Guide to Effective Freeway Performance Measurement

DETAILS

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AUTHORS

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Responsible Senior Program Officer: Andrew C. Lemer

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GUIDE TO EFFECTIVE FREEWAY PERFORMANCE MEASUREMENT

This digest presents the results of NCHRP Project 3-68, "Guide to Effective Freeway Performance Measurement." The project was conducted by Cambridge Systematics, with Richard A. Margiotta as Principal Investigator.

INTRODUCTION

Freeway performance measurement uses statistical information to determine if a highway system is meeting the objectives of effectively serving the traveling public. Most state transportation agencies set such objectives and collect data on traffic and related aspects of freeway operations to assess performance. However, there are other possible users of freeway performance measures, such as metropolitan planning organizations (MPOs), freight carriers, public-transportation administrators, and emergency-services operators, and other aspects of performance than observations of traffic that are important to freeway managers and the public. No single organized framework or comprehensive set of measures for freeway performance assessment has gained widespread acceptance to serve the needs of the full range of potential users of performance information.

The objective of NCHRP Project 3-68, "Guide to Effective Freeway Performance Measurement," was to develop a guide on the effective use of freeway performance measures in operating a freeway system and in meeting the information needs of a large spectrum of potential local, regional, and national users.

This digest describes the framework for performance measurement that was developed. The Guidebook itself, presenting detailed, step-by-step procedures for measurement and reporting of freeway performance, is available as part of *NCHRP Web-Only Document 97* and may be accessed from the TRB website (www.TRB.org) where readers should search on the title of the publication. The study emphasized congestion and mobility but considered safety, operational efficiency, ride quality, environmental factors, and customer satisfaction as well.

The guide was designed to answer four primary questions: (1) what measures should be used to characterize freeway performance; (2) how can these measures be developed with available data and models; (3) how should freeway performance information be communicated to users of that information; and (4) how can freeway performance measures be used in decision making. The guide is written to address primarily the interests of state departments of transportation (DOTs) and MPOs; the latter are responsible for bringing together the interests of local governments in their areas and the state to coordinate transportation system development and management.

In the past few years, transportation agencies have sought to use performance monitoring to respond to demands for accountability to the public and state legisla-

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tures and requirements of the Transportation Equity Act for the 21st Century (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, extended the earlier legislation's emphasis on performance monitoring, particularly with regard to system operations and management. The deployment of intelligent transportation systems (ITS) technologies can make a vast amount of data available for analysis. However, challenges such as the following must be faced before freeway performance measurement becomes "standard practice" and is embedded in the transportation decision-making process:

- **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 LOS concept. The 2000 edition of the HCM 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 LOS are required to capture the effect of operational strategies, which are often more subtle than capacity expansion projects. Implementing operational strategies usually never eliminates congestion but rather improves it slightly. These effects are not captured with the broad LOS ranges recommended by the HCM.
- **Based on the data available, congestion is growing in areas of every size.** The Texas Transportation Institute's (TTI's) *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. 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 increased. Further, congestion consumed 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 in 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. This is 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

[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 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 has an extensive sensor system (485 lane-miles) and a formal incident management program from which detailed performance measures could be developed, however.

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 (e.g., identifying evacuation routes) and operations (e.g., 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.
- **Although 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 resulting from 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 the research team's work has demonstrated, freeway surveillance data generated from ITS technologies can be used effectively for these purposes.
- **In the short term, some combination of surveillance data, planning data, and modeling must be used to support freeway performance measurement.** Given that 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.
- **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 and measures and data to support them. However, the profession must move beyond the simple reporting of freeway performance trends—performance measures must be used to develop better investment decisions.

THE RESEARCH PROJECT

Although the primary objective of the project was to produce a practical Guidebook to provide 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 user," research was needed to determine what measures should be used to characterize freeway performance, what data could be used to implement these measures, how performance information should be presented to facilitate management decision making, and what are current practices related to freeway performance measurement. The project report summarized here describes the underlying research and presents in the Guidebook a comprehensive approach to measuring the performance of urban and rural freeways.

