CHAPTER FOUR

CURRENT STATE OF THE PRACTICE

A survey of state transportation agencies and MPOs was conducted in September of 2001. Thirty-five agencies responded to the survey. Nineteen of the respondents were state DOTs, with the remaining 16 agencies MPOs. Eighty-five percent of the responses were received from planning offices within these agencies, whereas only 15% of the responses were received from operation's offices. Eighty percent of the agencies in areas with populations of more than 500,000 responded that they use performance measures. The major results of the survey may indicate

- Performance measures were reported less frequently in an operational environment. This may be a product of the survey being directed to planning units in the organizations from TRB's primary organization contact. Planning-related performance measure programs typically have more visible performance measure programs in the agency. In either case, the results of the survey may be biased to performance measures in the planning arena rather than the operations environment.
- Agencies in larger (population) areas are more likely to have a performance measure program in place. This may be a result of the resources available to larger agencies or that these agencies have more complex congestion and mobility issues to manage that may not be adequately addressed by more traditional measures of effectiveness such as LOS.
- There are opportunities for improvements in transportation operations. Many agencies have not formally adopted performance measures, but rely solely on experience and intuition to understand the conditions that exist on the system or to evaluate alternative strategies for improving operations.

HOW ARE PERFORMANCE MEASURES BEING USED?

A wide range of possible applications for performance measures was reported in the research. However, the results of the survey of state DOTs and MPOs revealed that performance measures are primarily used for the following purposes:

- *Responding to legislative mandates*—There is an increasing emphasis for organizations to be accountable to legislatures or other oversight boards for the efficacy of expenditures on transportation programs. These programs are usually mandated for annual reporting and the measures derived by legislators or through rules implementing the measures in the transportation agency.
- *Planning processes, including budget and funding allocations*—These programs are usually tied to transportation policies and objectives and reported at the macroscopic level. The performance measures are included in the plans themselves or referred to as mobility performance measures. Increasingly, performance measures are being mainstreamed in agency strategic plans and long-range transportation plans.
- *Quality initiatives*—These activities are directed at improving the quality of the delivery of services by the agency to the users of transportation services. They are typically related to Deming Quality Initiatives, Total Quality Management Programs, Sterling Quality Initiatives, or the International Standards Organization's Standard 9001 efforts.
- *Congestion management systems and evaluation*—Many agencies have continued with the transportation management programs established by ISTEA and report on the progress of relieving congestion and evaluating alternatives for implementation.
- *ITS operations and evaluations*—These performance measures are intended to evaluate the benefits of providing ITS and are typically a mix of output measures and operational-related outcome measures.
- *Safety management systems*—Many agencies have continued with the transportation management programs established in ISTEA and report on the progress of making facilities safer.
- *Permit processes for commercial driveways*—Agencies use performance measures such as LOS to assess permits for driveways along highway segments.

WHAT PERFORMANCE MEASURES ARE USED?

A wide range of performance measures is currently used. Table 6 summarizes the performance measures that are used by the survey respondents and their potential application areas. The measures used by the TTI in the *Urban Mobility Report* (Lomax et al. 2001) developed each year on the nation's 68 largest urbanized areas are also commonly used (Table 7). These measures are reported annually and are commonly referenced by the media and in planning studies to compare congestion between areas. Any synthesis of performance measures for operational effectiveness of highways would be remiss without summarizing the

TABLE 6
PERFORMANCE MEASURES AS REPORTED IN THE SURVEY OF STATE DOTS AND MPOS

Performance Measure	Typical Definition	Responses
Level of service (LOS)	Qualitative assessment of highway point, segment, or system using A (best) to F (worst) based on measures of effectiveness	11.0
Traffic volume	Annual average daily traffic, peak-hour traffic, or peak-period traffic	11.0
Vehicle-miles traveled	Volume times length	10.0
Travel time	Distance divided by speed	8.0
Speed	Distance divided by travel time	7.0
Incidents	Traffic interruption caused by a crash or other unscheduled event	6.0
Duration of congestion	Period of congestion	5.0
Percent of system congested	Percent of miles congested (usually defined based on LOS E or F)	5.0
Vehicle occupancy	Persons per vehicle	5.0
Percent of travel congested	Percent of vehicle-miles or person-miles traveled	4.0
Delay caused by incidents	Increase in travel time caused by an incident	3.0
Density	Vehicles per lane per period	3.0
Rail crossing incidents	Traffic crashes that occur at highway–rail grade crossings	3.0
Recurring delay	Travel time increases from congestion; this measure does not consider incidents	3.0
Travel costs	Value of driver's time during a trip and any expenses incurred during the trip (vehicle ownership and operating expenses or tolls or tariffs)	3.0
Weather-related traffic incidents	Traffic interruption caused by inclement weather	3.0
Response times to incidents	Period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene	2.0
Commercial vehicle safety violations	Number of violations issued by law enforcement based on vehicle weight, size, or safety	1.0
Evacuation clearance time	Reaction and travel time for evacuees to leave an area at risk	1.0
Response time to weather-related incidents	Period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene	1.0
Security for highway and transit	Number of violations issued by law enforcement for acts of violence against travelers	1.0
Toll revenue	Dollars generated from tolls	1.0
Travel time reliability	Several definitions are used that include (1) variability of travel times, (2) percent of travelers who arrive at their destination within an acceptable time, and (3) range of travel times	1.0

measures of effectiveness used in the HCM. The HCM is considered the international authority on the analysis of highway segments and systems in operations and planning. Table 8 summarizes the measures of effectiveness (performance measures used to determine LOS in the HCM).

WHICH MEASURES ARE MOST IMPORTANT TO AGENCIES?

Because of the wide range of performance measures being used, a primary question is: what measures are more important to the agencies using them? The following section summarizes the survey responses.

Measures of the number of persons or vehicles served were most commonly reported as the most important measures, including

- Volume,
- VMT,
- Persons-served expressed in person-miles traveled, and
- Freight-volume served expressed in truck-miles traveled.

Use of these quantity measures for operational effectiveness does not relate to the quality of the traveling experience but to the magnitude of the persons, vehicles, or freight served. These measures are important for transportation agencies because many agency's goals and objectives include maximizing the number of persons, vehicles, or freight served at a given performance level. For example, if a transportation agency decides to add lanes to a highway, it is likely that it may continue to operate at capacity during the peak hour, but more persons, vehicles, and freight are served.

The quantity measures were cited as the most important for their ease in collection and reporting and the ability to derive other measures from these basic measures. Examples of the measures that can be derived from these measures include

TABLE 7
TEXAS TRANSPORTATION INSTITUTE'S CONGESTION MEASURES IN THE *URBAN MOBILITY REPORT*

Measure	Definition	Calculation Method
Roadway congestion index	Cars per road space	$\dfrac{\dfrac{VMT_{Freeway}}{Lane-mile_{Freeway}} \times VMT_{Freeway} + \dfrac{VMT_{Arterial}}{Lane-mile_{Arterial}} \times VMT_{Arterial}}{13{,}000 \times VMT_{Freeway} + 5{,}000 \times VMT_{Arterial}}$
Travel rate index	Amount of extra travel time	$\dfrac{\dfrac{60 / Speed_{Freeway}}{60 / FreeflowSpeed_{Freeway}} \times VMT_{Freeway} + \dfrac{60 / Speed_{Arterial}}{60 / FreeflowSpeed_{Arterial}} \times VMT_{Arterial}}{VMT_{Freeway} + VMT_{Arterial}}$
Delay per eligible driver	Annual time per driver	Total delay (includes recurring and incident delay) per eligible driver
Delay per capita	Annual time per person	Total delay (includes recurring and incident delay) per person
Wasted fuel per eligible driver	Extra fuel due to congestion	Difference between fuel consumption in existing conditions and fuel consumption based on free-flow speeds per driver
Wasted fuel per capita	Extra fuel due to congestion	Difference between fuel consumption in existing conditions and fuel consumption based on free-flow speeds per driver
Congestion cost per eligible driver	Annual "tax" per driver	Costs in dollars of congestion based on comparison of existing conditions and free-flow conditions per eligible driver
Congestion cost per capita	Annual "tax" per capita	Costs of congestion based on comparison of existing conditions and free-flow conditions per eligible driver

TABLE 8
HIGHWAY SEGMENT AND SYSTEM PERFORMANCE MEASURES

Facility Type	Performance Measures
Basic freeway section	Density (passenger cars per hour per lane)
Weaving area	Density
Ramp junctions	Density
Freeway facilities	Average vehicle speed
Multilane highways	Density
Two-lane highways	Percent time delay
Signalized intersections	Average vehicle delay
Unsignalized intersections	Average vehicle delay
Arterials	Average vehicle speed
Interchanges	Average vehicle delay

(Adapted from *Highway Capacity Manual 2000*).

- Fuel consumption,
- Noise impacts, and
- Air quality impacts.

It should be noted that the measures that were reported as the most important to the agency may or may not be the most important to the users of the transportation system. Several of the research and transportation agencies evaluated in this synthesis reported the need to better define what measures are the most important to the users. Strategies such as stated-preference surveys and psychometric studies were identified as potential techniques to better determine what performance measures and operational characteristics are most important to the users.

The following measures were also identified as indicators of congestion levels.

- Measures of the quality of travel or congestion levels were the second most commonly reported most important measures. Examples of these measures included
  - V/C,
  - Delay,
  - LOS,
  - Speed, and
  - Travel time.
- Other measures that were reported as the most important included

- Safety measures
  - Crashes or incidents per million VMT, and
  - Severity of crashes (fatality, injury, or property damage).
- Reliability,
- Efficacy of freight movements,
- Capital costs in proportion to travel time,
- Accessibility,
- Environmental
  - Air quality, and
  - Noise.
- Equity/environmental justice,
- Cost-effectiveness,
- Vehicle occupancy and HOV lane performance,
- Pavement and bridge condition,
- Percent of system congested,
- Number of miles operating at desired speed ranges,
- Queuing of traffic,
- Performance measures derived from ITS data
  - Predictability of travel times,
  - Reliability of travel times,
  - Number of incidents,
  - Number of stops for assistance,
  - Number of stops served by service patrols,
  - Incident response times, and
  - Percent of ITS equipment operational.
- Customer satisfaction (users and partners)
  - Ease of driving through construction zones,
  - Ease of driver licensing,
  - Payment of fees and taxes,
  - Ability to bid projects and receive bid information timely and accurately, and
  - Streamlined procedures for contracting.

From this long list of congestion-related measures, there was no consensus among agencies as to what are the most important performance measures. However, performance measures that describe the number (quantity) of persons (or vehicles) served and the quality of travel were the most commonly reported.

HOW LONG HAS YOUR AGENCY USED PERFORMANCE MEASURES?

The study found that the age of performance measures programs varied greatly. Several agencies based the age of their performance measures' system on the age of traffic monitoring systems, such as HPMS, which can be 50 years old. Twenty-nine agencies reported the age of their programs; the average age was 14 years, the median and mode were both 10 years. This is consistent with the literature review, from which it was determined that a significant increase in published performance measures-related research occurred in the early 1990s. Some agencies are currently developing more comprehensive performance measures programs.

WHAT MEASURES ARE USED IN OPERATIONS?

