NCHRP 08-36, Task 102

Assessing Alternative Methods for Measuring Regional Mobility in Metropolitan Regions

Requested by:

American Association of State Highway and
Transportation Officials (AASHTO)
Standing Committee on Planning

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Executive Summary

The objective of this project is to assess methods for defining and measuring mobility in metropolitan regions. How an agency or jurisdiction defines and measures mobility greatly determines selection of strategies and ultimately investment decisions. In metropolitan areas, measuring mobility at the system level is often limited to the measure of traffic congestion and resulting delay on the freeway and signalized arterial networks. Although traffic congestion does inhibit mobility, it alone may not be a sufficient measure of system performance, particularly as transportation agencies strive to embrace a more multimodal approach to transportation planning.

The study took a broad perspective on mobility. Some definitions of mobility used in the past have implied only the measurement of congestion on facilities. The study approach includes that perspective but enlarges it to include the performance of trips as well as the idea of accessibility – the ability to reach opportunities.

Domestic Use of Mobility Performance Measures

A review of state departments of transportations (DOT) and metropolitan planning organizations (MPO) was undertaken. In general, it appears that mobility performance measurement is a widespread activity among transportation agencies with many currently producing performance statistics and many others planning to do so in the short term. A wide variety of mobility performance measures were found to be in use, including traditional ones such as level of service and v/c ratio as well as some more directly related to travel time, such as delay and the travel time index. Data to develop the measures directly from travel time measurements are becoming more common, but many agencies still use analytic methods and models to develop the measures. Measures related to travel time reliability are just beginning to creep into practice.

International Use of Mobility Performance Measures

All the transportation agencies covered in an international scan conducted for this project use similar sets of measures commonly used in the United States, such as congestion and travel time. Other measures are related to road safety, trip reliability, and accessibility. *Measures of customer satisfaction are also widely used by those agencies*. For example, UK transportation agencies measure time reliability by the average delay experienced in the worst 10 percent of journeys for each monitored route.

Measures relating to freight movement and transit were found in many performance measurement efforts. However, in most cases, performance measurement is implemented within a modally focused agency, so performance measures were targeted at decisions relating to the performance of that modal network. But many agencies are moving away from a traditional mode-centric focus to a broader, more inclusive approach to surface transportation planning in highly congested urban areas, so the examined agencies placed a great emphasis on transit service, rail passenger service, land use integration, and moving people and freight as well as vehicles as they continued to develop their performance measures.

Performance Measures for Managing Mobility-Oriented Programs

A variety of principles and tenets were developed by the study relating to mobility performance measures:

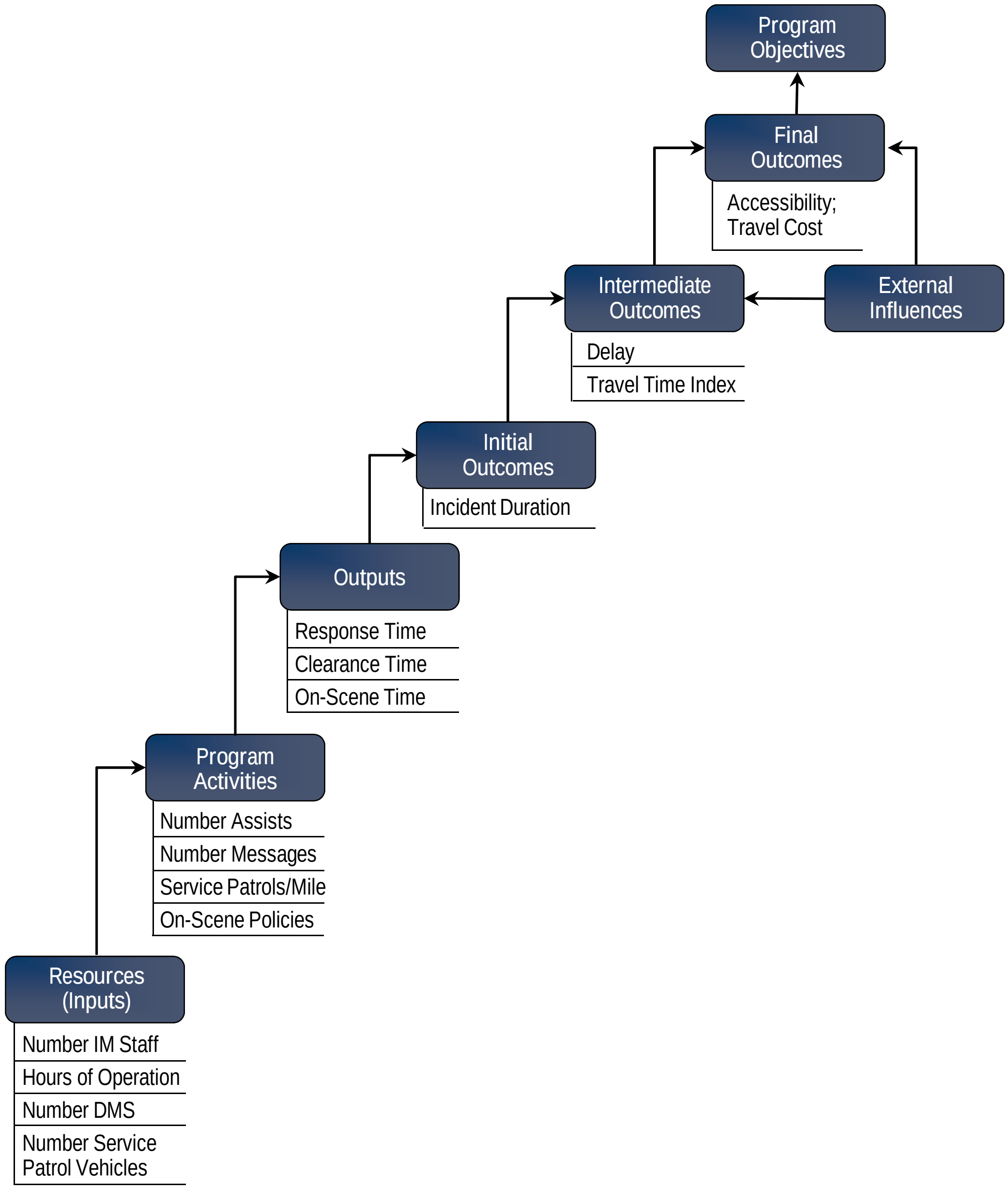
1. **Linkage to strategic planning.** Performance measurement is used to monitor progress toward achieving the vision, goals, and objectives of an agency or firm. These things are usually specified as part of a strategic planning process that identifies the directions an agency wishes to take in providing transportations services.
2. **"Mobility" should be the overarching term for the movement of people and freight over the transportation system.** While several taxonomies can be constructed for organizing the concepts used in this project, Mobility is the main feature of interest. Congestion and Accessibility are considered to be features of Mobility.
3. **Travel time as the basis for mobility measures.** Despite the use of capacity-based metrics such as the v/c ratio, a comprehensive mobility measurement program – which includes both historical monitoring and forecasting activities – should rely on measures that are grounded in travel time. Travel time-based metrics are the foundation for all scales of performance – facility, corridor, and areawide spatial scales. They also are a key component of measuring accessibility.
4. **A comprehensive and "linked" mobility performance measurement program.** The focus of this report was on outcome-related performance measures. However, to be effective in managing programs, a comprehensive set of input, output, and outcome measures must be constructed and linked. In this linkage, measurement programs are established as a series of linked levels, with different performance measures for each level. The so-called "Program Logic Model" has been applied to the programs of many public agencies; Figure ES.1 shows the components of the Model and some example measures for an incident management program.

   However, it is clear that agencies will require a fully linked mobility performance measurement system to address several emerging issues:

   a. **Explaining outcomes.** Outcomes are required to gauge the impact on system users ("mobility customers"). However, when they are used to track conditions over time, they can only indicate if things are better or worse – but they do not tell us why. We need lower-level measures that relate to the ***investment process itself*** to understand why conditions change, as well as an understanding of external influences.

b. **Performance-based management.** Similarly, we do not manage congestion level – we manage the activities that have an effect on congestion. Therefore, we need to have measures that relate to how effectively we are undertaking day-to-day activities. This is the difference between producing mobility performance reports that highlight changes in outcomes (initial outcomes like congestion level or final outcomes like accessibility/travel cost) and using performance measures to manage our programs.