Freeways are access-controlled highways characterized by uninterrupted traffic flow. Freeway performance refers primarily to congestion and mobility, particularly the quality of traffic flow or traffic conditions as experienced by users of the freeway. Measures of this principal aspect of performance are related typically to congestion levels, travel-time reliability, and throughput, but may also include indicators related to disruptive roadway events that impede traffic flow (e.g., crashes or other incidents, weather, and work zones). The research also considered other important aspects of freeway performance: freeway safety, operational efficiency, ride quality, environmental consequences (e.g., air pollution emissions and fuel consumption), and customer satisfaction.

Research Approach

The project research sought to use current practice and recent research as a basis for developing recommendations for measuring freeway performance. There were several components of the research:

- The research team reviewed the literature and integrated their own experiences with Federal, state, and local agencies to compile a list of potentially useful performance measures and their applications.
- The team conducted benchmarking interviews with agencies in ten areas (see Table 1) to ascertain the state of the practice. Six of the interviews included multiple agencies, usually involving state operations personnel and state and local planners; four interviews were conducted with operations personnel only.
- Researchers drafted an interim report with a detailed annotated outline for a guide. The report proposed basic principles for freeway performance measures to guide the rest of the project and subsequent applications of performance measures. The NCHRP project panel was asked to review and critique these interim products.
- Following the annotated outline, the research team constructed approximately 400 annotated slides to form the basis for the Guidebook. The slides were distributed to state and metropolitan agencies in five areas and these agencies 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;
  - New York State DOT/Capital District Transportation Committee.
- Based on the validation interviews, the annotated outline was revised and analysis procedures for using ITS data were described to prepare the draft Guidebook presented to the NCHRP project panel for review.

Table 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 is 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. Cambridge Systematics is leading the evaluation.	Hampton Roads STC, VDOT Hampton Roads Planning District Commission

Table 1 (Continued)

Metro Area	Reasons for Selection	Agencies Interviewed
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 website 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 (MAG)
6. Los Angeles, California	Caltrans HQ actively involved in performance measurement for both operations and planning activities. Caltrans is funding development of an arterial monitoring system to supplement the freeway monitoring system. Real-time freeway congestion information 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 prepares an annual performance report.	See Note[b]
9. San Antonio, Texas	TxDOT Operations has shown interest in better exploiting their data resources.	CHART (Maryland)
10. Washington, D.C.	CHART very active in incident management performance measures; expansion of Hampton Roads ADMS being planned for Northern Virginia.	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 MPO in Portland (Metro) and the Eugene/Springfield area (Lane Council of Governments), academia, and the local FHWA office.

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

Benchmarking Interviews

The benchmarking interviews constituted an important element of this research effort. These interviews of more progressive agencies were designed to document what might be considered "leading-edge" applications of freeway performance measurement as a tool for system development and management. Not all of the agencies interviewed were found to have undertaken performance measurement activities. The interviews engaged both state and local transportation agencies to investigate motivations for undertaking freeway performance measurement, the types of measures being used and their specific applications, data sources and data collection activities involved in implementing performance measures, and issues of data quality. Principal findings from the benchmarking interviews are discussed later in this digest.

Guidebook Development

Both benchmarking and validation interviews provided information on technical and institutional issues that were influential in the guidebook's development. The interviews made clear the need for effective explanations of why freeway performance measurement is a useful management tool and what aspects of performance should be measured to make that tool most effective. The guidebook's development was shaped by the interrelationship of local, regional, state, and national activities in planning, design, operations, and maintenance, and by the specific mechanisms in place for data collection and analysis, that can be used for performance measurement. An understanding of the needs and interests of the broad audience for performance measures, including agency officials and system users, influenced the guide's structure. The guidebook's structure is described later in this digest.

Relationship to Other Research Efforts

At the time that NCHRP Project 3-68 was ongoing, there was much other activity in the area of performance measurement, particularly for considering congestion and mobility aspects of performance. Table 2 summarizes the principal efforts that this project's researchers reviewed and indicates the relationship of these efforts to Project 3-68. Many of these other efforts were drawn on in this project to provide examples of freeway performance measurement.