Operators of limited access facilities—interstates, expressways, tollways, etc.—and operators of arterial road networks of all shapes and sizes have the need for some form of data and performance measures to support management functions. Basic core management functions are those functions that are generally applicable to all types of highways regardless of their classification or use, although the specific operational requirements, the associated information needs, the methods/technologies for collecting the information, and the level of deployment of data collection infrastructure may vary significantly.

Traffic Control

Traffic control often varies by roadway category. For arterials this may include traffic signal coordination, whereas for expressways this function may include ramp metering and interchange control. Other potential traffic control subfunctions include reversible lane control, variable speed limits, and integrated expressway—arterial control. Evacuation, special event, and military deployment routes usually have special traffic control needs. Performance measures that are commonly used for traffic control include

- Travel speeds,
- Travel time,
- Delay,
- Bandwidth,
- Queue length,
- Green time per cycle length,
- Cycles of delay per vehicle (the number of cycles a vehicle must wait prior to being given green time), and
- Throughput (passenger cars per hour).

Incident Management

Incident management includes both predicted and unexpected incidents, so that the impact on the transportation network and traveler safety is minimized. Activities include incident detection, verification, diagnosis, response (e.g., routing and tracking response vehicles), diversions, and clearance. Incidents include vehicular accidents, or crashes, in addition to other types of lane or roadway closures. Typical performance measures that are used in incident management systems include

- Crash rates;
- Crash type and location;
- Additional delay attributable to crashes;
- Average vehicle speeds and travel times (used to identify where crashes may have occurred);
- Cost of police traffic management operations;

- Emergency vehicle response times;
- Queue dispersion time;
- Incident detection, response, and clearance times; and
- Location and status response vehicles.

Traveler Information

Traveler information functions include providing information to en-route motorists through roadside elements such as dynamic message signs and highway advisory radio transmitters. The information collected can also be used for information dissemination to travelers by other means (e.g., Information Service Providers, radios, and other in-vehicle devices). These applications include Advanced Traveler Information Systems (ATIS).

System Coverage

Since 1999, ITS America and the U.S.DOT have focused on the data needs to support traveler information and the performance measures that are needed to support these needs. Those involved reviewed multiple market research reports and concluded that a survey of Washington State DOT traffic website users provides a reasonable representation of traveler information users in general. The following listing summarizes the relevant questions with the most frequent answers listed in order of popularity.

- Why use the website?
  - To assess traffic congestion on their route,
  - To judge the effects of incidents on their trip,
  - To decide among alternate routes,
  - To estimate their trip duration, and
  - To time their trip departure.
- What benefits are perceived from use?
  - Saved time,
  - Avoided congestion,
  - Reduced stress, and
  - Avoided unsafe conditions.
- What action results from the information?
  - Changed route or time of departure to maximize trip time.
  - Changed route or time of travel to reduce the stress of driving in congestion, perhaps lengthening trip distance or duration.
  - Adjusted expectations; listened to an audiotape book, made phone calls, changed appointments, and made alternative arrangements.

Based on these needs, ITS America identified specific data requirements to support traveler information. The following performance measures and data were determined to be the most needed in ATIS applications:

- Average travel speeds or times,
- Reports of abnormal events along their route,
- Images to view the route for themselves, and
- Route-specific weather conditions.

Weather Management and Snow/Ice Management

Weather management includes detecting and forecasting weather—related hazards such as snowy/icy road conditions, dense fog, high winds, and approaching severe weather fronts. This knowledge can be used to more effectively deploy road maintenance resources. It can also be used in conjunction with other core functions such as traffic control (e.g., variable speed limits and signal coordination timings), incident management (e.g., routing response vehicles), and traveler information (e.g., general advisories and location-specific warnings).

Snow/ice management is applied to regions that experience snowfall and includes identifying the potential loss of vehicle traction, maneuverability and/or stability, the need for plowing (maintenance vehicle dispatch), lane(s) obstructions or other impairments to plowing, need for chemical application, low/loss of visibility, other impairments to vehicles/crews, short-term weather forecasting, and monitoring maintenance vehicles. Snow/ice management may be considered a specialty function of the overall weather management core function.

Performance measures associated with weather management and snow/ice management are used to describe air and road surface temperature, visibility, humidity and precipitation, wind speed and direction, road surface condition to characterize local climate, and roadway conditions.

Highway operators also often have the need to support additional management functions. Although not applicable to all operators, these functions are discussed here.

Freight Management

Freight management is applied on freight routes and includes gathering vehicle classification information. It may also include automated clearance at roadside facilities, automated clearance at border crossings, ramp rollover warnings, downgrade warnings, monitoring vehicles carrying hazardous materials, and monitoring and warning over vehicle height. Performance measures to support freight management include vehicle length, height, and weight, and the number of axles that can be used to identify the individual characteristics of passing vehicles. Some motor carrier compliance offices on brake conditions also accumulate safety inspection statistics. Although not reported in the survey, some agencies report truck crashes as separate from total accident rates. Commercial vehicle enforcement/inspection times and costs are also used.

Military Deployment Management

Military deployment consists of traffic control and incident management functions situated along military deployment routes. Performance measures associated with military deployment management are similar to traffic and incident management performance measures with the addition of estimated time to arrive measures that predict a travel time along a desired route.

Special Event Management

Special event management is the management of traffic during special events, whether a one-time event, an annual event, or recurring events such as sporting contests or school holidays. Performance measures associated with special event management are similar to traffic and incident management and include basic traveler information functions, but may also include performance measures related to clearance times (time for vehicles to clear an event center or the time required for evacuees to depart a dangerous area) and parking management measures (percent of spaces occupied and space turnover rate) for special event management.

Evacuation Management

Emergency evacuation management is traffic control and incident management functions applied on evacuation routes. Performance measures associated with evacuation management include measures associated with traffic and incident management and traveler information functions, but may also include operational performance measures such as speeds, volumes, and delays.

Survey Results

Most of the applications for performance measures identified through the research and the survey of state DOTs emphasized planning rather than operational uses. Many of the responding state DOTs reported very little formal development or long-term monitoring in operations. Only seven state DOTs (36% of the DOT respondents) reported the use of any performance measures in real-time. (MPOs are typically not involved in the operations of highway segments and systems and were not expected to provide operational performance measures.) Speed or travel time and incidents were the only measures that were reported used in real-time. The primary uses of these measures were in ITS operations centers or for providing data to travelers through ATIS. The performance measures reported to be used in operations included

- Travel time data for signal timing analysis,
- Safety measures to identify crash prone locations,
- Pavement and bridge conditions to prioritize maintenance activities,
- Construction project management, and
- ITS operations measures to support
  - Freeway traffic management,
  - Incident management, and
  - Traveler information systems.

An analysis of the results of the survey indicated that there are two possible explanations of the survey results: (1) that many measures are available and can be used to support operations, but few are actually put into practice or (2) that the survey respondents were directed to planning offices within their agencies and the use of performance measurement in operations is underreported.

State DOTs typically collect data for their entire state-maintained system either through the measurement of all components or through sampling. MPOs rely principally on state DOTs for their data collection, but the system they are concerned with is more expansive, considering all major public roads. Accordingly, MPOs typically reported a significantly lower percentage (30–50%) of coverage. These results are similar to the analysis of data system coverage reported in the literature.

WHAT OTHER MEASURES ARE BEING USED?

Several other agencies reported agency performance measures that relate more to performance (outputs) of the agency than the outcomes (conditions experienced by the user). These measures include

- Performance-based budgeting,
- Number of guardrail blunt ends,
- Percent of railroad crossings actively protected,
- Weigh-in-motion,
- Video log images,
- Ability to achieve strategic objectives,
- Sufficiency index of geometric and pavement conditions, and
- Number of signals retimed per month.

WHAT OTHER USES FOR PERFORMANCE MEASURES WERE REPORTED?

Although this synthesis emphasizes the use of performance measures for the operational effectiveness of highway segments and systems, many of the respondents reported alternate uses of performance measures for other than highways that included

- Transit,
- Bicycles,
- Pedestrians,
- Control of outdoor advertising,
- Justifying involvement of emergency services,
- Grant writing,
- Staff appraisals,
- Snow and ice operations performance, and
- Organizational performance index.

WHO ARE THE INTENDED AUDIENCES FOR THESE MEASURES?

The agencies responding to the survey of state DOTs and MPOs and the literature review were very consistent in the intended audiences for performance measures. These audiences included decision makers within their agencies, partner organizations, and the public as follows:

- Governor's office,
- Legislature,
- Agency management,
- Agency staff,
- Elected officials,
- Other agencies
  - FHWA,
  - State DOTs,
  - MPOs, and
  - Municipalities,
- Public.

HOW ARE PERFORMANCE MEASURES REPORTED?

The typical performance measures report occurs on an annual basis and is part of a transportation plan document. The measures are reported using a combination of written text (9%), tables (37%), charts (24%), and maps (24%). The report is typically made available on a website or published electronically on CD-ROM. The operational performance measures are used in ITS operations centers and may be disseminated using ATIS through a variety of media including television, radio, websites, and subscription-based services.

HOW ARE DATA COLLECTED IN SUPPORT OF THE PERFORMANCE MEASURES?

A recent analysis of the Metropolitan ITS Deployment Tracking Database, a repository of deployment data for the 78 largest metropolitan areas in the United States, indicates that 70 of the 78 areas (90%) are gathering at least some type of traffic flow, incident, or transit vehicle location data. Figure 5 summarizes several key categories of data collection by their total aggregated deployment in the 78 metropolitan areas as reported in 1997 and 1999 and projected in 2005. The analysis also indicates that only a handful of areas collect data over a large portion of their region. In 2000, for example, 39 metropolitan areas reported some sort of freeway surveillance, but only 9 areas reported covering greater than 50% of their total mileage. By 2005, 27 areas project that they will have 50% or more of their freeways under electronic surveillance.

No definitive information exists to characterize data collection deployment beyond these top 78 metropolitan areas; however, the consensus is that deployment is quite limited.

Data Collection Techniques

The following section summarizes the major data collection techniques for gathering transportation system status data.

Traffic Sensor Data

Data of this type are speed, travel time, volume, vehicle classification, and occupancy or other numerical measurements used to characterize the flow of vehicles at a specific point or over a specific segment of a roadway. These data can be generated from many types of detection systems, such as loop detectors, microwave, infrared or sonic detectors, video image detection, automatic vehicle identification, license plate matching systems, and wireless phone probes. Volume, occupancy, classification, and speed data are typically collected at a point in the roadway (point data). Travel times are currently estimated based on "spot data" due to the costs of manually collecting these data historically. Ideally, these data will be collected over a section of a roadway using probe vehicles or other emerging technologies.

