway management systems. However, every areas defines data elements and collects data differently. Work zones are occasionally collected as part of incident data. Collection of weather data is uncommon.

Data Quality

- The quality of data from ITS roadway sensors is a major concern of agencies and has even caused trepidation in using the data for freeway performance measurement (e.g., Atlanta). Data quality problems can be traced primarily to two sources: 1) improper installation (including initial calibration and acceptance testing of equipment), and 2) inadequate detector maintenance due to funding shortfalls. This is a serious problem for freeway performance measurement, especially since ITS roadway sensors provide continuous data at the small time and geographic increments necessary to support sophisticated measures (reliability, congestion by source). The most extreme case is Houston which basically relies on probe readers for travel-time estimates, they do not rely on the roadway sensors originally installed. As a result, since volumes are not available, not all the performance measures that are possible can be constructed.

- Several agencies have done formal studies of data quality. One strategy to deal with data quality (identified by GDOT) is to concentrate calibration and maintenance on "key" detectors, with the idea that these can be used to detect major problems (e.g., at known bottlenecks). The key detectors can then be used to adjust measurements from the remaining detectors. However, it is unclear how the adjustments will be done and how well this procedures will work to improve data quality. Further, developing performance measurements from a few isolated detector locations also is highly problematic, since most of the detailed performance measures are based on converting detector measurements to travel times in a corridor, the efficacy of this approach is in doubt.

- When formal archived data management systems are implemented, data quality control checks are instituted. However, these are post hoc in nature, they can test for inconsistencies based on valid ranges, checks against theory, and checks against history, but subtle errors in accuracy still occur and are unknown. (The only way to determine accuracy is to independently validate field measurements.)

Table B.2 Interview Summaries[1]

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
1. Minneapolis-St. Paul, MN	TMC confirms traffic incidents with nearly 285 closed-circuit TV (CCTV) cameras posted along 210 miles of metro area freeway. Information on incident location and resulting traffic back-ups are relayed to travelers via Traffic Radio, Traffic TV, various Internet sites and a telephone service. The RTMC provides traffic information to local radio and television traffic reporters as well. Travelers also are alerted to traffic problems via 70 electronic message signs placed throughout the freeway system. TMC staff also operates 430 ramp meters and 4,000 loop detectors (traffic sensors).	In an annual Departmental Results report, MnDOT tracks a number of performance measures statewide. Performance measures have therefore become part of an institutional reporting process.
2. Seattle, WA	WSDOT has a very active freeway management program, including: freeway ramp meters throughout most of the instrumented freeway system; an active, roving, service patrol program; a coordinated, multi-agency incident management program, including designated WSDOT incident management staff; and a very active traveler information system, including a 511 call-in line, a heavily used web site that displays a congestion map and access to both still images and streaming video. WSDOT has adopted "WSDOT's Congestion Measurement Principles" which are as follows: • Use real-time measurements rather than computer models whenever possible; • Measure congestion due to incidents as distinct from congestion due to inadequate capacity; • Show whether reducing congestion from incidents will improve travel-time reliability; • Demonstrate both long-term trends and short- to intermediate-term results; • Communicate about possible congestion fixes by using an "apples-to-apples" comparison with the current situation; and • Use plain English to describe measurements.	Original mandate from state legislature resulted in the annual performance report known as *Measures, Markers, and Mileposts*, the "departmental accountability" report published by WSDOT each quarter to inform the legislature and public about how the Department is responding to public direction and spending taxpayer resources. Agencies now using performance measures as part of everyday practice to help make informed decisions.

[1] Most interviews conducted during Spring and Summer of 2004.

Table B.2 Interview Summaries (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
3. Hampton Roads, VA	The Smart Traffic Center (STC) is the Virginia Department of Transportation's (VDOT) high-tech, customer service approach to regional freeway traffic management and communications. The Freeway Traffic Management System installed at STC consists of an extensive computer controlled, fiberoptic-based communications and control network installed along 31 miles of the area freeways (I-64, I-264, I-564, and I-664), 80 closed circuit television cameras plus access to 36 additional cameras in the tunnels and bridges, more than 85 dynamic message signs and more than 1,050 vehicle detectors strategically positioned across the entire Hampton Roads region, Wide-Area Highway Advisory Radio System (HARS), and Freeway Incident Response Teams (FIRT) patrolling more than 70 miles of interstate in the region.	The Smart Travel Lab (STL) at UVA is responsible for gathering and archiving performance data from the region's loop, radar, and acoustic detectors. The STL does not report travel time and speed performance measures on a regular basis, but uses the Hampton Roads Smart Traffic Center loop data for research. From the research, more direct use of performance measures in day-to-day operations is hoped to be achieved. Output measures are more developed and in use than outcome measures.
4. Milwaukee, WI	The TOC archives many different types of operations data. As part of planned enhancements to their data archiving system, they plan to include a performance reporting "module" in their new data warehouse.	A formal performance measurement program, the Freeway System Operational Assessment (FSOA) program, bas been instituted to provide better information to operators, public officials, and travelers. The impetus for FSOA came from the MONITOR traffic operations center, where WisDOT engineers were dealing with operational problems created by a "project" mentality in the planning and project development process. FSOA was created to provide a comprehensive, systemwide assessment of the safety and operational performance of all freeways in the Waukesha District, and to provide a framework in which geometric and/or operational improvement projects could be considered in the current project development process.