Of the projects listed in Table 2, NCHRP Project 7-15 is the closest in nature to the research undertaken in this project. 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. The project's results are meant to cover all highway types, not just freeways. NCHRP 3-68 activities were coordinated with those of the Project 7-15 team to ensure synergy and avoid duplication. The Project 7-15 results should be a useful complement to the research results summarized in this digest and the Guidebook.

PRINCIPAL FINDINGS OF THE RESEARCH

The research yielded various findings of interest to those engaged in developing and using freeway performance measures. The benchmarking interviews were a primary source of data from which these findings are drawn; Tables 3 through 7 detail relevant aspects of these interviews. The research team drew on their own experience and the interviews to derive the findings, related to the state of practice in freeway performance measurement, agency motivations for undertaking performance measurement, specific types of measures and their use, and issues related to data needed for performance measurement.

The State of Practice

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). Although the motivations of private firms and public agencies differ, many tools and principles from business are useful in both worlds. Performance measurement, which has been used in the private sector for some time, is one of these tools. Public-sector practitioners are recognizing that using performance measures allows them to improve their functions in at least three ways: (1) deficiencies are identified with better precision and improvement strategies can be better tailored to the deficiencies; (2) public relations are enhanced because statistics are reported to give the public greater assurance that professionals understand the problems; and (3) regarding characterization of freeway performance with

(*text continues on page 12*)

Table 2 Relationship of NCHRP 3-68 to Other Performance Measurement Research

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 are 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 the strategies.	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 how (1) transportation organizations structure the performance measurement function; (2) they organize and deliver performance information; (3) performance measures are used to guide decisions at levels from top management down to operations; and (4) 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.

Table 3 Benchmark-Agency 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; and a very active traveler information system, including a 511 call-in line and a heavily used website 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's) 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, fiber optic-based communications and control network installed along 31 miles of the area freeways (I-64, I-264, I-564, and I-664), 80 CCTV 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.
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, has been instituted to provide

Table 3 (Continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
		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 twofold: (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 on 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 every day 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.*	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.

(*continued on next page*)

Table 3 (Continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
5. Phoenix, Arizona *(continued)*	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.	
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 1 in the overnight and weekend periods. The Motorist Assistance Patrol and	The performance measures are primarily derived to develop a "deficiency" report and to provide data for the changeable message signs and website. 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.

Table 3 (Continued)

Metro Area	General Background Information	Motivation for Conducting Performance Measurement
	most other operational treatments operate only on weekdays. This is focused on the urban areas with very little interaction with rural areas around Houston.	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.
9. Washington, D.C.	**Maryland** CHART 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 website 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 website 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′ × 40′ located at the stopbar) and system detectors (6′ × 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 is beginning a department-wide performance measurement program.
10. Atlanta, Georgia	The NaviGAtor Program is the Georgia Department of Transportation's (GDOT's) high-tech, customer service approach to regional freeway traffic management and communications. The NaviGAtor system consists of n extensive computer-controlled, fiber optic-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 CCTV 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 4 Congestion/Mobility Performance Measures Under Consideration in Selected Benchmark-Agency 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).

respect to congestion/mobility, having information on the outcomes of investments provides high-level input to transportation programming decisions. (Note: Performance measures conventionally referred to as outcome or output are referred to herein as quality-of-service and activity-based measures, respectively; the research team found these latter terms to be more evocative of the true nature of the performance measures.)

Collection of quality data is required to build the foundation of a freeway performance measurement program. Detailed and accurate data are needed to support an effective, comprehensive freeway performance measurement program. Much of such data already is being collected in some form by ITS deployments. However, data quality has proven to be a major issue, and new data collection programs will be needed to provide some of the required data.