Incident/Event Reports

These data are characterized by descriptive information on planned or unplanned occurrences that affect or may affect traffic flow. Information on incidents such as construction/maintenance, events, road conditions, weather conditions, and crashes is also collected. These data are usually manually entered into a "system," although they can be stored and communicated either as text or through numeric codes. The manual entry into a system is the key differentiation from the traffic sensor data type. Recent advances in center-to-center interface standards will allow data communication between centers and the automatic saving of data in the databases. There are several types of road-related incidents/events, including

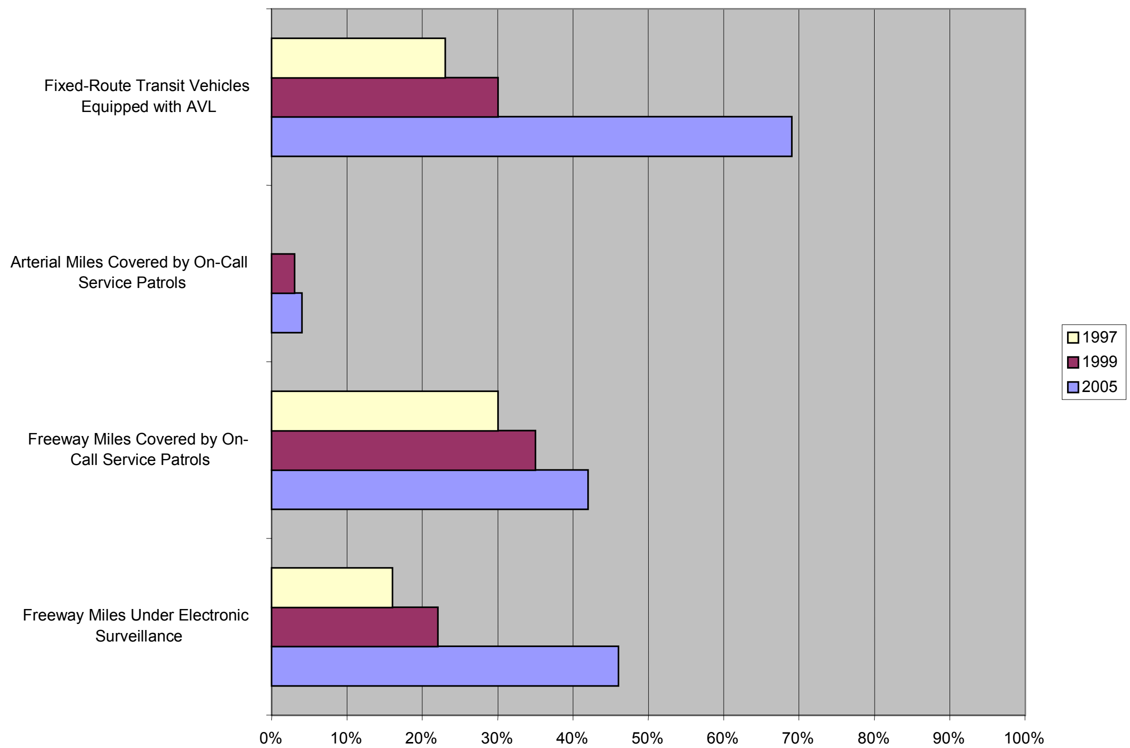

FIGURE 5 National summary of deployment (by percent deployment opportunity).

- Crashes, breakdowns, or other unplanned vehicle stoppages;
- Planned or emergency roadway construction or maintenance;
- Special events;
- General road conditions;
- General weather conditions;
- Traffic control device malfunctions; and
- Disasters.

There are currently no national standards or guidelines. Although police-investigated traffic accidents are usually reported in consistent formats from region to region, a national data definition effort is needed to record and analyze these data. Video images are commonly used to monitor the start and clearance time of incidents. Algorithms based on traffic characteristics collected using traffic sensor data can also be used to determine incident durations, but video is usually preferred.

Images

These data represent a snapshot of a roadway to give a visual depiction of current traffic conditions and are used primarily by operators. Images give a quick impression of traffic conditions that can be easily assessed by operators or travelers. However, this type of data is not conducive to deriving detailed information, such as that which can be provided by traffic sensors. The data quality of images also varies from single images to broadcast quality video.

Road/Environmental Sensor Station Data

These data encompass a wide array of sensors including those that monitor weather, roadway, surface, and air/water quality conditions. These sensors can provide roadside data such as

- Elevation/atmospheric pressure;
- Wind data: direction, speed, gust direction, gust speed;
- Temperature: air, wet-bulb, dew-point, 24-h maximum, 24-h minimum;
- Humidity/precipitation: relative humidity, adjacent water depth, adjacent snow depth, roadway water depth, roadway snow and packed snow depth, precipitation indicator and type, precipitation rate, snowfall accumulation rate, ice deposit (thickness), precipitation start time, precipitation end time, total precipitation past *X* hours;
- Radiation: solar radiation, total sun, cloud cover situation;
- Visibility: surface visibility (measured in tenths of a meter), visibility situation (clear, fog, smoke, sea spray, blowing sand/dust, sun glare, insect swarms);

- Pavement sensing: pavement type, elevation, solar exposure, surface status (dry, moisture trace, wet, chemically wet, ice warning/watch, snow warning/watch, absorption, dew, frost), surface temperature, pavement temperature (2–10 cm below surface), surface water depth, surface salinity, surface conductivity, pavement freezing point, surface black ice signal, subsurface type, subsurface temperature, subsurface moisture;
- Pavement treatment: number of treatments, treatment type/mix (sand, dirt, gravel, cinders, water, salts, etc.), treatment form (dry, pre-wet, liquid), treatment amount (kilograms per lane-kilometer), treatment width; and
- Air quality: carbon monoxide, carbon dioxide, nitrous oxide, nitrous dioxide, sulfur dioxide, ozone, particulate matter.

Other Data Collection Techniques

Other data collection techniques identified by respondents included

- Accelerometers (profilometer) for road surface condition, bridge inspection, and pavement condition;
- Accident reports;
- Aerial photo surveys;
- Census data for population and employment;
- Floating car studies;
- Roadway characteristics inventories—for basic geometric and traffic control information;
- Railroad crossing inventory;
- Project-specific information;
- Customer survey;
- Modeling/estimation; and
- Travel survey.

Table 9 summarizes the results of the survey and includes other known professionally accepted data collection techniques.

Data collection occurs over a wide range of frequencies. This is a function of the requirements for data reporting and helps determine whether data will be used for planning applications or operations. Data to be used in the support of planning applications are typically collected once per year or sampled once every 3 years and used to estimate annual conditions. Several agencies reported quarterly data collection; however, these were for smaller systems. Volume, counts, and speed information are collected using roadside equipment such as inductive loops or microwave radar traffic monitoring systems. Travel time studies using floating car methods or travel surveys are performed less frequently; that is, every 5 or 10 years or when there is a specific project need.

Operational-related data are principally derived from ITS systems, and the frequency of data reporting ranges from 5 s to 5 min.

Typically, state DOTs are fully responsible for the standards and requirements for data collection and data collection activities to support performance measures. In some cases, the state DOT partners with one or more local agencies to provide some of the data. These data collection activities may be performed by agency staff or by consultants who use agency standards and criteria. Validation of local agency data may be performed by the state DOTs, with the exception being safety data, which are typically provided by law enforcement agencies and compiled and analyzed by the state DOTs.

Costs of Data Collection Systems in Support of Performance Measures

To reduce costs most data collection systems for performance measures rely on traditional data and reporting systems such as the HPMS. Where additional data collection is needed to support measures that cannot be derived from the other data sources, new data collection systems are required. However, the costs are typically integrated in congestion management or monitoring systems to cover all activities. Several agencies provided estimates of the costs of their data collection programs to support performance measures. The data provided were expressed in full-time equivalents or actual dollars. These data were converted to dollars based on an equivalent cost (including overhead and benefits) of $100,000 per annual full-time equivalent for office staff and $50,000 per year for field staff (Table 10).

For many agencies, funding to support this data collection has evolved over time as a part of the transportation planning process. Agencies with active programs identified funding to support the data collection as part of the institutional change that led to their implementation. Several agencies reported allocation of the funding through their business planning process, quality initiative, or in response to legislative mandates.

The typical funding programs used included federal and state programs. Federal PL (planning) funds, planning and research funds, and surface transportation programs were the most commonly cited sources of the funding. Several agencies reported using internal operational funds to support their programs.

HOW ARE THE DATA STORED AND WHO IS RESPONSIBLE FOR THE DATA?

Data are typically stored in a mainframe or personal computer database. Several agencies reported that no single

TABLE 9
DATA COLLECTION TECHNIQUES AND TYPE OF DATA PROVIDED

Technique/Technology	Data Element
Customer surveys	Customer satisfaction
	Incident response times
	Satisfaction with maintenance/construction zones
	Satisfaction with traveler information
	Satisfaction with HOV lanes
	Satisfaction with ramp meters
	Satisfaction with service patrols
Travel surveys	Origin–destination
	Number of daily trips and purpose
	Trip-based travel time
	Travel predictability
	Congestion tolerance
Inductive loops	Traffic volumes and classification
	Density (indirectly through vehicle occupancy)
	Speed
	Lane occupancy
Other nonintrusive vehicle detectors[1]	Traffic volumes and classification
	Density
	Speed
	Lane occupancy
Video surveillance[2]	Incident detection
Probe vehicles[3]	Travel times
	Speeds
Modeling/estimation[4]	Capacity
	LOS
	VMT
	Evacuation clearance time
	Percent system congested
	Percent travel congested
	Duration of congestion
	Travel times
	Speed
	Benefits
	Queuing
	Delay
	V/C ratio

Note: This table does not include all of the data collection techniques reported, but only the results that were reported most often. HOV = high-occupancy vehicle; VMT = vehicle-miles traveled; LOS = level of service; V/C = volume/capacity.

[1]Includes hoses/tubes, radar, acoustic, video, and seismic technologies.
[2]Does not include video detection: surveillance use only.
[3]Using transponders, license plate surveys, and global positioning systems (GPS).
[4]For existing and forecasted data using travel demand models, unique models, or simulation models.

TABLE 10
COSTS OF DATA COLLECTION PROGRAMS

Statistic	MPOs	DOTs
Mean	$278,000	$5,966,667
Median	$200,000	$2,500,000
Mode	$200,000	
Minimum	$5,000	$200,000
Maximum	$1,200,000	$25,000,000
Count	12	9

Notes: MPOs = metropolitan planning organizations; DOTs = departments of transportation.

person or office was responsible for the storage of data, but rather a distributed approach was used for the storage and responsibility of data. Several agencies did report a centralized approach within their traffic monitoring office. Typical data storage was for 5 to 10 years. However, other agencies reported that data were stored for an indefinite period.

ROLE OF INTELLIGENT TRANSPORTATION SYSTEMS IN OPERATIONAL PERFORMANCE MEASURES

ITS are the application of communication and information technology to traffic and incident management. The use of information collected using ITS technologies is the primary operational environment where performance measures are most likely to be employed. ITS technologies and strategies also provide the greatest opportunity to share resources in the collection of data needed to support mobility performance measures. To understand the potential for partnerships within this area, a review of the use of performance measures associated with ITS was performed. This review consisted of a study of national and statewide documents and the reporting of performance measures associated with ITS, and a survey of practitioners to determine the state of the practice of performance measurement in ITS.