Table B.2 Interview Summaries (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
4. Milwaukee, WI (continued)		The impetus for developing an operations performance monitoring process is two-fold: 1) The TOC wants to communicate the benefits of operations to WisDOT managers/administration as well as other nontechnical leaders and elected officials; and 2) The TOC already has significant archived data resources that could be used, and there was an opportunity to develop this capability as part of planned enhancements to their data archiving system. Data from the MetaManager system drives many project development decisions. Thus, the operations group would like to develop the traffic analogy to MetaManager, which would essentially be a freeway performance reporting system based upon archived traffic operations data.
5. Phoenix, AZ	There are approximately 100 miles of High-Occupancy Vehicle (HOV) lanes in the area. The HOV lanes are restricted during peak traffic hours between 6:00 a.m. and 9:00 a.m. and 3:00 p.m. and 7:00 p.m. During these hours, travel on the HOV lanes is limited to vehicles with two or more occupants. Vehicles travel more than 22.5 million miles on Phoenix's freeway system everyday according to the CY2002 Highway Performance Monitoring System (HPMS) Report. This volume translates to approximately 8.22 billion annual VMT on the 189 miles of freeway. As a result, recurring bottlenecks and congested corridors are significant problems in the area. The Maricopa Association of Governments has identified 16 congested segments in the preliminary draft working paper of the *MAG Regional Freeway Bottleneck Study*. A freeway management system (FMS) that uses intelligent transportation technologies to collect freeway data and to monitor freeway conditions to optimize traffic flow covers approximately one-half of the freeway system in the Phoenix metropolitan area. TTG plans to extend the coverage area in the future.	The original impetus was to support ADOT's Strategic Action Plan, which is performance-based. Performance measures are at the core of this effort. Agencies are discovering uses for performance measures beyond fulfilling the requirements of the Strategic Action Plan.

Table B.2 Interview Summaries (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
6. Los Angeles, CA	The Division of Operations of Caltrans 7 is responsible for constructing and maintaining all interstate and state highways in the Greater Los Angeles Area. It has developed an Advanced Traffic Management System (ATMS), which "integrates recurrent/nonrecurring incident detection, verification, incident response, planned events of freeway management, and field element operational control." ATMS uses electronic devices, such as loop detectors, to collect freeway performance data. The information collected by ATMS is fed to the District's Transportation Management Center (TMC) and forms the basis for many performance measures. Caltrans aims to optimize traffic flow by managing existing traffic operations and anticipating future demands.	Preliminary internal or "agency" performance measures for operations have been drafted. Two implicit policies in developing the measures are: 1) measures need to be monitored as well as forecast; and 2) measures should be modally and jurisdictionally blind whenever possible. In addition, Caltrans follows a system management philosophy. As such, freeway performance is not evaluated independent from the rest of the system. SCAG is required to produce a Regional Transportation Plan (RTP). As part of this effort, SCAG has developed goals and performance measures that aimed to evaluate the performance of the Plan. SCAG also takes a holistic, modally blind approach, where the goals and measures are applied to the entire transportation system. While freeway data are collected in such a way that they may be singled out for evaluation, they are not generally being reviewed apart from the whole system.
7. Portland, OR	Part of statewide study of performance measures.	ODOT had a historical performance measurement process that was in need of updating to capture the effect of operational treatments on congestion/mobility.
8. Houston, TX	The hub for traffic operations in the greater Houston area is the Houston TranStar (Greater Houston Transportation and Emergency Management Center). The Houston District of TxDOT is responsible for state maintained roadways within a six county area encompassing 5,948 miles with a population of approximately 4.9 million persons, 3.6 million of which are in Harris County. Houston TranStar generally covers about 235 centerline miles of the freeways located within Harris County only. Operations are typically focused on peak periods. There are four operators on duty in the Center during each weekday peak, two in the midday and one in the overnight and weekend periods. The Motorist Assistance Patrol and most other operational treatments operate only on weekdays. This is focused on the urban areas with very little interaction with rural areas around Houston.	The performance measures are primarily derived to develop a "deficiency" report and to provide data for the changeable message signs and web site. An Annual Report also is prepared to describe the activities, actions, and benefits from TranStar. The "deficiency" report identifies the technologies and their operating status. It is used to guide maintenance activity, especially in the case of dangerous potholes or inoperable signs or signals. There are some emerging programs, principally the Texas Metropolitan Mobility Plan, which may require more extensive performance reporting, but there is no Central Office-type mandate for measures or monitoring data.

Table B.2 Interview Summaries (continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
9. Washington, D.C.	**Maryland –** CHART currently has traffic sensors at 1.0- to 1.5-mile spacing along some sections of I-70, I-83, I-95, I-270, I-495, I-695, I-795, and U.S. 50. Many sections do not have any instrumentation. There also are video cameras in the same areas as the sensors. Sensor and camera coverage is shown on the CHART web site located at http://www.chart.state.md.us. The traffic sensors provide volume, occupancy, and speed. University of Maryland is starting a process to archive this VOS data. CHART recently awarded a contract to a vendor to design reports for presenting the VOS and incident data. Currently, sensors are only used to update the real-time traffic maps on the web site and in the operations centers. **Virginia –** The Northern Virginia (NOVA) District operates more than 800 signalized intersections and automatically receives data from more than 11,000 loop detectors. NOVA has both presence detectors (6 feet by 40 feet located at the stopbar) and system detectors (6 feet by 6 feet located 200-300 upstream from the stopbar). All loops are set up to detect volume, occupancy, and speed.	**Maryland –** SHA and CHART participate in the Maryland DOT "Managing for Results" program. The program was initiated in 1999. It is linked to a Business Plan: goals, objectives, and performance measures, and strategies to achieve goals are linked. **Virginia –** VDOT beginning a department-wide performance measurement program.
10. Atlanta, GA	The NaviGAtor Program is the Georgia Department of Transportation's (GDOT) high-tech, customer service approach to regional freeway traffic management and communications. The NaviGAtor system consists of an extensive computer controlled, fiberoptic-based communications and control network installed along 222 miles of the area freeways (I-20, I-75, I-85, I-285, and GA 400), 319 closed circuit television cameras on the freeways plus 211 additional cameras on the arterial system managed by local jurisdictions, more than 100 dynamic message signs and more than 1,100 vehicle detectors strategically positioned across the Atlanta region, and Highway Emergency Response Operators (HERO) patrolling more than 250 miles of interstate in 55 vehicles in the region.	Development of an Operations Business Plan, which follows the "vision-goals-objectives-performance measures-targets-actions" sequence is driving the implementation of performance measures at NaviGAtor.