Figure ES.1 Program Logic Model Adapted for Incident Management



Source: Based on Poister, Theodore H., *Measuring Performance in Public and Nonprofit Organizations*. ISBN 978-0789-4999-0, San Francisco, 2003.

c. **External influences.** Many factors – including those outside the control of transportation agencies – will influence outcomes. These external influences make it difficult to isolate the effect of congestion mitigation programs of all kinds, but it makes it imperative that they be monitored, to provide explanation of trends at a minimum.

d. **Measurement scale and the role of project evaluations.** Largely because of factors external to programs under agencies' control, areawide performance reporting masks underlying problems and makes it impossible to pinpoint emerging problems. Because most congestion mitigation strategies are focused on specific facilities, their effect will be diluted in areawide numbers that include subareas where no improvements have been made and congestion has grown worse.

e. **Cost-effectiveness and efficiency measures.** Both of these measures weave in the notion of costs. Cost-effectiveness measures relate the cost of investments to the change in outcomes; an example is the cost per change in delay or accessibility. Efficiency measures relate the cost of investments to outputs; an example is the cost per increase in capacity. Cost-effectiveness measures have been used in transportation as a basis for comparing alternatives within a specific project (e.g., different designs, transit versus highway improvements), but for the most part, we have shied away from using them to report global performance.

f. **User cost measures.** There has been a growing interest in translating the rather dry mobility measures into costs incurred by users as a means of communicating the consequences of poor mobility and the positive effect of transportation investments. As with cost-effectiveness and efficiency measures, most of the profession's experience with these measures has been at the project planning stage.

g. **Facility-based versus trip-based mobility.** Largely due to data availability, transportation performance programs have focused on what happens on the facility, yet our customers view their experience in relation to the entire trip. The data to monitor entire trips by travelers is on the horizon; it is likely that within the next five years, these data will be available mainly from private vendors of travel time information. The issue then becomes: *how do investment and policy decisions change if they are based on trip performance rather than facility performance?*

h. **Accessibility as an integrated transportation-land use measure.** Trip-based mobility measures are the starting point for accessibility measures, but they are blind to trip purpose or opportunity; they just measure the performance of trips within a given time window. Accessibility measures layer on the trip purpose or type of destination represented by the trip and are meant to measure the ease of reaching opportunities – goods, services, activities and other destinations. Three factors affect accessibility: congestion (or impedance), transportation system connectivity, and land use patterns. Thus, accessibility measures capture all four of these simultaneously; it is still important to understand the contribution of components, especially mobility as this is under more direct control of transportation agencies and easier to communicate to a general audience for a greater range of purposes. Note the accessibility can apply to the ease of getting to activities (such as jobs, recreation, shopping) or aspects of the transportation system itself (freeways, transit route, bike facilities).

i. **Managing programs with mobility performance measures.** With the data now available, agencies can report mobility performance for a large part of their transportation systems. However, this is only a first step. It is important to report performance for a number of reasons: to demonstrate knowledge of where the problems are, transparency in programs, and identifying the effects of investments. The next level is to use performance information to manage programs. This can take the form of directing individual investments and defining program structure and size. Very little experience exists in this area and as a result this study did not investigate how agencies could manage with mobility measures. In fact, the issue is much broader than just mobility and includes all other functional areas of concern to transportation agencies (e.g., safety, pavements, bridges, maintenance).

Recommended Mobility Performance Measures

Table ES.1 shows the recommended performance measures for reporting mobility outcomes by transportation agencies.