Measuring congestion and mobility aspects of freeway performance is not yet well developed. Based on the benchmarking interviews and the research team's experiences on other projects, the biggest need for support to develop and implement effective performance measures is in the area of congestion and mobility. Customer satisfaction, significantly linked to congestion and mobility, is not well understood or predicted by available management tools. Efforts to develop new tools is likely to be required as agencies engage more actively in freeway performance measurement.

Travel-time reliability is being recognized as a characteristic of congestion that is on an equal footing with average congestion levels. Traditionally, mobility/congestion aspects of performance have been defined in terms of average or "typical" conditions on the freeway. However, travel-time reliability, the level of consistency in travel conditions over time, is becoming a major theme for operators because it relates directly to (1) the events that cause travel conditions to vary from day to day and (2) road-users' travel experience.

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 address this issue, but more detailed articulation of the characteristics of congestion and travel-time variability are needed for effective performance measurement.

Quality-of-service (outcome) and activity-based (output) performance measures must be linked and tied to the mission of the transportation agency. Development and reporting trends in performance measures at one level of detail usually ask "why did this happen?" Practitioners need to be willing to address this question more deeply by constructing lower levels of performance measures (activity-based) linked to the upper levels (quality of service).

Performance measurement and communication of performance measures must be tailored to local needs and preferences. Local issues vary from place to place; any guidance on performance measurement must be viewed ultimately as an example rather than a prescriptive. In addition, the state of practice in reporting performance measures is evolving; practitioners must be free to try new formats and presentation techniques to communicate information to decision makers.

(*text continues on page 26*)

Table 5 Types of Performance Measures Used by Benchmark 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 95th percentile.	• HOV usage; • Roadway congestion index; • Percentage of daily travel in congestion; • Percentage of congested lane-miles in the peak period; • Percentage 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 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 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.

(*continued on next page*)

Table 5 (Continued)

Metro Area	Operation Agencies	Planning Agencies
2. Seattle, Washington (*continued*)	• 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, Virginia	**Outcome** • Speed; • Volume; and • Occupancy. **Output** • Number of total incidents by type; • Number of vehicles involved; • Number of lanes blocked; • FIRT vehicle mileage; • TOC staff availability; • Number of variable message signs; • Average times for incident duration; • Average times for response; • Miles of STC coverage; • Number of messages placed on the signs; • Availability of STC field equipment; • Percentage 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 three 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 reliabil-

Table 5 (Continued)

Metro Area	Operation Agencies	Planning Agencies
		ity. Freight-specific measures are not included, but freight is considered under the “Interconnection” qualitative assessment.
5. Phoenix, Arizona	**Outcome Measures** • Speed; • Average percentage of freeways reaching LOS E or F on weekdays; • Traffic volumes/counts; and • Vehicle occupancy. **Output Measures** • Number of total incidents; • Number of Level 1 incidents; • TOC staff availability; • Number 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 website; • Number of calls to TTG’s traveler information phone system; • Number of entries into HCRS; • Number of sites with HCRS; • Number of messages placed on the signs; • Availabilities of FMS; • Availability of HCRS; • Percentage of surveillance devices responding; • Percentage of time 511 available; • PC system availability; • Dollar of mandatory employee training; • Percentage of mandatory supervisor training; • Percentage of employees with >32 hours of training; • Years of ADOT experience; • Turnover rate; • Number of injuries; • People attending TOC tours; • Number of 511 comments; and • Percentage of responses within 10 days to constituents.	• Congestion Index (percentage of posted speed); • Travel time; • Segment delay (seconds/mile); • Stop delay (<3mph) (seconds/mile); • Average speed (percentage 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.
6. Los Angeles, California	With the exception of HOV facilities, Caltrans District 7 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 several travel time- and throughput-based	**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

(*continued on next page*)

Table 5 (Continued)

Metro Area	Operation Agencies	Planning Agencies
6. Los Angeles, California *(continued)*	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 reliability metrics to highlight the variability in travel time between origins and destinations. **HOV Facilities** *Output Measures* • Total length of HOV facilities; and • Net change in lane-miles. *Outcome Measures* • LOS during peak periods; • Travel time savings per mile; and • Daily and hourly volume on HOV facilities both in terms of the number of vehicles and of people.	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); • Percentage variation in travel time; • Percentage p.m. peak work trips within 45 minutes of home (Accessibility); and • Percentage 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.
8. Houston, Texas	• Speed; • Delay; • Incident response time for large truck incidents; and • Website 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.	N/A

Table 5 (Continued)

Metro Area	Operation Agencies	Planning Agencies
	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)** • Percentage of freeway lane-miles below congested volumes per lane.	