Table B.3 Congestion/Mobility Performance Measures Under Consideration in Selected DOTs

State	Performance Measures
Florida	• Person-miles traveled • Truck-miles traveled • Vehicle-miles traveled • Average speed • Average delay per vehicle • Average door-to-door trip time • Variance of average travel time or speed ("Reliability"; not yet defined) • Vehicles per hour per lane during peak hour ("Maneuverability") • Percent highway miles at LOS E or F • Percent VMT at LOS E or F • Vehicles per lane-mile ("Density") • Lane-mile-hours at LOS E or F ("Duration of Congestion")
Oregon	• Roadway miles at V/C > 0.70 during peak period • Hours of delay from nonrecurring congestion • Delay per incident • Hours of delay per system user (multimodal)

Table B.4 Types of Performance Measures Used by Agencies

Metro Area	Operation Agencies	Planning Agencies
1. Minneapolis-St. Paul, MN	• Average incident duration. • Percent of highway miles with peak-period speeds < 45 mph. • Travel-Time Index. • Travel times on selected segments, including mean, median, and 95th percentile.	• HOV usage. • Roadway congestion index. • Percent of daily travel in congestion. • Percent of congested lane-miles in the peak period. • Percent of congested person-miles of travel. • Annual hours of delay. • Change in citizen's time spent in delay. • Congestion impact on travel time. • Travel-Time Index.
2. Seattle, WA	*Real-Time Operations* • TSMC staff use displays of three primary sets of information to determine the performance of the freeway system. These three displays include: – A "congestion map" based on vehicle lane occupancy; – A set of computed travel times for 30 representative "trips" on the freeway system; and – A bank of television monitors displaying various CCTV images. *Operations Planning/Output Measures* • Many output measures tracked; a sample includes: – The number of loop detectors deployed; – The number of loops currently functioning; – The percentage of loops functioning during a year;	The planning process incorporates all of the performance measures discussed above. In addition, the planning process uses the additional summary measures of: • Person-hours of travel; • Vehicle-hours of travel; • Person-hours of delay; • Vehicle-hours of delay; • Vehicle-miles of travel; and • Person-miles of travel.

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
2. Seattle, WA (continued)	– The number of service patrol vehicles currently deployed; – The number of hours of service patrol efforts supplied by WSDOT; – The number of motorist assists provided by those service patrols by type of assistance provided; and – The number, duration, and severity of incidents by location (roadway segment) and type of incident. *Operations Planning/Outcome Measures* • The average vehicle volume by location and time of day and by type of facility (HOV/GP lane); • The average person volume by location and time of day and by type of facility; • The frequency of severe congestion (LOS f) by location; • The average travel time by corridor and major trip (O/D pairs;) • The 95th percentile travel time by corridor and major trip (also reported as Buffer Time); • The number of very slow trips (half of FFS) that occur each year by time of day and major trip; • The amount of lost efficiency (speeds < 45 mph) by location; • The number of times that HOV lanes fail to meet adopted travel-time performance standards; and • The percentage of HOV lane violators observed by monitoring location.	
3. Hampton Roads, VA	*Outcome* • Speed; • Volume; and • Occupancy.	HCM LOS ranges, developed with a combination of models and roadway surveillance data; specifically: • Lane-miles operating at LOS F.

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
3. Hampton Roads, VA (continued)	*Output* • Numbers of total incidents by type; • Number of vehicles involved; • Number of lanes blocked; • FIRT vehicle mileage; • TOC staff availability; • Numbers of variable message signs; • Average times for incident duration; • Average times for response; • Miles of STC coverage; • Numbers of messages placed on the signs; • Availability of STC field equipment; • Percent of surveillance devices responding; • Turnover rate; • Number of hours worked – operators; • Number of hours worked – FIRT drivers; and • Number of miles driven – FIRT drivers by route.	
4. Milwaukee, WI	Still under development, but several concepts are being applied: • Average congestion level (exact definition still being discussed); • Congestion duration (to quantify peak spreading); • Travel reliability (exact definition still being discussed);	• Benefit/cost ratio – Quantitative monetized benefits include: 1) travel-time savings versus a no-build scenario; 2) value of improved traveler information; and 3) crash reduction. All benefits and costs are projected using three scenarios: best case, midrange, and worst case.

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
4. Milwaukee, WI (continued)	• Road safety index (exact definition still being discussed); • Measures for freeway service patrol (such as decrease in related incident congestion and secondary crashes); and • Impacts of work zones.	• Environment – Qualitative assessment of changes. • Interconnection – Qualitative assessment of benefits for multimodal transportation and nondrives. • Partnerships – Qualitative assessment of likely sources of public support and/or opposition. *Consideration Of Other Performance Measures* WisDOT has considered the use of travel-time reliability in their models and may implement a monetized benefit value for reliability in the future. At this point, however, the Project Appraisal Report does not directly address travel-time reliability. Freight-specific measures are not included, but freight is considered under the "Interconnection" qualitative assessment.
5. Phoenix, AZ	*Outcome Measures* • Speed; • Average percent of freeways reaching LOS E or F on weekdays; • Traffic volumes/counts; • Vehicle occupancy; • Outcome Measures; • Numbers of total incidents; • Numbers of Level 1 incidents; • TOC staff availability; • Numbers of variable message signs; • Average times for acknowledgment;	• Congestion Index (percent of posted speed). • Travel time. • Segment delay (seconds/mile). • Stop delay (<3 mph) (seconds/mile). • Average speed (percent of posted speed). • Average speed (mph). • Average HOV lane speed (mph). • Running speed ((length/travel time) stop delay). • Total volume. • HOV lane volume.

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
5. Phoenix, AZ (continued)	• Average times for response; • Average times of closure; • Miles of FMS; • Number of traffic interchange signals connected to central system; • Number of hits to TTG's traveler information web site; • Number of calls to TTG's traveler information phone system; • Number of entries into HCRS; • Number of sites with HCRS; • Numbers of messages placed on the signs; • Availabilities of FMS; • Availability of HCRS; • Percent of surveillance devices responding; • Percent of time 511 available; • PC system availability; • Dollar of mandatory employee training; • Percent of mandatory supervisor training; • Percent of employee with >32 hrs of training; • Years of ADOT experience; • Turnover rate; • Number of injuries • People attending TOC tours; • Number of 511 comments; and • Percent of responses within 10 days to constituents.	• General purpose lane volume Congestion Index (percent of posted speed). • Percent peak-period truck volume. • Percent peak-period volume. • Lane-mile operating at LOS F. • Hours operating at LOS F.