Table ES.1 Recommended Mobility Performance Measures

Category	Measurement Scale	Geographic Scale		
		Facility	Corridor	Areawide
Quantity of Travel	Facility-Based	Total VMT	Total VMT	Total VMT
		Truck VMT	Truck VMT	Truck VMT
		Total PMT	Total PMT	Total PMT
		SOV PMT	SOV PMT	SOV PMT
		HOV VMT	HOV VMT	HOV VMT
		Transit PMT	Transit PMT	Transit PMT
	Trip-Based	N/A	N/A	N/A
Quality of Travel	Facility-Based	HCM-based LOS	HCM-based LOS	HCM-based LOS
		Vehicle Delay	Vehicle Delay	Vehicle Delay
		Person Delay	Person Delay	Person Delay
		Travel Time Index	Travel Time Index	Travel Time Index
		Planning Time Index	Planning Time Index	Planning Time Index
		Percent On-Time	Percent On-Time	Percent On-Time
	Trip-Based			Travel Time Index
				Planning Time Index
				Percent On-Time
Accessibility	Facility-Based	N/A	N/A	N/A
	Trip-Based			Cumulative Opportunity Index
Capacity Utilization	Facility-Based	Density	Duration of Congestion	Duration of Congestion
		Demand-to-Capacity Ratio	Spatial Extent of Congestion	Spatial Extent of Congestion
		Duration of Congestion		
		Spatial Extent of Congestion		
	Trip-Based	N/A	N/A	N/A

The Next Level of Performance Measurement – What Does the Future Look Like?

- **Developing and Reporting Accessibility Measures –** The current state of the practice for mobility performance measurement is almost entirely focused on reporting facility performance, largely because of data availability. However, given current trends in technology and in the private sector provision of data, we fully expect data to become available shortly that will allow direct measurement of trip performance, and by extension, of accessibility. (In the interim, models can be used to synthesize trip-based performance.) Accessibility is comprised of two components: 1) the presence of opportunities; and 2) the ease with which those opportunities can be obtained or "reached." Thus, measuring accessibility goes beyond simply the performance of the transportation system – it also measures how users interact with the landscape of opportunities. Accessibility can be improved by improving the movement between opportunities or by moving opportunities closer to users. Because transportation is a derived demand – people engage in it not for its own sake but because it allows access to opportunities – accessibility is a key indicator of the quality of life for a transportation agency's customers. It is not a replacement for measuring the performance of the transportation system, but an adjunct to it.

- **Data for Accessibility Measurement –** Point-to-point travel times are readily estimated from regional travel demand models, and are produced as a standard output at the resolution of the model (e.g., hourly, or at least peak hour and off-peak). Many other capacity/delay models that use regional travel demand model outputs can further refine these point-to-point estimates. Better than modeling (at least for the current period), these data can also be measured in cities that have robust traffic data collection efforts. This is especially true on freeways, where DOTs often collect traffic data for freeway traffic operation efforts (e.g., ramp metering). Arterial traffic data is archived in some cities (and should be archived in all), and can be used to estimate travel times on signalized facilities. Newer technologies are making what was once difficult to measure now much simpler. Data from GPS systems by vendors such as TomTom, Inrix, and Navteq provide good coverage of travel speeds on the road network, and are being archived historically at a detail sufficient for future accessibility measurements. These measures can further be differentiated by time of day, so that morning, midday, afternoon, and free-flow accessibility measures can be obtained. With the datasets from GPS vendors, mean and standard deviation of travel times on a link basis should also be able to be estimated, so that in addition to an average (mean) accessibility, the reliability of accessibility can be measured. These data sets are not free, but they are often purchased by state DOTs and metropolitan planning organizations for other purposes, and can be used for accessibility calculations.

- **Fitting Mobility Performance into the Agencywide Context: Performance Management and the Congestion Management Process –** Performance management – the continuous process of improvement driven by assessing, reporting, and acting on the performance of the system – is becoming a guiding principle for making transportation investments. Performance management provides the basis for this process by helping transportation agencies make decisions based on objective data, communicating results to executives and the public in a meaningful way, and providing the key inputs that can and should be used to establish priorities. The private sector has a long history of successfully managing their businesses by tracking performance, evaluating whether particular strategies worked well, and funding those activities that have produced the best results. A CMP should include a data collection and monitoring system, a range of strategies for addressing congestion, performance measures or criteria for identifying when action is needed, and a system for prioritizing which congestion management strategies would be most effective. The CMP is the logical place where the mobility performance recommendations in this report can be implemented. For transportation planners, it represents a major shift in focus from the long term to the near term in terms of addressing mobility problems. It also implies that the performance measurement activities of multiple agencies must be coordinated. This includes the regional planning agency responsible for the CMP as well as operations, transit, and land use regulatory agencies.

