CHAPTER THREE

CURRENT STATE OF RESEARCH

Prior to the 1990s, research on performance measures was focused on the measures of effectiveness used by traffic engineers in highway capacity and quality of service studies. However, as congestion levels increased nationwide, many of these traditional measures of effectiveness became less meaningful. Concurrently, governments were seeking new ways of understanding trends and conditions of travel behavior and the operational effectiveness of the improvements they were making to the system. A third trend was the wider-scale implementation of intelligent transportation systems (ITS). The systems engineers and scientists who contributed to the ITS model deployments drew from their backgrounds in the use of performance measures to monitor performance and feedback systems. As a result of these new trends, interest in performance measures for operational effectiveness and research related to the science of performance measures applied to highway systems increased during the 1990s.

SEMINAL WORKS

Some of the most influential research publications on the use of performance measures were published during the 1990s. These works defined needs for performance measures and outlined additional areas of research that were needed to better define performance measures, and to determine data requirements and reporting needs and methods. The following is a review of this work.

Performance Measures for Multimodal Transportation Systems

This report developed by Pratt and Lomax (1996) recommended the following principles when developing operational and planning performance measures and systems.

- *Match mobility performance measures with objectives*—Only if mobility performance measures are consistent with established goals and objectives for transportation and related systems can they be used to control the processes and achieve the desired results.
- *Understand the effects of improvements*—The selected performance measures must quantify the effects of the anticipated range of improvement options for the full range of impacts to be understood.
- *Address people and goods*—An important aspect of performance measures is the ability to identify their effects on the movement of people and goods and on the achievement of travel and shipping objectives.
- *Use common denominators*—To facilitate comparisons within multimodal systems, common denominators such as speed, acceptable travel time, and person throughput are needed.
- *Development of measures should not be governed by data concerns*—The availability of data and analysis procedures should not be considered in the process of identifying the best possible set of performance measures. After the performance measures are identified, they should act as a starting point for the process.
- *Employ both multimodal and mode-specific measures*—Multiple transportation modes need to be measured together, to analyze the total effect, and separately, to identify individual deficiencies.
- *Remember the audience*—The knowledge basis and levels of interest of the various users of transportation performance measures are different and must be considered if measures are to satisfy communication needs.

In the study, *Measures of Effectiveness for Major Investment Studies,* Turner et al. (1996) identified measures of effectiveness that can be used to compare the benefits and impacts of transportation improvements for a major investment study. These candidate measures were qualitatively evaluated according to the following criteria:

- Applicability to individual and aggregate transportation modes,
- Ease of measure for calculation and analysis,
- Accuracy of measurement results,
- Clear and consistent interpretation of results, and
- Clarity and simplicity.

Table 2 identifies the performance measures recommended for major investment studies in this report. The researchers concluded that the following significant factors should be considered when selecting measures of effectiveness for a major investment study:

- Match the measures with the goals and objectives of the study;
- Develop and select the measures early in the study with key input from local decision makers;
- Use a comprehensive set of measures, but do not substantially duplicate or restate benefits or impacts;
- When possible, quantify impacts and do not simply use subjective judgment;

TABLE 2
PERFORMANCE MEASURES FOR EVALUATING THE IMPACT OF TRANSPORTATION IMPROVEMENTS

Area of Impact	Performance Measures
Transportation performance	Average travel time Average travel rate Total delay Person-miles of travel in congested ranges Person-hours of travel in congested ranges Person movement Person movement speed Accident reduction
Financial/economic performance	Benefits/costs ratio (using full-cost analysis) Financial feasibility Cost per new person-trip
Social impacts	Number of displaced persons Number and value of displaced homes Neighborhood cohesion Accessibility to community services
Land use/economic development impacts	Number and value of displaced businesses Accessibility to employment Accessibility to retail shopping Accessibility to new/planned development sites
Environmental impacts	Energy consumption Mobile source emissions Noise levels Visual quality/aesthetics Vibration Water resources Wildlife/vegetative habitat Parkland/open/green space Cultural resources Agriculture/forest resources Geologic resources Hazardous wastes

- Provide perspective on the magnitude of the impacts; and
- Identify error levels of calculation in relation to the measure values.