10. Atlanta, Georgia	**Outcome**
	• Hampered by data quality concerns. Currently experimenting with 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;
	• Percentage of time devices are available;
	• Number of media communications by outlet;
	• Website 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 6 Uses of Performance Measures by Benchmark Agencies

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 non-usage 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 drivers needed 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 are 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 operator's shift hours. The FIRST incident data is used to adjust individual patrol routes for the FIRT drivers and to define the FIRT drivers needed 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 are collected and saved, but not yet used for management pur-	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 historical 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

Table 6 (Continued)

Metro Area	Operation Agencies	Planning Agencies
	poses. The current system is stored by use of Automated Maintenance Management software and all equipment is tracked by cabinet location.	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, 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" 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, 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 LOS E or "F" on weekdays to determine if the Group's objective of operating 60 percent of the freeways at LOS 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. Last, 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 historical 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	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.

(*continued on next page*)

Table 6 (Continued)

Metro Area	Operation Agencies	Planning Agencies
6. Los Angeles, California *(continued)*	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 historical database and presents the information in various forms. PeMS' 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.	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.
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 is 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 are 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 operator's shift hours. The HERO (service patrol) incident data are used to adjust individual patrol routes for the HERO drivers and to define the HERO drivers needed per shift.	N/A

Table 7 Data Collection, Analysis, and Quality Procedures of Benchmark Agencies

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 are 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 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 are 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 outlying from expected values or nonchanging over a specified time period, notes missing or off-line detectors, and assigns 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 consisting of 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 various 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 operates 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 time stamps 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).

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Table 7 (Continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
2. Seattle, Washington *(continued)*		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, 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 to registered users, including STC and HRPDC staff, as well as any user requesting access for research purposes. Data analysis 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 website. 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 detectors 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 reporting data continuously.	Traffic count data are collected by VDOT through a statewide count program. The current system uses traffic count machines at specified locations for 2 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 3 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 are 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 the current ITS data archiving system to support several initiatives, one of which is 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	**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 7 (Continued)

<table>
<tr><th>Metro Area</th><th>Data Collection and Analysis Procedures</th><th>Data Quality Procedures</th></tr>
<tr><td></td><td>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).</td><td></td></tr>
<tr><td>5. Phoenix, Arizona</td><td>Operations performance data are being collected by FMS using in-pavement loop detectors and passive-acoustic detectors. Incident detection and verification are done by CCTV and by 911 cell phone calls from travelers. The system is linked to ADOT's Highway Condition Reporting System (HCRS), the main conduit for reporting highway conditions to the public. The powerful computer system can automatically retrieve weather forecast and advisory information from the National Weather Service. The system 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.</td><td>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.</td></tr>
<tr><td>6. Los Angeles, California</td><td>Caltrans

Caltrans has spearheaded a data archival, processing and analysis system known as Freeway Performance</td><td>The data quality of ATMS-generated information has been hampered by loop detector failures. At any given time, only about 70 percent of the</td></tr>
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Table 7 (Continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
6. Los Angeles, California *(continued)*	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 various sources into one central system so as 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 three modules: highway, real-time traffic, and mapping. Four other modules are planned for 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 modelling is then used to project future speed and delay and calculate the travel time savings that would result if recommended improvements are made.	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, 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 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 have been kept since the system came on line in 1993. The incident portion of the database is 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 website for each	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 ensure that any nonoperational