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
6. Los Angeles, CA	With the exception of HOV facilities, Caltrans District 7 currently does not use a formal system to measure performance. Therefore, the type of performance measures it collects and the uses of such data are limited. However, with the introduction of the Transportation System Performance Measures (TSPM) Program, performance measures will likely become more important in the near future. The proposed TSPM includes a number of travel time and throughput-based measurements as well as other nonmobility measurements. It is proposed that interregional travel time in key travel corridors be monitored with actual origins and destinations. This shall include both people and goods movements. Total person-hours of delay also shall be measured. A standard delay definition that can be applied to all modes has yet to be developed. TSPM also includes a reliability metrics to highlight the variability in travel time between origin and destinations. *HOV Facilities* *Output Measures* • Total length of HOV facilities; and • Net change in lane-miles. *Outcome Measures* • Level of Service (LOS) during peak periods; and • Travel-time savings per mile. Daily and hourly volume on HOV facilities both in terms of the number of vehicles and of people.	*Caltrans* A Highway Congestion Monitoring Program (HICOMP) is mandated by the State of California to help achieve Caltrans' stated objectives of increasing efficiency and reducing delays on the State's freeway system. Each Caltrans district monitors freeway congestion level based on the following basic travel-time parameters: • Magnitude (vehicle-hours of delay per day – vhdpd); • Extent (congested directional miles – cdm); and • Duration (hours). HICOMP defines recurrent congestion as a condition lasting for 15 minutes or longer and vehicular speeds are 35 miles per hour or less during peak commute periods on a typical incident-free weekday regardless of the posted speed limit. The total delay per segment is calculated by multiplying hourly vehicle volume by the duration of congestion in hours by the travel time exceeding that when traveling the same distance at 35 miles per hour. • SCAG. • Total delay (vehicle-hours and person-hours). • Total VHT. • Total VMT. • Average System Speed, "Q" (=VMT/VHT). • Percent variation in travel time.

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
6. Los Angeles, CA (continued)		• Percent p.m. peak work trips within 45 minutes of home (Accessibility). • Percent capacity utilized during peak conditions.
7. Portland, OR	N/A	• Travel Time Index (TTI). • Travel Delay. • Buffer Index (BI). • Volume-to-capacity Ratio (V/C). • Travel Time. • Speed.
8. Houston, TX	• Speed. • Delay. • Incident response time for large truck incidents. • Web site usage and comments.	N/A
9. Washington, D.C.	*Maryland (CHART)* *Goal:* Improve mobility for our customers. *Objective:* Reduce congestion delay and associated costs caused by incidents by one percent annually. *Performance Measures* Output: • Average incident duration; and • Number of incident responses and complete reports.	N/A

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
9. Washington, D.C. (continued)	Outcome: • Percentage of reduction in incident congestion delay; • Reduction in user costs ($ million) associated with incidents; and • Reduction in truck user costs ($ million) associated with incidents. *Maryland (Statewide)* • Percent of freeway lane-miles below congested volumes per lane.	
10. Atlanta, GA	*Outcome* • Hampered by data quality concerns. Currently experimenting with a two categories of congestion: Moderate (speeds between 30-45 mph) and severe (<30 mph). Considering additional performance measures, including reliability. *Output* • Traveler information calls: – Total calls; – Calls per day; – Calls per route; – Calls by type of call; – Average call length; and – Average answer time. • Incidents managed: – By category; – Detection method; and – Impact levels (general categories). • Number of construction closures; • Device functioning;	N/A

Table B.4 Types of Performance Measures Used by Agencies (continued)

Metro Area	Operation Agencies	Planning Agencies
10. Atlanta, GA (continued)	• Percent time devices are available; • Number of media communications by outlet; • Web site visits by type of information requested; • Service patrol assists: – By shift; – By type; – By detection type; and – By route. • Service patrol service times (auto versus truck): – Response time; – Clear time; and – Notification to clear time.	

Table B.5 Uses of Performance Measures

Metro Area	Operation Agencies	Planning Agencies
1. Minneapolis-St. Paul, MN	The operations outcome measures of travel speed and its derivatives of travel time and reliability are just now being developed for use by the RTMC staff. The primary reason for the previous nonusage is data quality as described in the Data Quality section and the recent move to the new RTMC Building. The RTMC staff uses the output measures for incident and staff efficiency to provide benefits information to MnDOT management and to the public. The incident data is published monthly by RTMC staff and distributed to MnDOT management staff. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The FIRST drivers incident data is used to adjust individual patrol routes for the FIRST drivers and to define the FIRST divers need per shift.	Performance data also serve as a basis for Metro Council plans and reports such as the Regional Transportation Plan, the Transportation Improvement Plan, the annual update of the Transportation Systems Audit and various operations studies. Although performance measures generally are not linked directly to specific investments, the findings and recommendations of the plans ultimately play a part in influencing investment decisions.
2. Seattle, WA	WSDOT uses performance measures to help allocate resources, determine the effectiveness of a variety of programs, and help plan and prioritize system improvements, primarily from an operations perspective. A variety of measures are computed. Not all of these measures are routinely reported outside of the Department, but key statistics that describe either the current state-of-the-system, trends that are occurring, or the effectiveness of major policies are reported quarterly as part of the Department's efforts to clarify why it is taking specific actions and to improve its accountability to the public and public decision-makers.	Statistics allow comparisons of the relative performance of various corridors or roadway sections under study. These aggregated statistics also can be converted to unit values (e.g., person-hours of delay per mile) to further improve the ability to compare and prioritize the relative condition of corridors or roadway segments.
3. Hampton Roads, VA	The operations outcome measures of travel speed and its derivatives of travel time and reliability currently are not used in real time by the STC or the HRPDC staff. The primary reason for the nonusage is that the data quality is often inadequate as a basis for making operations decisions.	HRPDC provides regional planning and policy decisions in areas of transportation, air quality, and regional development. The performance measures allow member agencies to make informed decisions on matters concerning not only the local jurisdictions but the Hampton Roads region as a whole.