Alternative Performance Measures for Transportation Planning: Evolution Toward Multimodal Planning

This research project by Meyer (1995) examined key characteristics of performance-based transportation planning. Several illustrations of planning as it was evolving at the time were presented and the following observations were made.

- *System performance is a concern*—System performance can be defined based on what is important to the (1) owner and (2) the user of the transportation system. Both types of measures are needed and should be distinguished.
- *Measures must be tied to the roles of transportation*—The application of performance measures to systems versus small elements of the transportation system should be distinguished and the linkages between element and system performance must be made. Therefore, core values and goals must be identified and measures should be linked to specific goals and objectives. A family of measures is required to ensure that the role of transportation is fully described.
- *Outcomes and outputs*—Performance measures should relate to outcomes describing cause-and-effect relationships that involve owners and users. Outcome measures relate to the quality of life, safety, environmental quality, and economic opportunities. Performance measures should also relate to output measures, which are indicators of the direct production of an organization, such as lane-miles constructed.
- *Mobility and accessibility*—Both mobility and accessibility should be considered. As part of this approach, the distribution of benefits to users and the

TABLE 3
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

potential to increase the demand for services should be studied.

- *Travel time as a key indicator*—A total trip travel time was recommended for use. It has the strongest fundamental link between user perception and the mobility provided.
- *Performance measures should be tied to project evaluation criteria*—Similar to the need to tie performance measures to the values, goals, and objectives of the users of the system, performance measures should relate to the criteria established in project evaluations.
- *A strategic data collection and management plan is essential*—The success of performance measures is tied directly to the quality and quantity of data. Therefore, a critical element in implementing performance measures is the development of a strategic data collection program identifying the methodologies, techniques, standards, and frequency of data collection.
- *Development of new analysis tools*—New analysis tools are required that can report data and measures in ways that are easily understood by engineers, planners, elected officials, and users of the transportation system.

Techniques for selecting performance measures and recommendations on data collection frequencies were also provided. This report examined the incorporation of mobility and accessibility concerns in transportation planning, which included

- How is system performance defined and who defines it?
- What are the differences between an “output” and an “outcome”?
- What are the most appropriate performance measures?
- How should performance measures be used?
- What are the implications of performance-based planning on data collection and on the types of analysis tools that are available to transportation planners?
- How do performance measures relate to the goals, objectives, and measures of effectiveness?

The research was based on extensive case studies of state DOTs, MPOs, and transit planning agencies’ efforts related to performance-based planning. The following summarizes the key findings:

- Mobility and accessibility should be important measures of system performance.
- Travel time and modal availability should be the foundation for mobility performance measures.
- Accessibility measures should be incorporated into project planning and system evaluation approaches.
- Market segmentation and distributional effects of mobility and accessibility changes should be part of measuring system performance.

Performance Measures for Highway Capacity Analysis

This research project by May developed mobility performance measures and level of service (LOS) criteria for the year 2000 edition of the *Highway Capacity Manual* (HCM). The project recommended vehicle- and person-trip time and delay as the primary systemwide performance measure for highway segments and systems. A methodology was recommended for combining analyses using the HCM’s procedures to aggregate these measures to the system level. The measures recommended for highway segments are summarized in Table 3.

Quantifying Congestion (Volumes 1 and 2)

This report, prepared by Lomax et al. (1997), was one of the first nationally accepted research documents on performance measures. The report addressed the following purposes for performance measures:

- Monitoring needs and studies,
- Design analyses and operational analyses,
- Evaluation of alternatives,
- Establishing base conditions and setting priorities,