- **Explaining Outcomes and Diagnosing Mobility Problems.**

  – Evaluations of Implemented Strategies

    Performance measurement will increasingly be used beyond reporting and will be nested within an increasing number of agency activities. These will be oriented at understanding why mobility, reliability, and accessibility changed, what agency actions and external conditions affected the change, and how do "before" conditions compare to "after" conditions. This will require obtaining the proper data, using that data in ways to measure or estimate the appropriate measures and linking data from several data sets together to understand the results (for example, linking incident descriptions with travel time data to understand the role of collisions and rapid removal programs in reducing congestion).

    Traditionally, a lot of planning and analysis goes into the front-end of projects, they are implemented, but we rarely go back to see how they perform. In a customer-focused environment, however, it is critical to **evaluate constantly how well services are being delivered**, and to devise ways to improve delivery. Therefore, a formal evaluation process is seen as a key feature of a mobility performance program. Evaluations should be routine – not special undertakings – and having an established mobility measurement program enables this. For example, continuously collected mobility performance data means that special data collection efforts do not have to be made. Evaluations enable agencies to learn from successes as well as failures, and successful strategies can be highlighted as a public relations tool.

– Deconstructing Congestion: Congestion-by-Source

In order to target strategies effectively, knowing what the causes of congestion or general mobility problems are is required. This is true whether a highway segment, corridor, or region is being considered. The question usually asked is "how much of total delay is related to the underlying causes of congestion?" More broadly, it can be expressed as the "congestion pie," which assigns the relative contribution of each of congestion's recurring and nonrecurring components. FHWA has developed its own version of the congestion pie and has used it for several years in framing the congestion problem (Figure 8.4). The relative percents are based on a single study that used modeling methods for the country as a whole – urban and rural, freeway and nonfreeway, conditions are combined.

- **Incorporating Cost-Related Measures –** Many private sector performance measurement processes **–** as well as some public sector processes **–** include aspects of cost and return on investment. These can be cost-efficiency measures (cost per output produced) or cost-effectiveness (cost per outcome achieved). Cost-efficiency measures would be applied at the activity level (e.g., field incident management activities) while cost-effectiveness measures would accompany outcome measures based on travel time-based metrics. Cost-effectiveness measures can be used to choose or prioritize projects or to evaluate, for example, the cost of an hour of delay reduction or some unit of improvement in accessibility. The cost quantities will be for both agency costs and user costs; a comprehensive set of metrics would also include personal travel and freight travel cost measurements. These cost measures will be incorporated in several types of analysis at different points from the initial project decision to implemented project evaluation process.

  A major drawback to using cost-related measures for mobility is that external factors outside of the direct control of an agency can have a profound effect on outcomes. Demand, a strong determinant of both average congestion level and reliability, is subject to changes in the socioeconomic character of a region. Some method for controlling for changing demand patterns when tracking annual changes or performing before/after evaluations must be developed. Modeling the effect seems to be the best way to achieve this in the interim.

- **Making Decisions Based on Both Facility and Trip Measures –** A comprehensive mobility measurement program will involve using a combination of mobility, reliability, and accessibility measures, because they all inform analysts about the nature of mobility in a region. With new data sources being available, it will be much easier to do both facility- and trip-based analyses and incorporate a broader range of concerns. Even though the same mobility metrics can be applied to the performance of both facilities and trips, the nature of the measurements are different. Facility measurement describes the nature of congestion to which users are exposed. Trip measurement includes factors in addition to congestion exposure – how users interact with entire landscape. With regard to trips, users are generally free to change departure times and routes, and in some cases, destinations and modes as well. Further, over time, however, trip purposes and destinations change. What will result are multiple definitions of what a "trip" is, even though it may be measured with the same metric. For example, a work trip could start at the same time every day, use auto only, and use the same route every day. Alternately, these factors can vary to different degrees.