Table B.5 Uses of Performance Measures (continued)

Metro Area	Operation Agencies	Planning Agencies
3. Hampton Roads, VA (continued)	The STC staff uses the output measures for incident and staff efficiency to provide benefits information to VDOT management and to the public. The incident data is published monthly by the STC contractor and distributed to VDOT management staff. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The FIRT drivers incident data is used to adjust individual patrol routes for the FIRT drivers and to define the FIRT divers need per shift. Operations managers in the STC also use the data for diagnostic purposes in evaluating the effectiveness of implemented strategies under varying conditions. This activity also may be tied to training of STC operations personnel. The field equipment maintenance data is collected and saved, but it is not yet used for management purposes. The current system is stored by use of Automated Maintenance Management software and all equipment is tracked by cabinet location.	Historical performance measures reporting also is an important use of the metrics. The cyclical studies enable trend analysis for the travel demand model development and special reports for congestion and air quality; therefore, care is taken when metrics are developed or enhanced to ensure compatibility with historic data. Trend analysis is useful to pinpoint problem areas in both the long- and short-term. Performance data also serve as a basis for HRPDC plans and reports such as the Regional Transportation Plan, the Transportation Improvement Plan, and various bridge and tunnel operations studies. Although performance measures generally are not linked directly to specific investments, the findings and recommendations of the plans ultimately play a part in influencing investment decisions.
4. Milwaukee, WI	WisDOT plans to use performance measures for the following applications: 1. Communicating the benefits of and marketing operations to WisDOT managers/administration; 2. Benchmarking performance for and providing feedback to control room operators; and 3. Use for operations management and planning (e.g., fine-tuning ramp meter timing, scheduling lane and ramp closures, etc.).	The FSOA program has developed a "Project Appraisal Report" (see pages 3 to 5 for an example that could be used to: 1) compare various alternatives in a particular project, or 2) prioritize or rank various projects for programming and funding. The Project Appraisal Report includes one quantitative measure and three qualitative ("intangible") measures.
5. Phoenix, AZ	Performance measures are used by TTG for operations, emergency response, and traveler information applications. Each measure is employed to achieve the objectives set forth in the ADOT/ITD Strategic Action Plan.	The performance measures allow member agencies to make informed decisions on matters concerning not only the local jurisdictions but the region as a whole.

Table B.5 Uses of Performance Measures (continued)

Metro Area	Operation Agencies	Planning Agencies
5. Phoenix, AZ (continued)	The monitoring of speed and volume using FMS data allows TTG to measure the average percentage of Phoenix freeways reaching level of service "E" or "F" on weekdays to determine if the Group's objective of operating 60 percent of the freeways at a level "D" or better during rush hour is met. The speed and volume data also are used for ramp metering. Although TOC staffing level is measured, it is unclear that the information is being used to adjust work schedules. There also is no indication that the data are disseminated to field operations so that steps can be taken to rectify measures that do not meet stated objectives, i.e., clearance time. For freeway construction, performance measures are used in three ways. First, the measures help bolster priorities for freeways versus other transportation projects. They also provide justification of the one-half cent sales tax for construction of controlled access highways. Lastly, they are used by ITD to prioritize implementation.	One of the key purposes of the Travel Speed Study was to validate MAG's planning model as required by EPA. Therefore, the measures were developed specifically to meet this need. Historical performance measures reporting also is an important use of the metrics. The cyclical studies enable trend analysis; therefore, care is taken when metrics are developed or enhanced to ensure compatibility with historic data. Trend analysis is useful to pinpoint problem areas in both the long- and short-term. The bottleneck study was commissioned to address the problem areas identified in the Traffic Quality report. Performance data also serve as a basis for MAG plans and reports.
6. Los Angeles, CA	The primary use of performance measure is performance reporting. Performance is documented in two reports: the state-mandated HICOMP report and the HOV report. The information is then used for planning and program purposes on the state and local levels. Performance measures are generally not linked to investment decisions. However, they are sometimes used to justify specific programs. When fully adopted, PeMS has the potential to dramatically change the way congestion is monitored and performance is measured. PeMS retrieves information from real-time and historic database and presents the information in various forms. Its value lies in allowing planning and operations staff to base their decisions on real system performance data without spending an undue amount of resources on data collection.	SCAG performance measures are developed during the RTP process to evaluate alternatives and select the best ones for inclusion in the Plan. The performance measures are tied directly to at least one of six established RTP goals. The goals and performance measures do not emphasize the freeway system but include it as an integral part of a comprehensive transportation system that includes all modes.

Table B.5 Uses of Performance Measures (continued)

Metro Area	Operation Agencies	Planning Agencies
7. Portland, OR	N/A	The implementation of the measures and methodology will allow ODOT decision-makers to compare operations program benefits with other programs (e.g., safety, bridge, maintenance). The project provides the operations program with a process for estimating benefits, and this will help the program to identify places for additional study and investment. Finally, these methods will help define the return on operational investments.
8. Houston, TX	Very few performance goals. Some operations equipment reliability and timely repair standards are used. These goals are measured. Most use of performance measures are for real-time management of the system.	N/A
9. Washington, D.C.	*Maryland* Used for annual reporting and the development of specific strategies to meet mobility targets.	N/A
10. Atlanta, GA	The NaviGAtor staff uses the output measures for incident and staff efficiency to provide benefits information to GDOT management and to the public in a weekly newsletter format. The incident and traveler information data is published monthly and distributed to GDOT management staff and others. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The HERO (service patrol) drivers incident data is used to adjust individual patrol routes for the HERO drivers and to define the HERO divers need per shift.	N/A

Table B.6 Data Collection, Analysis, and Quality Procedures

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
1. Minneapolis-St. Paul, MN	Operations performance data are being collected by the RTMC using in-pavement loop detectors. The data is collected and stored in 30 second intervals. Incident detection and verification are done by CCTV monitoring by RTMC operators, radio calls from FIRST drivers and by calls from Minnesota State Patrol, who receive 911 cell phone calls from travelers. RTMC also shares video with the Minnesota State Patrol, MnDOT Metro District Maintenance, Metro Transit, cities, counties, and all local television stations. UMN conducts an annual ramp metering evaluation for MnDOT. The evaluation is through simulation and it is related to freeway performance. UMN is considering using some cost-based measures, such as a mainline wait time versus a ramp wait time cost comparison for the next ramp meter evaluation.	UMN-Duluth maintains the speed data archive, they receive raw data flat files daily from MnDOT. The data is collected and stored in 30 second intervals. MnDOT and UMN worked together to develop the data quality process for MnDOT. The data quality checks detect outlying and missing data. The data collection algorithm notes loss of communications, flags data that is outlying from expected values or data that is nonchanging over a specified time period, notes missing or off-line detectors and assign a substitute (fake) loop. This process is done only for historical data, not real-time data.
2. Seattle, WA	The Seattle performance measures effort is driven primarily by the existence of a significant archive of inductance loop data, which are collected by WSDOT's freeway ramp metering algorithm. This system consists of 620 loop stations comprising more than 4,080 individual loops, of which 1,020 are paired into dual loop stations and the rest are either single loops located in the freeway mainlines or on-ramps. An archive of the 20-second data is maintained at the University of Washington. In addition to the inductance loop data, WSDOT undertakes four additional, significant data collection efforts: • Vehicle occupancy data collection; • Transit ridership data collection; • Incident occurrence and response reporting; and • Public opinion surveys.	Each of WSDOT's data collection programs has a variety of quality control steps designed to increase the quality of the data collected, as well as to identify and remove from further analyses those data that do not accurately describe actual roadway conditions. The software that operate in the Type 170 traffic controllers used by WSDOT produces an eight bit error status code with each 20-second data packet transmitted from the field to the TSMC.