TABLE 4
CROSS-CLASSIFICATION OF THE USES OF CONGESTION MEASURES

Purposes for Which Congestion Measures Are Used	Monitoring and Needs Studies	Design and Operational Analysis	Evaluation of Alternatives	TDM, TSM, TCM, and Policy Studies	Development Impact Evaluation	Route and Travel Choice	Education
Identification of problems	•	•	•	•	•	•	•
Basis for government action/investment/policies	•	•	•	•	•		•
Setting of improvements priorities	•		•	•			•
Information for private sector decisions	•	•	•	•	•	•	•
Basis for national, state, and regional policies and programs	•			•	•		•
Assessment of traffic controls, geometrics, laneage, and regulations		•	•				•
Assessment of transit routing, scheduling, and stop placement		•	•				•
Base case (for comparison of alternatives)	•	•	•	•	•	•	•
Inputs for transportation models			•	•	•	•	•
Inputs for air quality and energy models		•	•	•	•		•
Measures of effectiveness for alternatives evaluation		•	•	•	•	•	•
Measures of impact of land development				•	•		•
Input to zoning decisions					•		•
Basis for real-time route choice decisions						•	•

Notes: TDM = travel demand management; TSM = transportation systems management; TCM = transportation control management.

- Developing impact evaluations,
- Commercial vehicle scheduling, and
- Education.

These purposes were then cross classified with specific applications in the transportation planning process as shown in Table 4.

This report recommended the following dimensions of congestion:

- Duration (temporal),
- Extent (geographic),
- Intensity (severity), and
- Reliability (variation).

The specific performance measures recommended in this research are as follows:

- Travel rate (minutes per mile), 60 min divided by the speed in miles per hour (mph);
- Delay rate (minutes per mile), minutes of delay divided per mile;
- Total delay (person-hours), sum of all person delay;
- Relative delay rate (dimensionless), delay rate divided by desired travel rate;
- Delay ratio (dimensionless), delay rate divided by actual travel rate;
- Speed of person movement (persons-mph), persons times speed;
- Corridor mobility index (dimensionless), speed of person movement divided by a normalizing value;
- Accessibility (percent), percent of destinations within *x* minutes;
- Accessibility (minutes), mean travel time to all destinations; and
- Congested travel (person-miles), sum of congested lengths times persons.

Planning Techniques for Estimating Speed and Level of Service

This NCHRP Project 3(55) and its companion, *Planning Applications for the Year 2000 Highway Capacity Manual* [NCHRP Project 3(55)2-A], prepared by Dowling et al. are authoritative references on the techniques for estimating speed and other "prime" performance measures needed in any estimating or modeling techniques. These reports contain a number of alternative techniques and recommend various approaches for implementing performance measures in planning practice.

RECENT ADVANCES IN RESEARCH

Most research related to operational performance measures published since the mid-1990s has extended these concepts and explored and recommended techniques for describing specific measures. Recent areas of research emphasis include reliability of operations and transportation systems and multimodal performance measures.

Reliability Performance Measures

Jackson et al. (2000) published *Florida's Reliability Method*, which included a recent survey of reliability performance measures used nationally, compared and assessed the strengths and weaknesses of reliability performance measures identified in research and through the practices of transportation agencies for planning and operations, and recommended reliability performance measures for use by the Florida DOT. The following review of alternative reliability performance measures was adapted from this report.

Historically, reliability has been associated with the performance of mechanical equipment or devices. In this context, reliability is defined as "the probability of a device performing its purpose adequately for the period of time intended under the stated operating conditions." However, reliability from a transportation system perspective has been defined in different ways by different researchers. The following definitions of reliability have been documented in the literature:

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

These definitions suggest that reliability is an indicator of the operational consistency of a facility over an extended period of time, measured as some function of the amount of recurrent and nonrecurrent delay that occurs over that period.

Just as a number of definitions are available for reliability, a wide range of techniques is reported for measuring reliability.

In *Measures of Effectiveness for Major Investment Studies*, Turner et al. (1996) define trip time reliability as the range of travel times experienced during a large number of daily trips. The range of travel times can be obtained by calculating the mean and standard deviation of travel times within a sample. For example, an uncongested facility might have a trip time reliability of 12 to 15 min for 85% of all trips, whereas on a congested facility the reliability might be between 20 and 30 min. This method was used in a recent study documenting the travel time savings and reliability benefits of high-occupancy vehicle (HOV) lanes over freeway main lanes. Lomax et al. (2000) suggest that this method can be used to calculate reliability for a variety of roadway systems, including single roadways, corridors, and areawide networks.