Table 7 (Continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
	day, and for a few days in advance when known. These are text files, not numeric or database files.	sites are repaired within certain time limits. The equipment has been extremely reliable both in the field as well as in the office. Most of the 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 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 are stored in a single Excel file record. U. of Maryland archives the 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 method for estimating the benefits of incident management programs, including estimating the amount of incident-related delay. This method is the first cut and is being improved. **Virginia** Virginia Transportation Research Center (VTRC) in Charlottesville receives all sensor data and archives the data. 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 be 95 percent accurate. The speed data were 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.
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 CCTV monitoring by TMC operators, calls to *DOT customer service representatives, radio calls from HERO drivers, and calls from 911 centers, who dispatch the local public safety responders. The TMC provides traffic and incident data in real time to the NaviGAtor website. The website 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. The primary focus of the archived	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 manufacturer 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;

(*continued on next page*)

Table 7 (Continued)

Metro Area	Data Collection and Analysis Procedures	Data Quality Procedures
10. Atlanta, Georgia *(continued)*	data management system 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.	• 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 is implementing the report's recommendations through an in-house VDS upgrade process.

Agency Motivations for Undertaking Freeway Performance Measurement

Four key trends are motivating local and state transportation agencies to undertake freeway performance measurement:

- **Legislative Mandates.** State legislatures are requiring government agencies to engage in performance measurement and reporting of performance statistics.
- **Agencywide Performance Measurement Initiatives.** Even in the absence of legislative mandates, DOTs and MPOs are initiating performance-measurement programs to implement a "customer focus" in their programs and to improve public relations and involvement.
- **Formal Business Planning, Particularly for Operations.** Agencies taking a formal business-planning approach to program management are finding that performance measurement is a necessary means for judging that plan targets are being met.
- **Quantification of Benefits for Freeway Programs, Particularly for Operations.** Operations personnel are discovering that their ability to compete for limited internal resources and management attention is affected by their inability to present quantitative measures of the public benefits of their proposed activities. Freeway performance measurement offers a tool that can place operations on a more equal footing with users of pavement, bridge, and maintenance management systems.

Types of Performance Measures and Their Use

Agencies are using both quality-of-service and activity-based measures to characterize freeway performance. Activity-based measures are used primarily by operating agencies, and primarily for incident-management activities and the operation of field equipment (e.g., sensors and cameras). 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. LOS as a metric is still in use in both planning and operations agencies, though it is not as widespread as it might have been in the past. Quality-of-service measures are used primarily for public reporting of agency activities.

Agencies are beginning to define more sophisticated measures for characterizing congestion and mobility performance but few such measures have been implemented. Reliability metrics have not yet found their way into widespread use. Customer satisfaction measures, where collected, are not used specifically for freeway performance measurement but rather as indicators of public opinion about how well an agency is dealing with congestion. The linking of performance measures (more specifically, performance changes over time or their level relative to preset targets) to investment decisions is not well established.

State DOTs and MPOs have, for the most part, not yet collaborated directly in developing freeway performance measurement programs. Responsibility seems to be split along traditional lines: DOTs tend to handle construction and operations while MPOs handle planning activities. Some MPOs and DOTs use similar measures to characterize freeway performance, but also develop other distinct measures for their particular agency's applications.

Issues of Data Collection, Analysis, and Quality

Agencies may use various sources to support performance measurement. Operations agencies, for example, rely primarily on archived roadway surveillance data; development of formal data-archive management systems is on the rise. MPOs may use travel demand forecasting and other models, sample-based travel-time runs from floating cars, and overlapping aerial photography. Some agencies are just now starting to use ITS data archives as a source of data for performance measures. Integration of the various available data sources [e.g., ITS roadway surveillance, events records (incidents, weather, work zones), and sample-based data] is not well developed.

Data quality, especially data from ITS roadway sensors, is a major concern of agencies and, in some cases, seemingly is deterring development of freeway performance measurement systems. Data quality issues can be traced primarily to improper installation, initial calibration, and acceptance testing of equipment, and to inadequate detector maintenance associated with funding shortfalls. When formal archived-data management systems are implemented, data quality control checks are instituted, but these checks can test only for inconsistencies based on presumed-valid ranges, theory-based projections, and/or historical observation. Methods for validating data during collection have not yet been perfected.