Table B.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
2. Seattle, WA (continued)		All vehicle occupancy data used by WSDOT are collected manually by student work crews. Data from the field are entered into personal data assistants (PDA) carried by the data collection staff as each observed vehicle passes the count location. Each field entry is time stamped as it is entered into the PDA. To ensure the quality of these data, a series of software programs has been written to determine whether staff are actually entering real observations. The two basic checks compare the speed at which timestamps are entered (too many too quickly mean that the data collector is "inventing" vehicles) and compare records against continuously repeated numbers (which is usually an indication that a data entry key is stuck in the "on" position). Once the data pass through the initial set of checks, the summary vehicle occupancy rates are checked against previous data collected at this same location.
3. Hampton Roads, VA	Surveillance data are compiled with incident data, and traffic data from selected arterial loop detectors in the Hampton Roads Archived Data Management System (ADMS). This recently developed system provides access to real-time and historical traffic volume, speed, and incident data for selected regional corridors. The ADMS server will be moved to the VDOT Central Office in Richmond in the near future. The data are managed using SQL Queries. They currently are available to registered users, including STC and HRPDC staff as well as any user requesting access for research purposes. Data analysis currently is conducted by Smart Travel Lab staff.	Traffic count data is collected by VDOT through a statewide count program. The current system uses traffic count machines at specified locations for two days of counting per year. Future plans may include use of STC data in areas where instrumentation is available. HRPDC obtains the traffic count data from VDOT for the Hampton Roads area.

Table B.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
3. Hampton Roads, VA (continued)	The data quality of STC-generated information has been hampered by loop detector failures. At any given time, only about one-half of the sensors are operational and the STC does not conduct a systematic sensor calibration process to validate the accuracy of the individual sensors. Further, their maintenance priority is the lowest among field equipment – both CCTV and VMS are a much higher maintenance priority. The operations staff does not use the speed data because of the low quality and travel speeds are reported on the traveler information web site. Realizing this problem impairs the effectiveness of the entire STC, VDOT is holding the Phase 2 contractor to much higher standards of installation quality than in Phase 1 and requiring detector calibration as part of the system delivery. The STC has developed a budget to repair, replace, and calibrate defective loop detector installed in Phase 1, however that effort has not yet been funded. The Smart Travel Lab, as part of the ADMS project management task, conducts data quality checks on the detector data. The checks can determine if a detector is on-line and is reporting data continuously.	HRPDC conducts a CMS analysis in the region once each three years. The travel speed collection is through floating cars. HRPDC plans to incorporate GPS technology in the next update of the CMS. STC data will be used in future updates when the ITS data quality is maintained. Since HRPDC obtains its data from VDOT, they do not conduct independent validation of data. The agency, however, does perform internal checks and cleaning of the data based on historical data and knowledge of local conditions.
4. Milwaukee, WI	WisDOT is enhancing and upgrading their current ITS data archiving system to support a number of initiatives, one of which is the freeway performance reporting. This upgrade is referred to as the "Data Extractor" project, and the data warehouse. The Data Extractor project is expected to make the TOC's data resources much more accessible, and will include scheduled (e.g., monthly) and ad hoc reporting functions. The core data types that will be included in the Data Extractor upgrade include: • Traffic detector data; • History of traffic detector failures; • History of traffic detector configurations; and • Lane and ramp closures.	*Loop detectors* As with most traffic operations centers, loop detector maintenance is an issue for WisDOT. The majority of their loops are double-loops for speed measurement, and they are typically installed in conduit. This installation practice helps somewhat.

Table B.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
4. Milwaukee, WI (continued)	*Complementary University Activities* The Traffic Operations and Safety Lab (Traffic Lab, or TOPS) at the University of Wisconsin-Madison is developing the TransPortal system, a data warehouse in which they hope to integrate numerous types of disparate data, such as: • Road-weather information; • Public safety/incident management; • Traffic data; and • Static information (e.g., historical crash records). The vision is that a system like this, once implemented, could be used to support operational decisions and possible state-to-state data exchanges (such as in GCM).	
5. Phoenix, AZ	Operations performance data are being collected by FMS using in-pavement loop detectors and passive-acoustic detectors. Incident detection and verification are done by closed-circuit television (CCTV) and by 911 cell phone calls from travelers. The system is linked to ADOT's Highway Condition Reporting System (HCRS) is the main conduit for reporting highway conditions to the public. The powerful computer system has the capability to automatically retrieve weather forecast and advisory from the National Weather Service. It also collects special events, road closures and detour information and communicates with TOC's central computer system to obtain incidents and roadway conditions information. Communications take place via the Internet, wide-area network, and dial-up. Data analysis is usually conducted by ADOT staff. Whenever possible, traffic counts are based on data collected by FMS. When loop detectors are not available, either because the system is down or because the survey area is outside the FMS coverage area, radars are used. The annual short-term traffic counts are done over a 48-hour period at 15-minute intervals. MAG uses two different data collection methods for the Traffic Quality report and the Traffic Speed Study: 1) overlapping aerial photography, and 2) floating cars.	The data quality of FMS-generated information has been hampered by loop detector failures. At any given time, only about 65 to 85 percent of the sensors are operational. Further, their maintenance priority is the lowest among field equipment. To account for poor detector data, an ITD staff does manual screenings. Techniques published by the Texas Transportation Institute have been helpful for this purpose. The data quality is documented and is available to those using the data.