However, the range of travel times itself is not very meaningful unless it is used to make comparisons of conditions along the same facility (e.g., northbound versus southbound travel, or HOV lane versus general-use lane travel). The range of travel times is also based on a fixed benchmark using the 85th percentile. The result is that the proportion of unreliable travel would always stay approximately the same. For example, using the 85th percentile, approximately 15% of the travel time observations would always be considered unreliable, regardless of the number of observations, the value of the mean travel time, or the standard deviation of travel time. This concept is depicted in Figure 2.

This technique also involves a two-tail test, in which unreliable conditions are considered to be those in which the travel time is either significantly better or significantly worse than average conditions. However, it is intuitive that a traveler would benefit from significantly better conditions, so that unreliable conditions should be those in which travel times are significantly worse than what is expected. The area of concern is the right tail of the distribution; therefore, a one-tail test is more appropriate. This concept is depicted in Figure 3.

Lomax et al. (2001) proposed that reliability could be measured as the difference in delay experienced on incident days versus nonincident days. Total delay is the amount of time lost due to congestion on a roadway segment and can be calculated using this equation.

$$\text{Total Segment Delay (veh-min)} = \left[\begin{array}{c}\text{Actual}\\\text{Travel Time}\\\text{(min.)}\end{array} - \begin{array}{c}\text{Acceptable}\\\text{Travel Time}\\\text{(min.)}\end{array}\right] \times \text{Vehicle Volume (veh)}$$

The acceptable travel time is the total travel time it would take to travel a segment during expected conditions. This travel time is generally calculated assuming travel at the posted speed limit, although it may also be calculated using a congestion threshold speed established from local

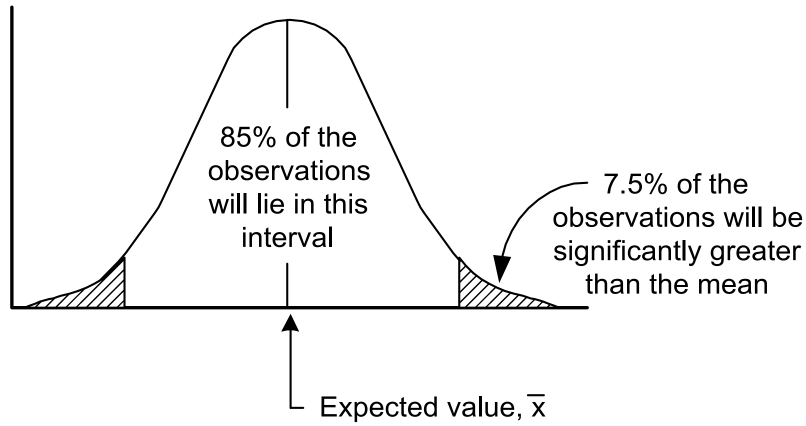

FIGURE 2 Illustration of two-tail test with a fixed benchmark.

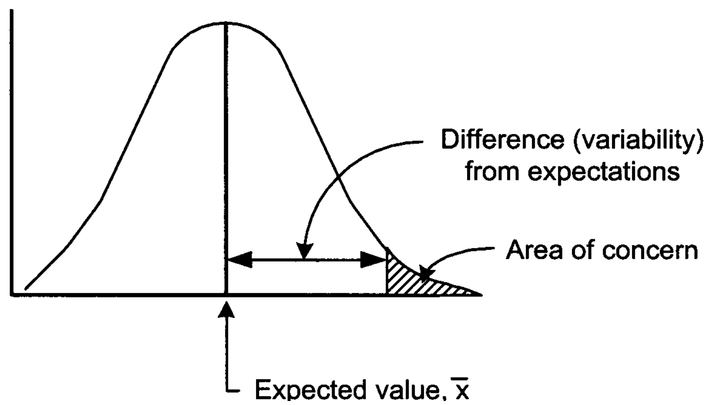

FIGURE 3 Illustration of a one-tailed test.

performance goals for mobility. Total delay along a corridor is calculated as the sum of the vehicle-minutes of delay on the individual segments of that corridor.

This technique for measuring reliability does not consider both recurrent and nonrecurrent delay. It is widely regarded that the travel time even on nonincident days may be far from acceptable.