Federal ITS Performance Measures

The Joint Program Office of the U.S.DOT is very active in the testing and evaluation of a number of performance measures. The primary measures recommended at a national level are used in the program review of major metropolitan ITS systems and benefits evaluation of system deployment. The measures employed in these analyses include

- Safety
  - Reduction in crash rates—Total, fatalities, and injury.
- Mobility
  - Reduction in travel time delay,
  - Reduction in travel time variability, and
  - Improvement in customer satisfaction.
- Efficiency
  - Increased throughput,
  - Productivity, and
  - Reduced travel costs.
- Energy and environment
  - Reduced emissions, and
  - Reduced energy consumption.

Each of these measures has been deployed and tested in major metropolitan ITS systems. National statistics have been extrapolated for many of the measures to summarize the estimated benefits of ITS.

Performance Measures Used in ITS Operations

As part of Florida's ITS strategic plan (PB Farradyne 1998) a survey was conducted involving 23 state DOTs and ITS operating agencies throughout the United States. Fifteen of the 26 agencies contacted provided either a written response to the survey form or forwarded relevant documents. These respondents are listed here.

- Gary–Chicago–Milwaukee Priority Corridor,
- Colorado DOT,
- I-95 Priority Corridor,
- Washington State DOT,
- Virginia DOT,
- Wisconsin DOT,
- Houston Priority Corridor,
- Minnesota DOT,
- Missouri DOT,
- California DOT,
- Maryland State Highway Administration Coordinated Highways Advisory Response Team (CHART),
- New Jersey DOT,
- Texas DOT, and
- Utah DOT.

At the time of the survey, 8 of the 11 agencies that responded to this question were not monitoring the performance of ITS equipment. Three agencies (Washington, Houston, and California) were conducting performance monitoring. Washington uses loops to determine speed and travel time, Houston uses toll tag readers to monitor speed, and California conducts studies at specific locations using different equipment and methods. The Florida DOT does not have a formal process for monitoring ITS performance, but some districts collect performance data on many individual ITS projects and use these data in operations management.

Performance measures used in operational management of highway systems and segments are usually associated with ITS and include delay and incidents. Observations of delays and incidents in real time in the highway environment result in the deployment of incident response teams, deployment of traveler information through roadside information signs, and other ATIS. Information on delays and travel times are used to influence traveler route and timing decisions.

DIFFERENCES BETWEEN RURAL AND URBAN SYSTEMS

The performance measures identified in the research literature and transportation agency applications were oriented toward urban highway segments and systems, but are not exclusively urbanized in nature. Many of the performance measures identified and discussed in this synthesis are applicable to both urban and rural applications.

However, the data requirements and reporting of these measures may be quite different because the audiences are different. Users interested in urban data tend to be commuters familiar with roadway networks and systems and who in an operational setting are more willing to make travel behavior or route changes. Commercial intercity travelers may be sensitive to small changes in travel times and speeds and be willing to alter their travel behavior or change their route. However, passenger intercity travelers tend to be less sensitive to small changes in travel times or speeds and are less willing to alter travel behavior or change route, particularly if it is for a nonwork-related purpose. In urban applications, estimating travel times using "spot speeds" is generally considered reliable for extrapolating trip travel times along corridors; however, in rural segments of any significant length (greater than 20 mi) probe data techniques are needed to reliably estimate travel times.

HIGHLIGHTS OF FEDERAL, STATE, AND LOCAL AGENCY PRACTICES

This section summarizes some of the federal, state, and local agency practices in the areas of performance measures for the operational effectiveness of highway segments and systems.

Federal Highway Administration

This annual *Performance Plan and Performance Report* documents the overriding mission, vision, goals, objectives, and measures of the FHWA. Within this plan, performance measures are tied to specific strategic goals and benchmarks are established for desired outcomes. The report includes trend charts and tables and specific strategies that will be employed to achieve the target benchmarks. The following list summarizes the measures used.

- Safety
  - Fatalities per 100 million VMT,
  - Number of highway-related fatalities,
  - Highway-related injuries per 100 million VMT,
  - Number of highway-related injuries (millions),
  - Accidents per 100 million VMT, and
  - Number of accidents.
- Mobility
  - Percentage of VMT on National Highway System (NHS) pavements with acceptable ride quality ($IRI \leq 170$ in./mile; IRI = international roughness index);
  - Percentage of bridge deck area classified as deficient for all average daily traffic (structurally deficient or functionally obsolete), reported for NHS and other bridges;
  - Percentage of those satisfied with the nation's highway systems;
  - Percentage of travel under congested conditions;
  - Percentage of additional travel time caused by congestion;
  - Annual hours of delay;
  - Increase in system reliability (to be defined); and
  - User satisfaction with operations of the highway system (to be defined).
- Productivity
  - Growth in congested travel,
  - Growth in congested delay,
  - Cost of highway freight per ton-mile (to be determined),
  - Hours of delay at border crossings (to be determined),
  - Travel time of key freight corridors (to be determined), and
  - Use of engineering/economic analysis tools for assisting benefits.
- Human and natural environment
  - Level of community satisfaction,
  - On-road mobile source emissions in short-tons, and
  - Wetland replacements in acres.
- National security
  - Percentage of miles on the Strategic Highway Network (STRAHNET) for defense mobility with $IRI \leq 170$ in./mile,
  - Percentage of STRAHNET bridges rated deficient, and
  - Percentage of STRAHNET routes under bridges with clearance greater than 16 ft.
- Organizational excellence
  - Customer/partner rating of the timeliness of decision making, usefulness of information, and competency of personnel;
  - Employee job satisfaction;
  - Percentage of payroll for training and development;
  - Percentage of obligations expended; and
  - Number of months to process documents required by the National Environmental Policy Act.

The mobility measures that are applicable to the operational effectiveness of highway systems and segments were derived from the FHWA's HPMS.

Intelligent Transportation Infrastructure Program

The U.S.DOT's Intelligent Transportation Infrastructure Program (ITIP), which was established in the Transportation Equity Act for the 21st Century (TEA-21), was a first attempt to document a core set of performance measures and data collection standards for use in operations and planning. Under this program, a preselected private partner will deploy a system in the selected area(s) that will result in the ability to measure the operating performance of the roadway system at a regional and national level. Specifically, the primary objectives of the program are

- To accelerate the integration and enhancement of intelligent transportation infrastructure in major metropolitan areas to enable and help manage the continuous monitoring of the roadway system for purposes of providing real-time as well as archived data to aid in the operation, planning, analysis, and maintenance activities of the U.S.DOT and state and local agencies;
- To enhance the quality, availability, and accessibility of transportation system performance data to enable the calculation of mobility performance and system reliability measures while at the same time satisfying system operational needs;
- To provide performance data and reports to the U.S.DOT;
- To provide a traveler information service that includes free public access to basic traveler information and supports the provision of a 511-based telephone service;
- To realize and publicize the benefits of regionally integrated and interoperable intelligent transportation infrastructure capable of supporting regional as well as national needs; and
- To provide private technology commercialization initiatives to generate revenues that will be shared with the transportation agencies.

TABLE 11
INTELLIGENT TRANSPORTATION INFRASTRUCTURE PROGRAM PERFORMANCE MEASURES

Performance Measures		Description
Annual person-hours of delay	=	daily vehicle hours of delay x 250 working days per year x 1.25 persons per vehicle
Percent congested travel	=	(VMT under congested conditions)/(total VMT for the area)
Travel rate index	=	(travel time under congested conditions)/(travel time under uncongested conditions)
Travel time percent variation	=	[(standard deviation)/(average travel time)] × 100%
Travel time buffer index	=	$\dfrac{\text{95\% confidence travel rate (in minutes per mile)} - \text{average travel rate (in minutes per mile)}}{\text{average travel rate (in minutes per mile)}} \times 100\%$
Travel time misery index	=	(average of the travel rates for the longest 20% of the trips) – (average travel rates for all trips)

Notes: VMT = vehicle-miles traveled.

The ITIP is designed to use and enhance existing surveillance infrastructure, while also allowing for the deployment of supplemental surveillance infrastructure. The proposed system must accommodate

- Creation of a process and mechanism to collect, integrate, archive, manage, and report new and existing transportation data for mobility and performance monitoring, planning, evaluation, and other similar purposes;
- Creation of a data repository for new and existing real-time traveler information for dissemination to the traveling public through a variety of delivery mechanisms, including support for a 511-based telephone service, provision of free basic traveler information to the public, and commercial traveler information services;
- Creation of a regional transportation information system that integrates and supplements existing surveillance infrastructure to support public sector transportation management needs and private sector commercialization;
- Accommodation/integration of existing transportation data collection, archiving, and dissemination mechanisms; and
- Collection of data primarily through wireless transmission along with some shared wide-area networks.

Additionally, the system must be operational within 1 year of the date of award.

The U.S.DOT will make $2 million available to each selected area through the Intelligent Transportation Omnibus Procurement contract vehicle. A 20% matching share totaling $500,000 must be provided in cash from nonfederally derived funding sources (either state, local government, or other private sector partners). Mobility Technologies, the selected contractor, will also contribute $500,000 in private funds to this project.

A set of national performance measures was designated and is supported by standards for data collection under this program. Tables 11 and 12 summarize these measures and the data standards.

California Department of Transportation

Performance measures should relate to outcomes describing cause-and-effect relationships that involve owners/operators and users. Outcome measures relate to the experience of the user and describe the quality of service provided during transport, such as speeds or travel times. Output measures are indicators of the direct production of an organization, such as lane-miles constructed. Because transportation system performance is influenced by many factors that transportation agencies cannot control, such as the weather, economic cycles, and land-use patterns, organizational management often favors output measures. Output measures are favored because they reflect actions the agency can take to improve highway performance; however, for them to be useful, they must also be considered in conjunction with outcome measures that describe the conditions experienced by the user.

The California DOT developed a framework for performance measures/indicators based on the following criteria relating to outcomes:

- The use of existing data sources to confirm existing activities in California's regional transportation planning organizations, wherever possible;
- The measures/indicators must be easy to use and simple to understand; and
- The measures/indicators should be measurable across all modes to the greatest extent possible.

The California DOT uses performance measures to

- Monitor and evaluate system performance,
- Share existing data and future forecast performance information,
- Develop modal-neutral customer and decision information,
- Build consensus on investment decisions, and
- Improve accountability of system development and operations.

Figure 6 illustrates the basic framework of the California DOT's performance measures program. The candidate

TABLE 12
INTELLIGENT TRANSPORTATION INFRASTRUCTURE PROGRAM DATA SPECIFICATIONS FOR MOBILITY MONITORING

Primary Data Element	Attributes: Preferred	Attributes: Acceptable	Supplemental Data Elements
Vehicle travel times (preferred)	For individual vehicles For defined roadway links up to 1 mi in length Coverage on freeways and arterial streets	5- to 15-min summary average For defined roadway links 1–3 mi in length Coverage on freeways only	Date of measurement Start time of travel time Anonymous vehicle identification
Vehicle spot speeds (acceptable)	1- to 5-min averages by lane Speeds obtained every 2 mi Coverage on freeways and arterial streets	1- to 5-min averages by direction Speeds obtained every 1–3 mi Coverage on freeways only	Date of measurement Start and end time for speed summary statistics Detector location identification (milepost or other location reference)
Vehicle volumes	1- to 5-min totals by lane Volumes obtained every 2 mi Coverage on freeways and arterial streets	1- to 5-min totals by direction Volumes obtained every 1–3 mi Coverage on freeways only	Date of measurement Start and end time for volume summary statistics Detector location identification (milepost or other location reference)
Roadway link and "corridor" identification	Definition of roadway links up to 1 mi in length	Definition of roadway links of 1–3 mi in length	Corresponding detector identification Milepost or location reference Roadway name and direction Sequence of link along a corridor Link length Number of lanes
Vehicle classification	The 13 vehicle classes defined in the Traffic Monitoring Guide (http://www.fhwa.dot.gov/ohim/tmguide/index.htm)	Passenger vehicles (cars and light pick-ups) Single-unit trucks Combination trucks (tractor trailers)	Date of measurement Start and end time for volume summary statistics Detector location identification (milepost or other location reference)

performance measures/indicators incorporated into the framework are summarized in Table 13.