Table B.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
6. Los Angeles, CA	*Caltrans* Caltrans has spearheaded a data archival, processing, and analysis system known as Freeway Performance Measurement System (PeMS) to facilitate performance measures calculations and analysis. PeMS includes data from roadway sensors and incident data from the California Highway Patrol and the Caltrans Traffic Accident Surveillance and Analysis System (TASAS). However, the application of incident data is not fully developed. The performance measures collected by ATMS and processed by PeMS are being fed into a newly developed Regional Integrated Intelligent Transportation System (RIITS). RIITS is a collaborate effort by Caltrans, the Los Angeles County Metropolitan Transportation Authority, and the City of Los Angeles. Its goal is to integrate traffic information from a variety of sources into one central system so to facilitate information sharing. It is accessible through the Internet (www.riits.net). The data also are being used by SCAG as basis for its transportation system analysis. *SCAG* SCAG has launched a Regional Transportation Monitoring Information System (RTMIS). RTMIS is a planning tool designed to "assist staff in monitoring and assessing the performance of the current transportation system against regional goals." RTMIS consists of four modules: highway, real-time traffic, and mapping. Four other modules are planned for future implementation. They include transit, aviation, nonmotorized, and maritime. SCAG relies heavily on Caltrans as its source of performance data. RTMIS has two input components: 1) HPMS; and 2) PeMS. Base year data are established for each mobility-related performance measure. Travel demand model is then used to project future speed and delay and calculate the travel-time savings that would result if recommended improvements are made.	The data quality of ATMS-generated information has been hampered by loop detector failures. At any given time, only about 70 percent of the sensors are operational. While there is a Detector Fitness Program in place, it receives no dedicated budget. Freeway maintenance activities are prioritized according to 1) safety, 2) roadway preservation, and 3) others. Loop maintenance is in the lowest priority category. Some detectors are not fixed for weeks or months. For this reason, it will remain a challenge to collecting quality data. Data go through a normalization process. Both sets of data, raw and normalized, are archived. Through PeMS, users can obtain information on data quality and detector health. An application has been developed in PeMS to account for poor detector data.
7. Portland, OR	The Oregon statewide procedure is based on using the HERS-ST model and an augmented HPMS data set.	No special data quality procedures undertaken beyond what normally occurs for HPMS.

Table B.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
8. Houston, TX	The data for the real-time traffic map are collected using vehicles equipped with AVI tags that are generally used for electronic toll collections on the network of the Harris County Toll Road Authority. Archived raw data has been kept since the system came on-line in 1993. The incident portion of the database is very extensive and provides details of each incident such as which lanes were closed, incident duration, and the actions taken to resolve the incident to name a few. Weather is not archived in the TranStar system. Work zone information has been archived since May 2002. Special events, work zone, and emergency road closure information are posted on the web site for each day, and for a few days in advance when known. These are text files, not numeric or database files.	On most days 100 percent of the AVI reader stations are operational at a given time. Some sensors may need to be temporarily removed because of freeway construction activities, but changes can easily be made in the structure of the look-up table of locations for matched pairs to estimate travel times such that continued data collection is not interrupted. TxDOT has a contractor provide maintenance services for the infrastructure needed to collect the AVI data; measures are in place to assure that any nonoperational sites are repaired within certain time limits. The equipment has been extremely reliable both in the field as well as in the office. A vast majority of short-term outages are a result of loss of communication or interruption of electrical service to the field sites.
9. Washington, D.C.	**Maryland –** CHART currently has traffic sensors at 1.0- to 1.5-mile spacing along some sections of I-70, I-83, I-95, I-270, I-495, I-695, I-795, and U.S. 50. The traffic sensors provide volume, occupancy, and speed. Incident data is stored in a single Excel file record. University of Maryland archives this data and compiles an annual operations evaluation report for CHART. Maryland SHA annually conducts customer surveys for the entire agency. A couple of questions regarding CHART are always included. CHART does not conduct a separate customer survey. University of Maryland has developed a methodology for estimating the benefits of incident management programs, including estimating the amount of incident-related delay. This methodology is the first cut and is being improved. **Virginia –** Virginia Transportation Research Center (VTRC) in Charlottesville receives all sensor data and archives it. VTRC conducts data quality checks. This function is being transferred to VDOT HQ. The Archived Data Management System developed for Hampton Roads is being extended to Northern Virginia. Several performance reports are available within the ADMS.	**Maryland –** Data quality checks are not yet being conducted for the sensor data. **Virginia –** As part of the ADMS development, an extensive series of quality control checks are being performed on the sensor data. VTRC tested the accuracy of the loops in 2002. They were found to 95 percent accurate. The speed data was off on many detectors and it was found that the installation quality was poor (installers did not measure the length and widths). The improperly installed loops have been corrected.

Table B.6 Data Collection, Analysis, and Quality Procedures (continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
10. Atlanta, GA	Operations performance data are being collected by the NaviGAtor system using a video detection system (VDS). The current detection system covers 222 centerline miles and consists of cameras covering each mainline travel lane at one-third-mile spacing. There are approximately 1,100 VDS detectors. The sensors collect data at 20 second intervals. Incident detection and verification are done by closed-circuit television (CCTV) monitoring by TMC operators, calls to DOT customer service representatives, radio calls from HERO drivers, and by calls from 911 centers, who dispatch the local public safety responders. The TMC provides traffic and incident data in real time to the NaviGAtor web site. The web site information also is available to be sent to PDA or cell phone users upon request. The Archived Data Management System currently is being upgraded by GDOT. The primary focus of the archived is the speed detectors (VDS). The archived data management system will eventually include the incident management system records along with the detector records. When fully operational this system will enable the various sources of data (VDS, NaviGAtor actions, HERO activities, construction activities and weather information) to be integrated and geo-located.	GDOT recently completed an analysis of the VDS data quality. The findings of that analysis are summarized as follows: • 90 percent accuracy is required to support desired applications; • The VDS manufacturers specifications allow that level of accuracy; and • Field tests found that individual camera accuracy was highly variable. The analysis concluded that several improvements should be made to the VDS: • Revise system design to provide more accurate data; • Identify and treat systematic errors to achieve accuracy and coverage to support desired data products; • Generate metadata to clearly identify data availability and validity of data sample for the user; • Update maintenance procedures and make maintenance more frequent; • Integrate other data (incident data, speed data from other sources such GPS and toll tag readers); • Identify stations that have higher probability of reporting true values, move focus from single camera accuracy to station and segment accuracy, and take advantage of redundancy and connectivity in the system; • Develop and use a data cleaning process; and • Generate truck percentage, VDS allows identification of trucks, but it currently is not used. GDOT currently is implementing the report's recommendations through an in-house VDS upgrade process.