- **Directing Mobility-Related Programs with Performance Management.** Performance management is currently receiving much attention by the transportation profession. Much of this emphasis is self-initiated by transportation agencies as they adopt a customer-oriented focus, and strive for accountability and transparency in transportation investment decisions. There is also a great deal of interest at the Federal level as well. As of this writing, it is uncertain if the Federal interest will take the form of Congressionally-imposed regulations on the management of Federal transportation programs, but performance management in some form is being discussed intensely.

  However, especially with regard to mobility, the profession has little experience in managing mobility programs with performance measures. Historically, agencies have used performance measures to identify needs (usually through the use of models rather than direct mobility measurements) and to assess impacts of project alternatives. But, monitoring the systemwide effect of mobility programs has been elusive. As data and monitoring systems become more sophisticated and ubiquitous, tracking trends will become easy to accomplish, but several "so what?" questions remain. That is, we may have the ability to monitor changes, but how do we use that information in an actionable way?

  – How large should a mobility program be? What overall level of investment is required to make progress toward performance targets? Agencies have competing needs to address – what are the implications of emphasizing one program area over another?

  – Perhaps more so than other program areas, changes in mobility performance are affected by forces external to a transportation agency's control. Primary among these is demand growth, either brought about by general economic conditions or in a more localized fashion due to land use changes. While demand growth certainly affects other program areas (e.g., safety, pavements, it is particularly egregious for mobility because of the well-documented nonlinear effect that demand growth has under already congested conditions. Other factors such as major weather and special events may also skew mobility measurements in a particular year.

  - Given the above, how strictly do we manage to outcomes? Should we manage to lower level output-oriented measures (e.g., performance at the project level) or do we somehow qualify or adjust outcome targets to account for external influences?

- **Standard Procedures for Computing Performance Metrics –** This report has recommended a core set of mobility performance measures to be used in the near term. However, merely specifying a metric does not ensure compatibility across areas. With the vast amount of data now available, there are many ways to take low-resolution travel time measurements and turn them into performance metrics. Specifically, temporal and spatial aggregation must occur and other data must be used as reference points (e.g., the selection of free-flow speeds) or in transforming the travel time data (e.g., volume used to weight measurements). Therefore, a strong need exists to develop standard procedures for computing performance metrics from "raw" measurement data. A formal standard could be developed, such as through a standards development organization like ASTM or AASHTO, or a set of guidelines can be produced, but having procedures that all agencies can follow will foster comparisons between areas.

1.0 Introduction

The objective of this research is to assess methods for defining and measuring mobility in metropolitan regions. How an agency or jurisdiction defines and measures mobility greatly determines selection of strategies and ultimately investment decisions. In metropolitan areas, measuring mobility at the system level is often limited to the measure of traffic congestion and resulting delay on the freeway and signalized arterial networks. Although traffic congestion does inhibit mobility, it alone may not be a sufficient measure of system performance, particularly as transportation agencies strive to embrace a more multimodal[1] approach to transportation planning.

Performance measurement is not an end unto itself. Rather, it is used to monitor progress toward achieving the vision, goals, and objectives of an agency or firm. These things are usually specified as part of a strategic planning process that identifies the directions an agency wishes to take in providing transportations services. This is the perspective taken in this report – that mobility performance measurement is part of a larger process of providing services and improving the quality of life for the customers of transportation.

The term "mobility" can be used in several contexts. In some contexts, "mobility" has been used to describe only the actual movement of travelers. However, for this report, we define mobility in a very broad sense, encompassing all aspects of how people move about the landscape. Thus, the idea of "accessibility" – how easily opportunities or activities can be reached and a key aspect of this report – is part of the overall mobility picture. In general, we use the following scales to describe mobility:

- **Facility-Based Performance –** What happens only on a predefined section of roadway, transit route, or other modal facility;
- **Trip-Based Performance –** What happens for a complete trip, from original origin to final destination; and
- **Accessibility Performance –** The cumulative effect of trip-based performance broken out by different types of opportunities.