THE GUIDEBOOK—AN OVERVIEW

The Guidebook that is the primary product of this research is available as part of *NCHRP Web-Only Document 97*. The Guidebook takes a comprehensive view of freeway performance measurement and monitoring and can be applied across the spectrum of applications, from analysis of trends reflected in historical performance to projection of future performance as part of long-term planning processes. The emphasis of the Guidebook, however, is trend analysis, both because benchmarking interviews in this project revealed this to be an area where agencies were experiencing particular difficulty and because NCHRP Project 7-15, still in development at the time of this project's completion, was to focus on developing and applying congestion and mobility performance measures for short-, mid-, and long-range applications.

The guidance on performance measurement is based on a set of principles developed by the research team. These principles are summarized in Table 8

Applying these principles, the research team considered the experience of benchmark agencies, the team's own experience, and work described in the literature to derive a set of recommended performance measures. These measures are presented in two categories: Core measures listed in Table 9 are those that should be developed by all agencies involved with freeway performance that have sufficient data available to them to undertake such development. In cases where data are not available, agencies should undertake developing the data necessary to compute the core measures. Supplemental recommended measures, listed in Table 10, are potentially very useful for particular applications, but are not considered essential for characterizing freeway performance. The Guidebook provides detailed information on how to measure congestion, what data and analytic methods should be used to develop the core and supplemental measures, how performance measures should be reported and communicated, and how the measures may be used in decision making.

Table 8 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[1] 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 perfor-mance 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 various 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.

[1]Volume-to-capacity

TABLE 9 Recommended Core Freeway Performance Measures

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (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-hour	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

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TABLE 9 (Continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (NTOC) Measures
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	
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
Throughout (Quality of Service)					
Throughout—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
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
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

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TABLE 9 (Continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (NTOC) Measures
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
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)					
Percentage of 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
Percentage 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
Percentage 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

[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 a 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.

[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.

[g]See text for discussion.

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

[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 10 Supplemental Recommended Freeway Performance Measures

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (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 inter-changes, 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	Percentage 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	Percentage 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)[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 percentage 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 percentage of favorable response to DMS messages	Defined by survey question	Percent			Not recommended by NTOC
Usage rates and percentage of favorable response to service patrols	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response to work zone management	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response to freeway planning process	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with completed projects	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with air quality	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with long-distance travel	Defined by survey question	Percent			Not recommended by NTOC

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Table 10 (Continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (NTOC) Measures
Percentage of favorable response with pavement condition	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with highway safety (how safe it is to travel?)	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with amount of salt used on main rural highways	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with environmental aspects of road construction	Defined by survey question	Percent			Not recommended by NTOC
Percentage of favorable response with environmental aspects of road planning and design	Defined by survey question	Percent			Not recommended by NTOC
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 percentages 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
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 by 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

(*continued on next page*)

Table 10 (Continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (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; 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	Annually	

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	User-specified
Operational Efficiency (Activity-Based)[u]				
Service patrol vehicles in operation per shift	Self-explanatory	Number	Section and areawide	User-specified
Percentage of 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
Percentage of equipment (DMS, surveillance cameras, sensors, ramp meters, RWIS) in "good" or better condition	Self-explanatory	Percent	Section and areawide	User-specified

(*continued on next page*)

Table 10 (Continued)

Performance Metric	Definition	Units	Geographic Scale	Time Scale	Relationship to National Transportation Operations Coalition (NTOC) Measures
Percentage 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		

[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.
[n]Usually included in statewide surveys of public's attitudes toward 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.
[q]Usually included in statewide surveys of public's attitudes toward 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.*
[s]Usually included in statewide surveys of public's attitudes toward transportation and service provided; also may be done at the local level.
[t]Usually included in statewide surveys of public's attitudes toward 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.

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