Key highway/operational performance measures in the California DOT program include mobility and reliability. Average delay per vehicle is used as a mobility performance measure and is derived from the difference between free-flow travel times, based on posted speeds, and the estimated travel times, based on measured or modeled speed estimates during the analysis period. Reliability is defined as the variability in transportation services between the expected and actual travel time. The percent variation, standard deviation of travel times divided by the average travel time, is used to estimate this variability. Application of this reliability measure in the cities of San Francisco and Los Angeles, and Orange and San Diego counties indicates that this variability measure may not be correlated with delays and that it depends on a number of factors, including the distance between interchanges, roadway geometries, and other factors.

In addition to the system performance measures identified as part of the transportation planning, operational performance measures were derived to serve the following purposes:

- To develop indicators/measures to assess the performance of California's multimodal transportation system to support informed transportation decisions by public officials, operators, service providers, and system users (talk about integration); and
- To establish a coordinated and cooperative process for consistent performance measurements throughout California (real integration).

Figure 7 shows the linkage of desired system performance outcomes that were identified through a public process. These outcomes are estimated by performance indicators and calculated using outputs from transportation agencies. Such measures are intended to support decision making at all levels in the department and address systems and corridors rather than piecemeal project benefits. Figure 8 illustrates this approach. As can be seen in the figure, monitoring and evaluation serves as the basis for making decisions on improvements to the transportation system.

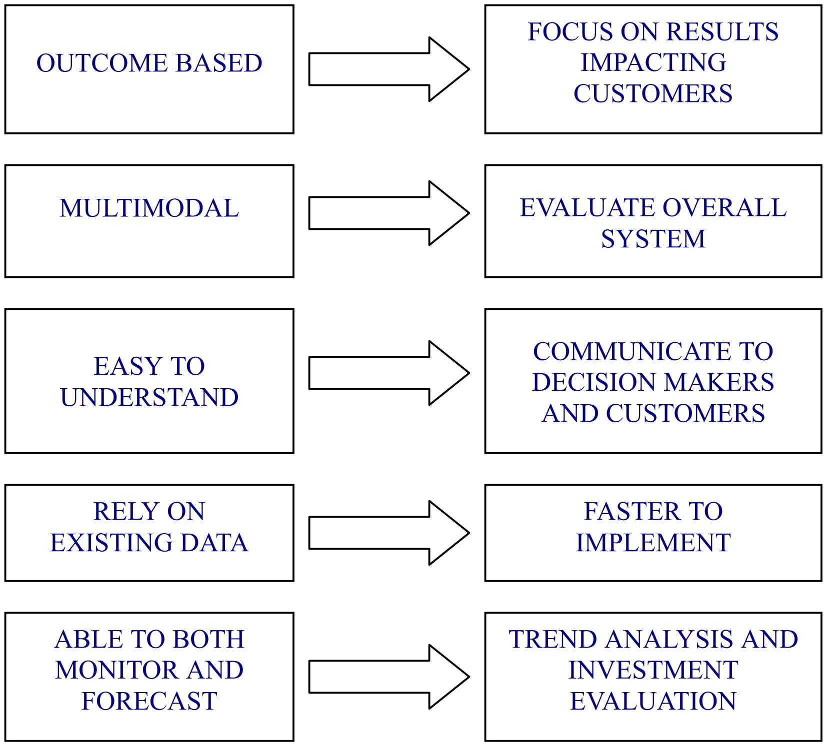

FIGURE 6 California DOT's performance measures framework.

TABLE 13
CALIFORNIA DOT'S PERFORMANCE MEASURES/INDICATORS

Desired Outcome	Definition	Candidate Measure/Indicator
Mobility/accessibility	Reaching a desired destination with relative ease within a reasonable time, at a reasonable cost with reasonable choices	Travel time Delay Access to desired location Access to system
Reliability	Providing reasonable and dependable LOS by mode	Variability of travel time
Cost-effectiveness	Maximizing the current and future benefits from public and private transportation investments	Benefit/cost ratio
Sustainability	Preserving the transportation system while meeting the needs of the present without compromising the ability of future generations to meet their own needs	Outcome benefit per unit cost
Environmental quality	Helping to maintain and enhance the quality of the natural, physical, and human environment	Household transportation costs
Safety and security	Minimizing the risk of death, injury, or property loss	Accident and crime rates
Equity	Distributing benefits and burdens fairly	Benefits per income group
Customer satisfaction	Providing transportation choices that are safe, convenient, affordable, comfortable, and meet customers' needs	Customer survey
Economic well-being	Contributing to California's economic growth	Final demand (value of transportation to the economy)

Notes: LOS = level of service.

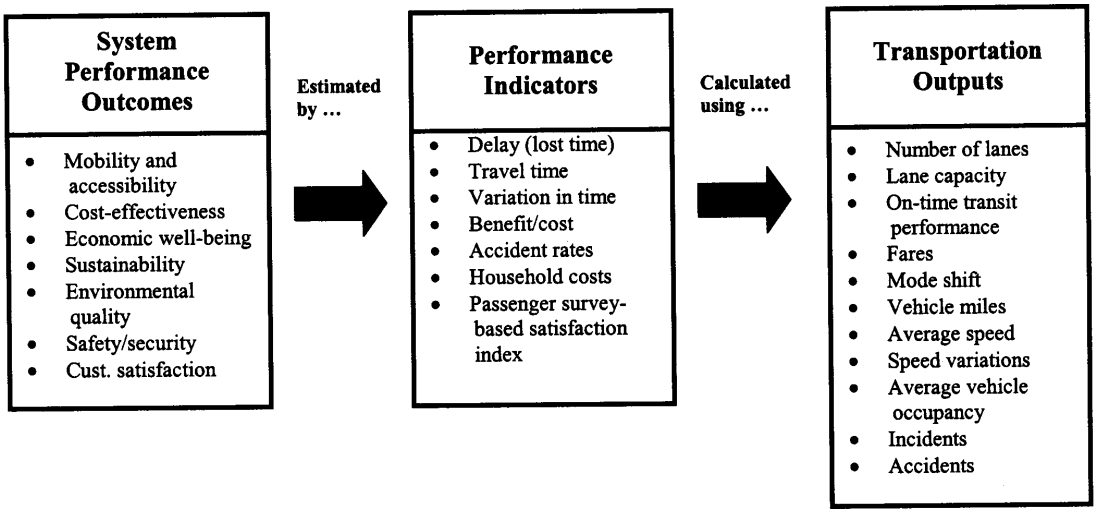

FIGURE 7 California performance measures.

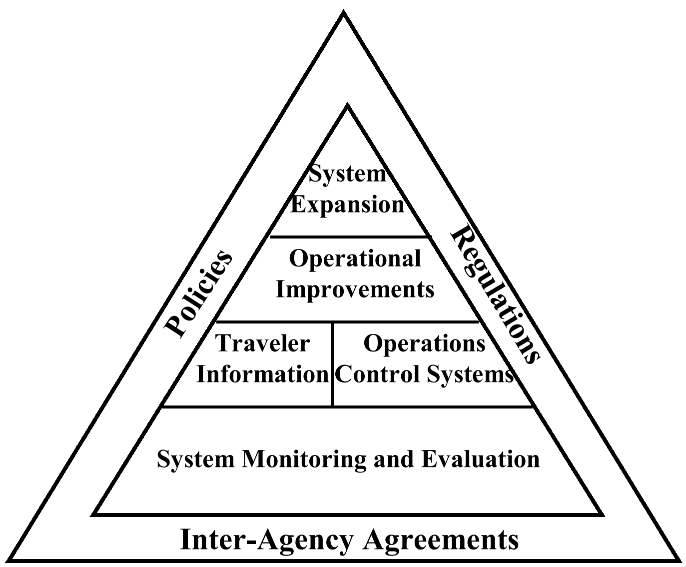

FIGURE 8 California DOT's operations-oriented decision approach.

Delaware Department of Transportation

Only if mobility performance measures are consistent with established goals and objectives for transportation and related systems can they be used to influence the processes and achieve the desired results.

The Delaware DOT addresses performance measures in its Statewide Long-Range Transportation Plan, *Transportation and Delaware's Future* (2000). Performance measures were derived from the goals and objectives of the plan. Table 14 summarizes these measures and their link to the goals, strategies, and policies of the plan.

Florida Department of Transportation

The Florida DOT developed a framework for performance measurement designed to characterize mobility in a manner understandable to the general public and decision makers. The recommended mobility performance measures reflect mobility from the users' perspectives, based on the following:

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

- The quantity of the travel (number of persons served),

TABLE 14
COMPONENTS AND MEASURES OF THE DELAWARE STATEWIDE LONG-RANGE TRANSPORTATION PLAN

Plan Components	Definitions	Measure Types	Measures
Goals	Broad desired end-states	Outcome performance measures with identified analytical tools	Customer satisfaction Travel time Sustainability of investments
Strategies	General approaches with objectives that advance the achievement of goals	Outcome performance measures answered with yes/no responses supported by indicators of progress	Support for existing communities Increased system capacity Increased safety Improvement and protection of air quality, environment, and cultural resources
Policies	Implementation schemes through specific action initiatives or policy-driven approaches to routine processes	Output performance measures at the most discrete level expressed as indicators of performance	Decrease in average trip length Decrease in the rate of VMT growth Increase in new revenue sources Decrease in mode share for single-occupant vehicle travel
Actions	Specific initiatives including procedural changes and capital improvement projects	Output performance measures including policy indicators and measures developed as part of specific project implementations	Increase in the tonnage of goods moved Increase in ridesharing Decrease in crash rate Increase in work zone safety

Notes: VMT = vehicle-miles traveled.

- The quality of travel (travelers' satisfaction with travel),
- The accessibility of travel (ability to reach the destination and mode choice), and
- The utilization of a facility or service (the quantity of operations with respect to capacity).

Three basic types of applications were identified for the mobility performance measures.

- Functional systems—These applications address the combination of similar facilities that serve the same function (e.g., interstates serve intercity travel).
- Areawide systems—These applications address the analysis of a combination of facilities and services that are defined by geographical boundaries.
- Corridors—These applications address the analysis of multimodal transportation services between a specific origin and destination. Corridor analyses usually consist of the analysis of one or more facilities and services that provide direct access between an origin and destination.

Table 15 summarizes Florida's mobility performance measures for these dimensions and applications.