Ikhrata and Michell (1998) define reliability as the probability that users will arrive at their destinations within the expected (average) travel time. They developed a reliability performance indicator, R, for the Southern California Association of Governments, which can be calculated as follows:

$$R = 1 - (\%\ \text{trips}_{\text{within}} - \%\ \text{trips}_{\text{exceed}})$$

where

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

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

Ikhrata and Michell anticipate that the reliability performance indicator can be calculated using commuter survey data available through the annual State of the Commute and Census Transportation Planning Package. However, the indicator is theoretical in nature, and the association is continuing to explore other concepts of reliability.

A preliminary investigation of this methodology revealed that because the indicator is based on the average travel time, approximately one-half of the observations will always fall within the average value and one-half will exceed it. Using this methodology, the reliability performance indicator will always have a value in the range of 0.9 to 1.1. Further examination revealed that even if the methodology was refined to incorporate a benchmarking method the value of the reliability performance indicator will increase as conditions become less reliable.

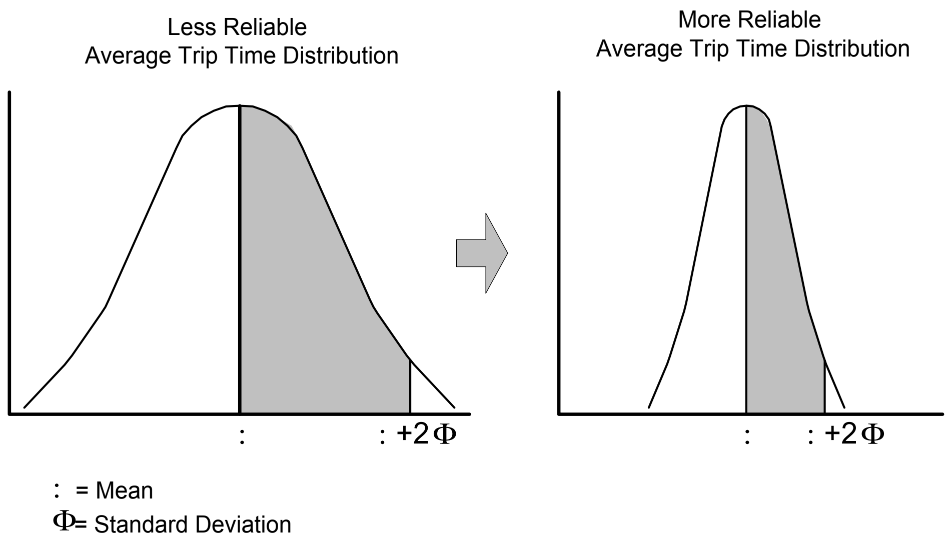

Figure 4 Illustration of California reliability measure.

The *1998 California Transportation Plan* (1998) defines reliability as the variability between the expected travel time (based on scheduled or average travel time) and the actual travel time (due to the effects of nonrecurrent congestion). "Reliable" segments are those in which travel time over the segment does not vary significantly from day to day. "Unreliable" segments have highly variable travel times. This concept is visually depicted in Figure 4.

The coefficient of variation describes the dispersion or variability of travel time, but does not really indicate how well conditions on the corridor meet travelers' expectations.

Rakha and Van Aerde (1995) examined the variability in traffic conditions during both typical nonincident conditions and incident conditions. The researchers attempted to identify typical weekday traffic conditions by establishing average typical conditions and then estimating the upper and lower bounds of these average conditions. This establishes average weekday statistical confidence limits based on the 95th percentile. Preliminary investigations revealed that use of the 95th percentile will only reflect the variability associated with crashes (nonrecurrent congestion) that occurred along the corridor. Additionally, it will not necessarily reflect the influence of crashes on traffic conditions in a consistent manner. The calculations associated with this technique also involve more complexity than other reliability methods.