Appendix C

Sample Questions Asked of Customers to Evaluate Agency Performance and Sample Measures

Pennsylvania Department of Transportation Highway Administration
Customer Satisfaction Survey (2002)

Survey Focus: Safety, Traffic Flow, and Ride Quality (Interstate, Traffic Routes and Secondary Roads)	
Safety	1. Prompt removal of snow and ice 2. Effective removal of snow and ice 3. Removal of debris and dead animals from roads 4. Sufficiently wide travel lanes 5. Appropriate traffic signs 6. Clearly readable traffic signs 7. Clearly visible traffic lines painted on the pavements 8. Clear sight lines on roads 9. Safe alignments 10. Smooth transitions from road to shoulders 11. Sufficient safety barriers and guardrails where needed 12. Safe on and off rams and intersections
Traffic Flow	1. Sufficient number s of travel lanes to handle existing traffic during peak periods 2. Sufficient number s of travel lanes to handle existing traffic during other times of day 3. Clearly identified travel lanes at work zones 4. Effective warning signs at work zones 5. Minimal travel delays at work zones
Ride Quality	1. Smooth road surfaces 2. Durable pavements that last a long time 3. Sufficient shoulders 4. Road repairs when needed 5. Timely completion of road repairs once work zone is established 6. Effective road repairs 7. Attractive landscaping in medians and along roadsides

Maryland State Highway Administration (SHA)
Business Plan (2004-2007)

Customer Satisfaction Goal: Provide services and products to our customers that meet or exceed their expectations.

Objective	Measure
Attain at least 80 percent overall Maryland Drivers' satisfaction rating of "A" or "B" biennially.	• Number of Maryland drivers • Number of Maryland drivers surveyed • Percentage of overall Maryland drivers' satisfaction rating SHA "A" or "B"
Annually attain at least 80 percent overall customer satisfaction rating of "A" or "B" after completion of construction projects.	• Number of customers affected by projects • Number of customers in affected areas surveyed • Percentage of external customers rating SHA "A" or "B" on outcomes of SHA projects
Attain at least 80 percent customer service rating of "A" or "B" with special interest stakeholder and partner advisory groups annually.	• Number of stakeholders in each group surveyed • Percentage of special interest stakeholder and partner advisory groups rating SHA "A" or "B"
Attain at least 80 percent "A" or "B" satisfaction rating biennially from Maryland drivers who completed the survey and also have contacted SHA.	• Number of Maryland drivers that were surveyed • Percentage of Maryland drivers who contacted SHA rating SHA "A" or "B"
Annually attain at least 80 percent rating of A or B by customers regarding SHA-maintained rest areas.	• Number of rest areas • Number of motorists using rest areas surveyed • Percentage of customers rating the rest areas as "A" or "B"
Annually demonstrate good citizenship practices in each county and Baltimore City by supporting community involvement initiatives throughout Maryland.	• Number of employees participating in community service activities on behalf of SHA • Number of events • Number of students reached • Number of school districts served • Number of Counties reached
Biennially meet or exceed the year 2000 level of internal customer satisfaction from the overall for the SHA Internal Climate Assessment.	• Total Number of Employees (includes in-house consultant and on-site contractual employees) • Number of internal customers surveyed • Rating levels of SHA internal climate assessment
Attain biennially at least an 80 percent internal customer service rating of "A" or "B" from the SHA Internal Climate Assessment.	• Percentage of employees rating SHA internal customer service "A" or "B" • Percentage of internal customer rating service "A" or "B"

Florida Department of Transportation

Customer Satisfaction Survey (2004-2005)

In both FDOT's business model and the FDOT 2004-2005 Short-Range Component and Annual Performance Report, external customer satisfaction is cited as a key performance measure and organization goal respectively. In order to determine whether it was meeting customer needs, FDOT conducted a customer satisfaction survey targeted at Florida residents, commercial drivers, elders, and Government Officials. Below are the questions asked.

Category		Item
Roadway signs and markings	1.	Spacing of exit and crossroad signs allow me enough time for travel decisions.
	2.	Overall, road signs are visible.
	3.	Road signs are clearly readable.
	4.	During the day, visibility of roadway striping and markings is good.
	5.	At night, visibility of roadway striping and markings is good.
Construction projects	6.	When FDOT construction projects were initiated in my area, I was notified through various media (newspaper, radio, television, fliers, etc.). [Note: the wording for Government Official survey different.]
	7.	When approaching a construction project, signs notifying me of the construction allowed me enough time to adjust my speed.
	8.	Construction zones were clearly marked.
	9.	Construction zones were safe to drive through.
	10.	When road construction was in progress, I was easily able to access local business.
	11.	Construction projects on state roads are completed in a timely manner.
	12.	I was satisfied with completed FDOT construction projects.
Travel Time and other roadway issues	13.	I am satisfied with the amount of time it takes to travel within local cities or towns.
	14.	I am satisfied with the amount of time it takes to travel between local cities or towns.
	15.	The overall level of traffic congestion on the State Highway System is acceptable.
	16.	Posted speed limits on the State Highway System are reasonable.
	17.	Most vehicles remain within the speed limit on the State Highway System.
	18.	Roadsides on the State Highway System are attractive.
	19.	Roadsides on the State Highway System are kept free of litter.
	20.	The timing of traffic signals allow pedestrians enough time to cross state roads.
Overall Satisfaction	21.	Overall safety on state roads.
	22.	Being able to walk safely on state roads.
	23.	Being able to ride bicycles safely on state roads.
	24.	Overall smoothness of the roads in the State Transportation System.
	25.	The transportation system provided by FDOT.

Other categories included: bike lanes and public transportation.