Maryland State Highway Administration

The Maryland State Highway Administration (MDSHA) has derived and publishes an annual *Highway Indicators Statistical Report* that provides a graphically oriented summary of performance trends. The performance measures identified are classified as follows:

- System extent
  - Centerline-miles,
  - Lane-miles,
  - Lane-miles by functional class,
  - Bridges,
  - Linear feet of sidewalk on state highways,
  - Noise barriers,
  - Signalized intersections,
  - Modern roundabouts,
  - Modern roundabout listing,
  - Park-and-ride facilities served by transit,
  - Park-and-ride facilities by number of spaces,
  - Park-and-ride facilities' listing,
  - NHS, and
  - Welcome centers and rest areas.
- System use
  - Annual VMT,
  - Annual VMT on state highways,
  - Annual VMT by region,
  - Annual VMT per licensed driver,
  - Historic use of state-operated rideshare facilities,
  - Traffic fatalities,
  - HOV lane use on I-270, and
  - Truck average annual daily traffic at selected locations.
- Capital invested
  - Annual MDSHA expenditures,
  - Funding distribution, and
  - Expenditures for community enhancements.
- Factors influencing system design
  - Population, labor force, and households;
  - Highway indicators (lane-miles, annual VMT, population, licensed drivers, registered vehicles, and labor force);

TABLE 15
FLORIDA DOT MOBILITY PERFORMANCE MEASURES AND DATA SOURCES

Mobility Performance Measures	Data Requirements	Source
Quantity of Travel		
Person-miles traveled	Average annual daily traffic (AADT)	Roadway characteristics inventory (RCI)
	Hourly k	Estimated from telemetered traffic monitoring sites (TTMS) system raw data files grouped by LOS facility types
	Hourly volume	Hourly k × AADT
	Length	RCI
	Vehicle occupancy	1990 National Personal Transportation Survey county-wide average journey to work data
Truck-miles traveled	AADT	RCI
	Hourly volume	Hourly k x AADT
	Length	RCI
	Percent trucks daily	RCI
	Percent trucks peak hour	Estimated TTMS system raw data files grouped by LOS facility types
Vehicle-miles traveled	AADT	RCI
	Hourly volume	Hourly k × AADT
	Length	RCI
Person-trips	Total person-trips	Florida Standard (travel demand forecasting) Model output files
Quality of Travel		
Average speed	Average segment speed	Estimated using planning applications from 1994 Highway Capacity Manual adapted for Florida and extended for saturated conditions
	Person-miles traveled	See above
Delay	Average segment speed	See above
	Free-flow speed	Estimated using posted speed limits in RCI
Average travel time	Distance	RCI
	Speed	See above
Average trip time	Door to door trip travel time	Florida Standard (travel demand forecasting) Model output files
Reliability	Median travel times	Six-week field studies
	Travel time distribution	Six-week field studies
Maneuverability	Hourly volume	Hourly k × AADT
	Length	RCI
Accessibility		
Connectivity to intermodal facilities	Intermodal facilities of significance	Public Transportation Office
	Intermodal connectors	Public Transportation Office
Dwelling unit proximity	System location	State highway system base map
	Dwelling units	Statewide transportation planning package from the 1990 Census
Employment proximity	System location	State highway system base map
	Employment location	Statewide transportation planning package from the 1990 Census
Industrial/warehouse facility proximity	System location	State highway system base map
	Industrial warehouse facility location	Statewide transportation planning package from the 1990 Census
Percent-miles bicycle accommodations	Miles of roadway with bicycle accommodations	Florida DOT bicycle coordinator
	Total system miles	RCI
Percent-miles pedestrian accommodations	Miles of roadway with pedestrian accommodations	Florida DOT bicycle coordinator
	Total system miles	RCI
Utilization		
Percent system heavily congested	Hourly volume	Hourly k × AADT
	Segments operating at LOS E or F	Use of generalized LOS tables
	Segment length	RCI
	System miles	RCI
Percent travel heavily congested	Hour volume	Hourly k × AADT
	Segments operating at LOS E or F	Use of generalized LOS tables
	Segment volume x length	See above
	System VMT	See above
Vehicles per lane-mile	AADT	RCI
	Length	RCI
	Lane-miles	RCI
Duration of congestion	Hourly volume	Hourly k × AADT
	Hours of the day that segments operate at LOS E or F	Use of generalized LOS tables
	Lane-miles	RCI (lanes) × RCI (length)

Notes: k = the ratio of volume in the analysis hour to AADT; VMT = vehicle-miles traveled.

  - Labor force and annual VMT;
  - Motor vehicle registrations; and
  - Licensed drivers, driving age population, and motor vehicles.
- System conditions
  - Number of congested intersections,
  - Percentage of congested intersections,
  - Number of deficient bridges,
  - Percentage of deficient bridges,
  - Pavement condition,
  - Congestion,
  - Travel rate index,
  - Hours of total delay,
  - Number of incidents that result in hours of total delay,
  - Percentage of lane-miles operating at LOS E or F, and
  - Express bus travel time.
- Community enhancements
  - Noise barriers, locations, and miles needed;
  - Sidewalk location and miles needed;
  - Bike trails and miles funded;
  - Streetscapes/neighborhood conservation, number of projects, and funding;
  - Wetlands reforestation, total and net acres created; and
  - Percent of emissions from mobile sources.

In addition to this annual report, the MDSHA published a *Four-Year Business Plan: 2000–2004* (2000) that identified the following additional mobility performance measures:

- Reduction in average incident response time,
- Reduction in average clearance time,
- Number of cumulative CHART/ITS devices installed,
- Number of regional traffic operations centers integrated with CHART,
- Number of website enhancements,
- Percentage increase in website hits,
- Percentage of cameras that are media accessible,
- Number of projects that are intended to enhance intermodal connections,
- Number of users of MDSHA park-and-ride lots,
- Percentage of centerline-miles along urban state roads within 0.6 mi of a transit station that has sidewalks,
- Complete website linkage,
- Projects that reduce recurring congestion,
- Intersection capacity projects where the V/C ratio has improved 1.0 or better,
- Reduction in fatal and injury accident rates,
- Reduction in number of pedestrian fatalities and injuries,
- Reduction in number of bicycle fatalities and injuries, and
- Reduction in motor carrier fatalities and injuries.

Minnesota Department of Transportation

These diverse sets of measures have evolved over time from a core set of performance measures that addressed system performance, organizational performance, and public values. The proliferation of measures resulted from a desire to tie measures to support budgeting principles of each specific goal and objective of their transportation plan, integrate and align planning and investment decisions through performance-based planning, reflect externalities out of their control, assist in making trade-off decisions, establish a hierarchy of measures throughout the department, and provide measures that resonate with customers and help explain the progress.

The Minnesota DOT (MnDOT) system performance measures include

- Pavement quality and estimated remaining service life,
- Deficient bridges and square feet of deficiencies (measured in square feet of area),
- Crash rates,
- High accident locations (intersections and rail crossings),
- Miles and hours congested,
- Mobility, and
- Reliability.

Of particular interest and importance is MnDOT's emphasis on freight and intermodal performance measures. These measures were established based on the results of a task force that included public and industry representatives. The task force emphasized the basic concepts that were important to them for the Twin Cities (Minneapolis and St. Paul) metropolitan area and statewide application, and MnDOT staff defined corresponding measures. Table 16 shows the performance measures proposed.

In a presentation, *Performance Measurement Directions and Issues* (2000), Larson identified current trends and issues in the MnDOT performance measure program. This presentation emphasized the integration of performance measures into the business planning process of the MnDOT and the family of measures used to support MnDOT's business plans. However, the presentation identified the following key customer needs that are important for highway performance measures:

- Time predictable trips;
- Smooth, uninterrupted trips;
- Safe trips;
- Timely and accurate information; and
- Responsibility with resources.

This presentation also identified market segmentation needs for performance measures as follows:

- Commuters,

TABLE 16
FREIGHT-ORIENTED PERFORMANCE MEASURES FROM MINNESOTA

Performance Concept	Performance Measures
Predictable, competitive Twin Cities' travel time	• Metro freeway travel time by route and time of day • Average speed on metro freeways by route and time of day • Congestion ranking of metro freeways, by route • Congestion level compared with other major metro areas
Economic benefit/cost	• Benefit/cost ratio of major state transportation projects
Transportation investment	• State's transportation investment and spending as percent of gross state product
Intercity travel time	• Peak-hour average travel speeds on major routes between 27 state regional centers • Shipper point-to-point travel time
Freight travel time to global markets	• Travel time to major regional, national, and global markets—by rail, air, water, and truck
Competitiveness of shipping rates	• Shipment cost per mile—by ton or value, by mode for major commodities
Crash rate and cost comparison	• Dollar value of crashes and crash cost comparison by mode • Crash rate per mile traveled by freight mode
Bottlenecks and impediments	• Number of design impediments to freight traffic, by mode, by type
Timely access to intermodal terminals	• Number of design impediments slowing access to truck, rail, air, and waterways terminals

- Personal travelers,
- Farmers,
- Emergency vehicle operations,
- Carriers,
- Shippers, and
- Intermodal.

In addition, Larson's presentation identified data management needs as follows:

- Standard methods for collecting data are needed, particularly for speed and travel times.
- Data and methodologies are needed to support system integration and linkages.
- Data currency (timeliness) is of particular concern. Users seek accurate data in near real-time for many applications and this demand for real-time traffic data makes quality control a challenge.

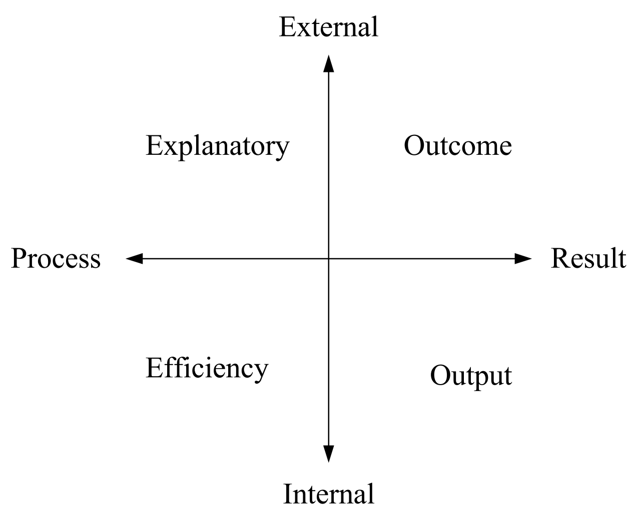

FIGURE 9 Texas DOT's balanced scorecard approach.

Texas Department of Transportation

The Texas DOT uses a balanced scorecard approach to developing performance measures (Figure 9). Measures have been designated to ensure that all four quadrants of the matrix that reflects focus (external vs. internal) and product (process or result) are addressed.