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

1. Travel time—The time it takes a typical commuter to move from the beginning to the end of a corridor. Because speed is determined along each segment as the traveler moves through the corridor, this travel time is a function of both time and distance. This is representative of the typical commuter's experience in the corridor.
2. Expected travel time—The median travel time across the corridor during the time period being analyzed. The median is used rather than the mean so that the value of the expected travel time is not influenced by any unusual major incidents that may have occurred during the sampling period. These major incidents will be accounted for in the percentage of how often the travel takes longer than expected, but will not change the baseline to which that unusually high travel time is being compared.
3. Acceptable additional time—The amount of additional time (Δ), beyond the expected travel time, that a commuter would find acceptable during a commute. The acceptable additional time is expressed as a percentage of the expected travel time during the period being analyzed. Times 5%, 10%, 15%, and 20% above the expected travel time are currently being considered. However, Florida practice recommended that preference surveys be conducted to determine how much difference from the expected commute a traveler would find acceptable. The Minnesota DOT recently completed its first such survey and found that acceptable delay tended to be an absolute number of minutes, regardless of travel distance for intercity travel and not a percent of travel time.

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

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

where

$\bar{x}$ = the median travel time across the corridor during the period of interest; and

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

The percent of reliable travel is calculated as the percent of travel on a corridor that takes no longer than this acceptable travel time.

A comparative analysis was conducted using traffic flow data for the following three study corridors: (1) I-95 in Jacksonville, (2) I-95 in Broward County, and (3) I-4 in Orlando. Two test corridors were also included in the project. The first test corridor was I-95 from south of Hallandale Beach Boulevard in Broward County to north of Yamato Road in Palm Beach County. Data for this corridor were collected as part of a 1999 Interstate Traffic Data Survey. The second test corridor was a 23-mi segment of I-405 in Seattle, Washington.

The reliability results suggest that the Florida Reliability Method is well suited for measuring reliability because it characterizes reliability as an indicator of how well conditions on the corridor meet travelers' expectations by establishing an acceptable travel time unique to the corridor. This definition matches well with the reliability definitions provided by operations researchers and used in other commercial transportation applications such as aviation (on-time arrivals), rail (on-time arrival), and integrated logistics (on-time or just-in-time delivery). Other methods describe the variability of travel time but do not report directly on reliability from this perspective.

The following recommendations were made regarding data collection for reliability measurement:

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

As part of the *Urban Mobility Report: 2000*, prepared by the Texas Transportation Institute (TTI) (Lomax et al. 2001), a reliability buffer index was introduced in 2002 that estimates the difference between the average travel time and the 95th percentile travel time as the extra time that has to be budgeted for a trip compared with the average travel rate to define a reliability index. In the middle of the evening peak, the sources of travel time variation are so significant that an extra 2 min per mile should be budgeted as the buffer, in addition to the average travel time of 1.5 min per mile.

Buffer Index (*BI*) = [95th percent confidence travel rate – average travel rate]/ [average travel rate] × 100%

This index assumes that the 95th percentile travel rate (minutes per mile) is the acceptable threshold for trip making by the user. As explained by the author

> What does all this mean? If you are a commuter who travels between about 7:00 a.m. and 9:00 a.m., your trip takes an average of about 30 percent longer (that is, the TTI value is 1.3) than in the off-peak. A 20-mile, 20-minute trip in the off-peak would take an average of 26 minutes in a typical home-to-work trip. The Buffer Index during this time is between 50 and 100 percent, resulting in a Trip Planning Time of 2.1 minutes per mile. So, if your boss wants you to begin work on time 95 percent of the days, you should plan on 42 minutes of travel time (20 miles times an average of 2.1 minutes per mile of trip for the peak period). But, to arrive by 8:00 a.m., you might have to leave your home around 7:00 a.m. because the system is even less reliable in the period between 7:30 a.m. and 8:00 a.m.

Although this concept is close to the user's perception of reliability, it assumes that the only trips that are unreliable are the last five percentage trips, and indirectly reports on the reliability as illustrated in the authors definition. The construct is flexible enough to allow using an alternate percentile trip for the threshold of acceptable performance. However, operations research has shown the percent of trips accomplished within an "acceptable time" is a more direct measure of reliability as experienced by the user.