The measures are derived from goals and objectives provided in the agency's strategic plan. One hundred and one measures are identified and maintained in a database. This database includes the traceability to the goals and objectives, definitions, data limitations, data sources, computation methods, and purposes of the measures. The following summarizes the highway operations-related and performance-related measures:

- Percent of state highway system mainline pavement mileage rated good or very good based on pavement management information system condition score,
- Percent of contracted federal dollars planned with MPOs,
- Total number of centerline-miles that are operational under traffic management systems,
- Percent of on-system bridges structurally deficient or functionally obsolete,
- Percent of highway construction projects with rights-of-way purchased on time,
- Percent of airports needing funding,
- Percent change in the number of public transportation trips,
- Percent of urbanized population living within one-quarter mile of a fixed-transit service route,
- Percent of U.S. Army Corps of Engineers-requested dredge disposal acreage provided,
- Percent of motor vehicle consumer complaints resolved,
- Number of research program products implemented within 2 years,

TABLE 17
VIRGINIA DOT'S SYSTEM MAINTENANCE AND OPERATIONS PERFORMANCE MEASURES

Performance Measure	Criterion	Data Custodian
Crash rate	Safety	Traffic engineering
Equipment crash rate		Employee safety and benefits
Personal injuries as factor of hours worked and type of site		Employee safety and benefits
Traffic movement (number of people moved per hour by corridor)	System operation	Traffic engineering
		Transportation planning
Sufficiency rating	Infrastructure quality	
Pavement		Maintenance
Structures		Structures and bridges

- Percent of engineering-related services contracted with the private sector,
- Statewide traffic crash fatality rate,
- Percent of drivers and front seat passengers complying with safety belt law,
- Percent of car seat/safety belt use for children ages 0–4 years,
- Proportion of driving while intoxicated-related fatal crashes to total fatal crashes,
- Number of high-crash locations improved,
- Percent of advertising signs in compliance with federal law,
- Auto theft rate,
- Economic loss associated with auto theft rate, and
- Road congestion index.

Virginia Department of Transportation

The Virginia DOT is moving toward becoming a proactive, customer-focused organization and has implemented a performance-based planning approach to assess agency performance and track the performance of the highway system. This system places a high regard for users' perspectives and this is reflected in their performance measures. The measures identified are derived from goals and objectives. In addition to the system maintenance and operations measures summarized in Table 17, a customer satisfaction goal is also defined.

Washington State Department of Transportation

Visual depictions of data can assist users in understanding trends and the meaning of complex data interactions. Visualization techniques available with common simulation software are also useful for demonstrating and educating decision makers about the meaning of various performance measures. ATIS use visualization through websites and interactive maps to assist users in understanding travel conditions using performance measures such as speed, delay, and incidents.

The Washington State Transportation Center (TRAC) at the University of Washington uses innovative techniques to display their performance measures. Figures 10–12 are examples of the use of innovative displays of performance measures information. Figure 10 is an example of an average daily site profile, composed of three site-specific traffic profiles used by the Washington DOT. The first is a line graph of an average 24-h profile of volume per lane per hour at a selected location for a specified direction of travel (across all lanes), at 5-min increments. The line graph is supplemented by a corresponding 24-h estimated speed profile to show average speeds at each data point on the volume curve. Finally, a 24-h reliability histogram indicates the percentage of time the location is congested, as a function of time of day.

The TRAC program can also produce an average daily corridor profile to depict lane-occupancy percentage at each location along a corridor for a specified direction of travel, at 5-min increments. As seen in Figure 11, the resulting graph is a contour map of the lane-occupancy percentage data (color-coded) according to the estimated congestion level.

The TRAC program can also provide an average travel time profile (Figure 12), which is composed of three 24-h profiles related to a specific trip. The first is a line graph depicting average travel time from one point to another on one corridor as a function of the time the trip starts. A second line graph depicts the 90th percentile travel time as a function of trip start time. Finally, a histogram of trip travel time reliability as a function of trip start time is provided by computing the likelihood (as a percentage) that the overall trip speed is less than 45 miles per hour (mph).

MetroPlan Orlando

Transportation System Indicators Report: Tracking the Trends: 1994–1998, examines transportation performance trends in the Orlando, Florida, metropolitan area over a 5-year period. The analysis considers several modes of travel, including private automobile, trucking, transit, aviation, rail, bicycling, and walking. The highway performance measures employed include

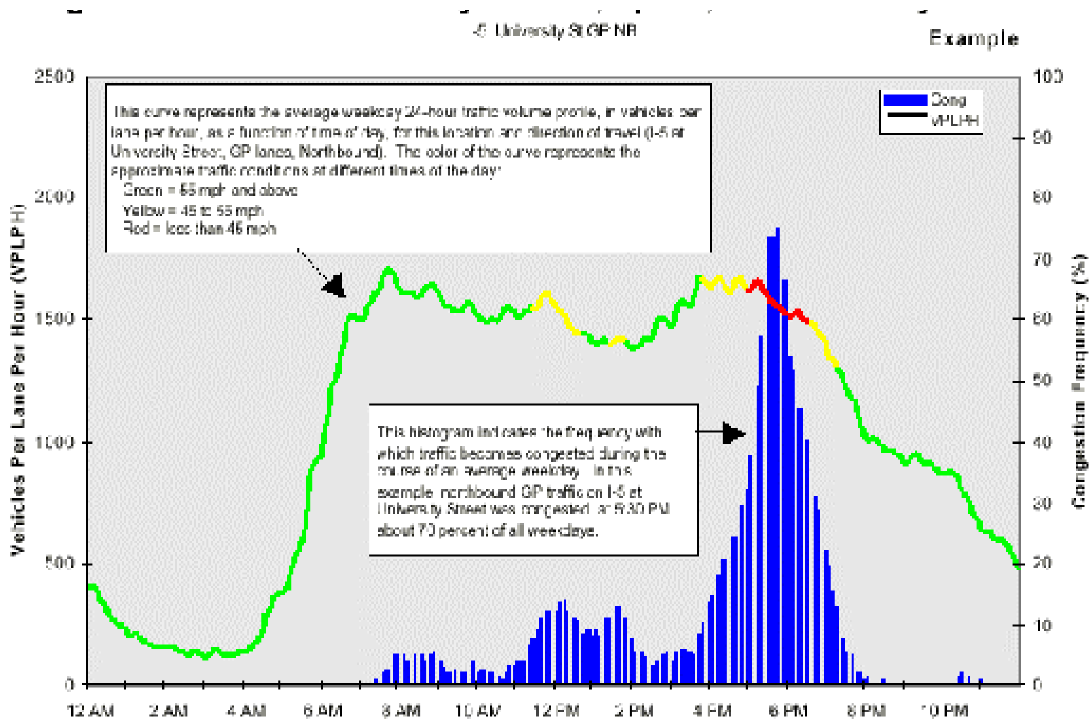

FIGURE 10 Estimated weekday volume, speed, and reliability profiles; I-5 University Street, general purpose, northbound.

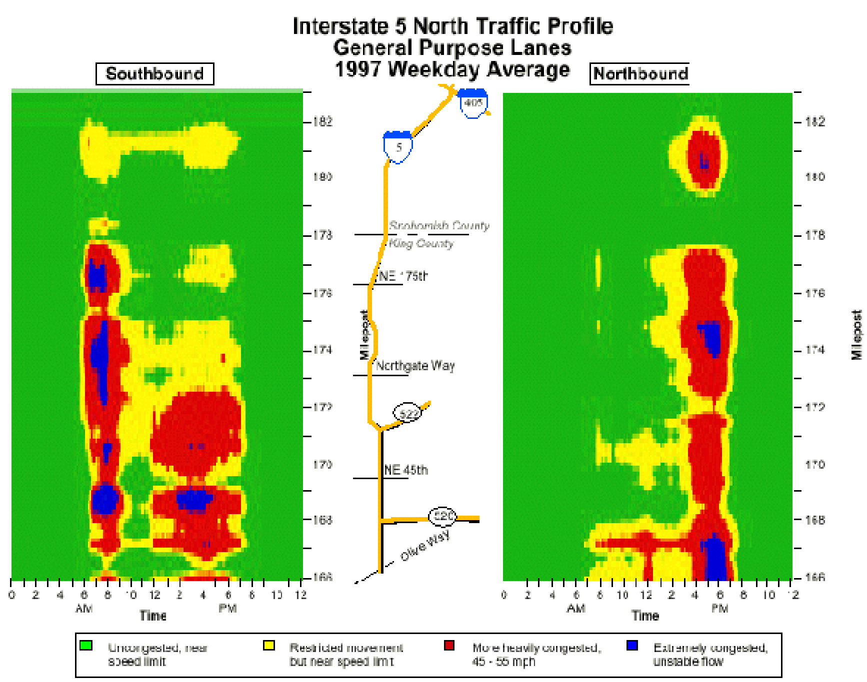

FIGURE 11 Sample temperature diagram of traffic conditions.

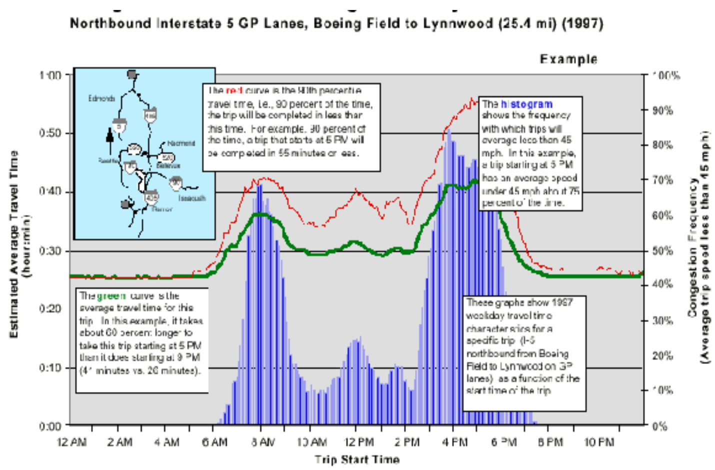

FIGURE 12 Example of estimated average weekday travel time. Northbound I-5, general purpose lanes, Boeing Field to Lynwood (25.4 mi).

- Traffic congestion index,
- Traffic accident rate, and
- Tons of cargo carried by mode.

TransGuide DataLink ITS Data Management System

The DataLink ITS Data Management System was developed by TransLink researchers as a means to easily access and analyze data collected by the TransGuide Transportation Management Center in San Antonio, Texas. The DataLink system contains volume, speeds, and lane-occupancy data collected from loop detectors typically spaced every 0.5 mi aggregated to 5-min intervals. The system is updated daily and archives are available from November 1997 to the present. The performance measures that are used by the system include

- Average speed by lane,
- Average vehicle occupancy by lane,
- Volume by lane,
- Estimated person throughput (volume) by lane,
- Persons times volume times speed by lane, and
- Flow rate (vehicles per hour).

Figures 13–15 provide examples of the graphical user interface capabilities of the system.

Maricopa County, Arizona, Highway Performance Report

This report documents the traffic conditions and other key indicators for the Phoenix, Arizona, metropolitan area. These measures were collected using a combination of aerial photo-survey and vehicle detection. The basic purpose of the study was to arrive at LOS for the major facility segments and intersections within the area. However, a number of other interesting performance measures were reported using tables and thematic maps. Trends were also available based on a similar study that was conducted in 1989. The performance measures reported included

- Weekday traffic volumes,
- Hourly variations in traffic volumes,
- Intersection LOS,
- Duration of intersection LOS F,
- Freeway LOS in general-use lanes,
- Freeway LOS in HOV lanes,
- Duration of LOS F on freeways,
- Employment density by traffic analysis zone,
- Residential household density by traffic analysis zone, and
- Comparison of 1989 and 1998 measures.

Albany, New York, Metropolitan Planning Organization

The Albany metropolitan area has been one of the leading users of performance measures in transportation planning in the United States. Beginning in 1992, when the Transportation Improvement Program update process was being revised in light of ISTEA, new approaches were adopted for incorporating system performance into planning and decision making. These measures include

- Access
  - Percentage of person-trips within a defined non-auto to auto difference,
  - Percentage of person-trips with a travel time advantage for non-drive-alone modes, and
  - Number or percent of major freight movements with modal alternatives.
- Accessibility
  - Travel time between representative locations, and

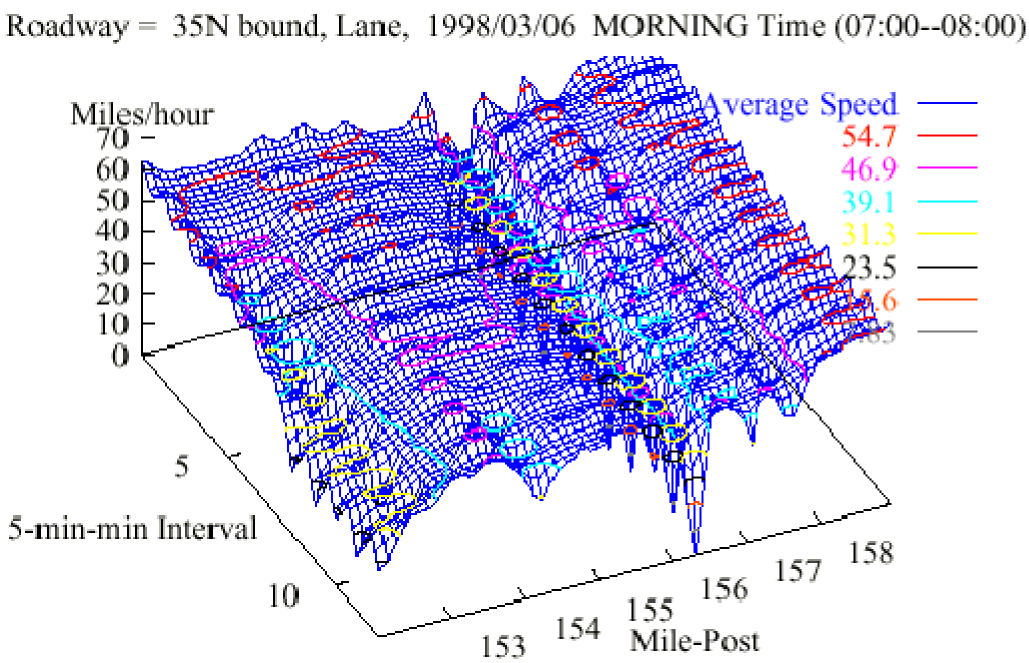

FIGURE 13 Sample display of speed performance measures from TransLink.

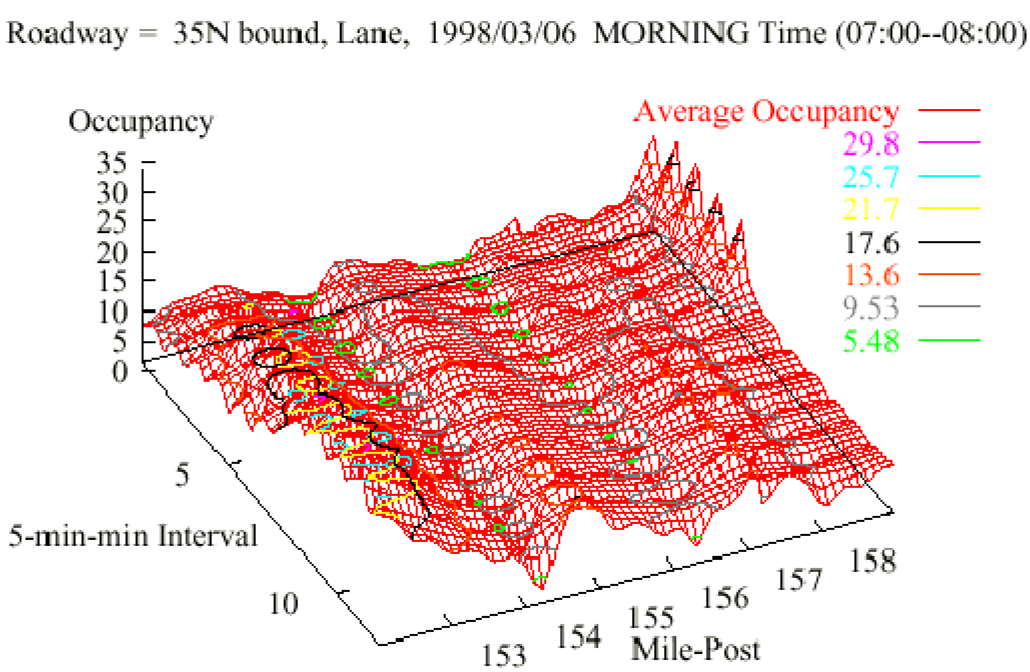

FIGURE 14 Sample display of occupancy performance measures from TransLink.

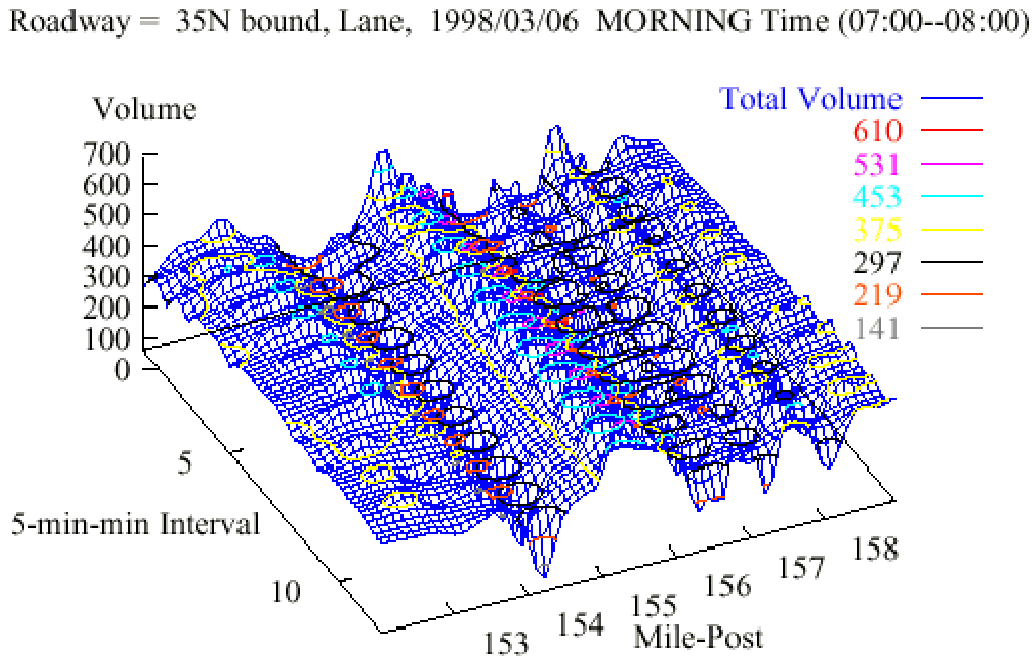

FIGURE 15 Sample display of volume performance measures from TransLink.

- Peak versus nonpeak by quickest mode.
- Congestion
  - Hours of excess delay, recurring and nonrecurring by mode.
- Flexibility
  - Reserve capacity on system,
  - Percentage of person-trips that could be accommodated by modes other than auto, and
  - Number of corridors with reasonable alternatives during closure.
- Safety
  - Estimated societal cost of transport and accidents.
- Energy
  - Equivalent british thermal units/day for transportation capital, maintenance, operation, and use.
- Economic cost
  - Annualized capital, maintenance, operating, and user costs; and
  - Value of commercial time in travel.
- Air quality
  - Daily emission levels, and
  - Air quality attainment status.
- Land use
  - Amount of open space,
  - Dislocation of existing residences and businesses,
  - Land-use transportation compatibility index, and
  - Community character index.
- Environmental
  - Impacts on sensitive areas, and
  - Noise exposure index.
- Economic
  - Narrative discussion of economic activity supporting or constraining features of the transportation system.

Transportation Research Board Peer Review

In August 2000, representatives from several states met in Madison Wisconsin, as part of a TRB Peer Review to discuss a range of topics including the quality and consistency of performance measures, data sources, availability and quality, and their use in transportation planning and operations. The states represented included California, Colorado, Florida, Illinois, Kentucky, Maryland, Minnesota, New York, Pennsylvania, and Texas. The Bureau of Transportation Statistics, FHWA, and TRB were also represented.

There was a consensus among the attendees on the challenges of performance measures programs presented during the exchange. These challenges were placed in nine categories as outlined here.

- Market research
  - What existing surveys are available to extract highway performance measures?
  - What lessons have been learned in other similar studies?
  - How can surveys be designed for internal (employees) and external customers?
  - When is market research the right tool?

- How do you develop customer satisfaction indicators?
- How do we develop standard indicators, methods, approaches, and questions?

- Mobility
  - How can we standardize approaches nationally to support a hierarchy of measures?
- Freight mobility
  - What measures are needed to describe freight mobility?
  - What data are needed to support measures?
  - What market segmentations are needed for freight mobility?
  - What intermodal connectivity connections are needed?
- ITS
  - What types of planning and performance measure data are needed from ITS?
  - How can we integrate traditional data collection systems (such as HPMS) with ITS data collection systems?
  - What is the reliability of ITS data compared with traditional statewide monitoring systems?
- Used in state governments
  - What measures are being used in state governments?
  - How do they impact decision making?
  - What is the payoff for policy-level measurement versus engineering-related measurement?
- Safety measures
  - What measures are available beyond accident rates and high accident locations?
  - How are these measures used in states?
- Sustainability measures
  - What measures are appropriate?
  - What data are required to support these data?
  - How do we consider measures for growth management?
  - How do we address economic justice?
- Goals, objectives, and measures
  - How do states' goals, objectives, and measures relate to federal goals and measures?
  - Is it appropriate to align the goals?
  - What common indicators are needed for all states?
  - How do these questions relate to other areas?
- Quality assurance of data
  - How do you approach data fusion from various databases?
  - How can we standardize data collection processes?
  - How can we leverage partnerships with MPOs and local governments to expand data coverage and share costs?
  - How will privatization affect data quality and standards?
  - What quality assurance standards are needed?
  - How should quality be addressed for new measures when it is difficult to determine quality?
  - How should other data collection efforts be coordinated with HPMS requirements?

This peer review demonstrates the varied use of performance measures in highway operations and there are a broad number of issues and challenges agencies still face in practical application of performance measure programs. The outstanding issues addressed in the review are consistent across all agencies surveyed in this synthesis. For these objectives to be resolved national consensus is needed on a set of core measures that will better serve transportation agencies' needs beyond the existing measures used in programs such as the HPMS and the HCM. These core measures should include standards related to data collection and quality, system coverage for reporting, and aggregation of results.