Multimodal Performance Measures

The *Multimodal Corridor and Capacity Analysis Manual* (Cambridge Systematics et al. 1998) identifies performance measures applicable to both users and nonusers of the transportation system, as well as measurement of the transportation facility itself. The following quantitative and qualitative performance measures apply to users of the transportation system:

- Service frequency,
- Travel time,
- Travel comfort,
- Travel time reliability,
- Probability of loss and/or damage, and
- Costs.

Performance measures applicable to nonusers of the transportation system include the following:

- Congestion costs,
- Noise,
- Fuel consumption,
- Emissions,
- Pavement maintenance costs, and
- Bridge maintenance costs.

Transportation facilities can be measured by the following aggregate measures:

- Volume/capacity (V/C) ratio for vehicles;
- V/C ratio for persons;
- V/C ratio for goods moved expressed in any of the following units—weight, cubic volume, or equivalent equipment movements such as truckload equivalent units;
- Speed on facilities and through nodes (time mean speed, space mean speed, and variability);
- LOS for key facilities and sources of delay;
- Cumulative person-hours of delay;
- Cumulative hours of delay for freight;
- Dollar value of cumulative delay for persons and freight;
- Cumulative delay by the most important delay sources (noncongestion-related delays, congestion-related delays, recurring delays, and nonrecurring delays);
- Passenger and freight vehicle-mile traveled (VMT) on a facility;
- Additional trips on a facility; and
- Accidents (persons and freight).

The *Multimodal Corridor and Capacity Analysis Manual* reported that regardless of which performance measures are chosen, the most important indicator of performance is the volume of traffic on the facility relative to capacity (V/C ratio). From a multimodal perspective, the V/C ratio is an indicator of the supply and demand for a facility and can be expressed in vehicles, persons, or goods moved. The V/C ratio can be measured over various aggregations of time to approximate performance measures. Examples of time aggregations include the V/C ratio during the peak-hour, peak-period, off-peak, 12-h, 18-h, and daily V/C.

Performance measures based on the impact of queuing and peak spreading on travel time were also identified as being needed. However, no specific methodologies were identified.

TABLE 5
PERFORMANCE MEASURES COMPARISON CRITERIA

General Criteria	Specific Criteria
Clarity and simplicity	The measure is simple to present, analyze, and interpret The measure is unambiguous The measure's units are well defined and quantifiable The measure has professional credibility Technical and nontechnical audiences understand the measure
Descriptive and predictive ability	The measure describes existing conditions The measure can be used to identify problems The measure can be used to predict change and forecast condition The measure reflects changes in traffic flow conditions only
Analysis capability	The measure can be calculated easily The measure can be calculated with existing field data There are techniques available to estimate the measure The results are easy to analyze The measure achieves consistent results
Accuracy and precision	The accuracy level of the estimation techniques is acceptable The measure is sensitive to significant changes in assumptions The precision of the measure is consistent with planning applications The precision of the measure is consistent with an operation analysis
Flexibility	The measure applies to multiple modes The measure is meaningful at varying scales and settings.

Adapted from Meyer (1995), Turner et al. (1996), Lomax et al. (1997), and Jackson et al. (2000)

SUMMARY

Research in performance measures for the operational effectiveness of highway segments and systems has evolved over the last 10 years. Seminal works established the common principles for performance measurement that build on successful practices and use professionally accepted techniques for measuring and estimating measures of effectiveness. More recent works define and support new measures in the areas of reliability and multimodal operations in the highway environment. These works have many common themes for defining and determining when performance measures are effective tools. Table 5 synthesizes many of these basic principles and will be used in chapter five in discussing the strengths and weaknesses of measures identified in chapter four.

However, continuing research is needed that emphasizes highway operational effectiveness from the travelers' perspective and how to better link performance measures to operational improvements so that efficiency gains can be achieved similar to those that occurred in the aviation industry in the 1980s. For this to occur, a paradigm shift is needed throughout all transportation agencies that are involved in the planning, design, construction, or operations of the highways to address a total systems and operational management approach throughout the life cycle of highway operational and ITS improvements. Several state transportation agencies, MPOs and local trans-portation authorities have embarked on this transformation and their practices are highlighted in chapter four.