In the past several years, the art and science of measuring congestion has advanced significantly due to the widespread availability of mobility-related data. Intelligent transportation systems (ITS) roadway devices that measure volume, speed, and lane occupancy, installed to support operations control

[1] For the purpose of this report, "multimodal" refers to a wide variety of modes taken by travelers, including single-occupancy vehicles, high-occupancy vehicles, transit, bicycling, and walking.

measures (e.g., ramp metering and incident management), also provide extremely valuable data on system performance when archived. More recently, the collection of vehicle probe data by private vendors for real-time traveler information also can be used to support congestion performance measurement, especially on roadways not covered by ITS such as rural and signalized highways. This explosion of data has enabled much more detailed and direct measurements of performance than has been possible in the past. Previously, agencies relied on either highly limited sampling of travel times or models to generate performance statistics. This report is based on the notion that agencies will not only take advantage of the currently available data but that data sources and types will continue to grow in the near future, enabling more system coverage and the measurements outlined herein.

2.0 Domestic Mobility Performance Measures

A review of mobility performance measures currently being reported and/or used by state DOTs in the most urbanized states was undertaken (Table 2.1). In addition to the states listed, Massachusetts, New Jersey, Pennsylvania, Indiana, and Arizona also were reviewed, but no formal use of mobility performance measures were found. Note that vehicle miles of travel (VMT) does not appear checked for some states. All states report and use VMT, but the focus here was in the use of VMT in mobility performance reports. A recent study documented mobility performance measures in use at selected large MPOs (Table 2.2).

Table 2.1 Mobility Performance Measures in Use by Selected State DOTs

	Note	FL	MA	CT	NY	NJ	PA	MD	VA	NC	GA	TN	KY	OH	MI	WI	MN	IN	IL	TX	NM	CO	AZ	UT	WA	OR	CA
V/C ratio (directly)		●																								●	
V/C ratio (indirectly) – percent of road network with traffic volumes greater than capacity or above congested levels		●		●				●	●	●		●	●	●	●		●								●		
• Percent of congestion-free travel on roadways																											
• Percent of roadway miles having acceptable level of service																											
Annual congestion cost	Amount of time and fuel wasted because of traffic congestion										●		●	●						●		●					
Lane-miles and passenger trips required to hold congestion constant													●														
Average commute time											●																
Roadway incident duration time, response time, or clearance time				●						●	●	●			●		●							●	●		
Travel time											●		●	●						●				●	●	●	●
• Travel time variability	WSDOT also measures HOV travel time and reliability	●									●														●	●	●
• Number of people taking reliable trips per day																											
Average speed											●															●	●
Average speed variability																											
Percent of population within 20 miles of a four-lane highway	Border-to-border and interregional connectivity										●																
Percent of state transportation funding spent on local road	Local connectivity to state system										●																
Vehicle-Miles Traveled, Total (as reported or used in mobility reports)	GDOT also measures Interstate share of VMT	●	●		●			●			●								●	●					●		
Vehicle throughput		●																							●		●
Freight vehicle-miles traveled		●																									
Freight tonnage and/or value								●																	●		
Supply chain costs by corridor	Include three components: the direct cost of shipping (cost of fuel, the truck, and hiring the driver), the direct inventory cost (the capital "carrying cost" associated with having the inventory on a truck, and the obsolescence cost (the value at risk from depreciating inventory). Congestion in a corridor drives up all three components										●																
Person throughput		●																							●		
Vehicle hours of delay		●											●	●						●		●			●	●	
Person hours of delay		●							●				●	●						●					●		
Lost throughput productivity	Percentage of a highway's lost vehicle throughput due to congestion when compared to the maximum five-minute weekday flow rate observed at a particular location of the highway for that calendar year																								●		
Lost lane-miles	Equivalent lost capacity on a roadway due to decreased lanes, weaving, or other congestion-related scenarios																										●
Duration of congestion		●																							●		
Accessibility time difference	From a particular point, time between the fastest and second-fastest state highway access points																										●
Total trip time																											
Mode split								●			●															●	

	Note	FL	MA	CT	NY	NJ	PA	MD	VA	NC	GA	TN	KY	OH	MI	WI	MN	IN	IL	TX	NM	CO	AZ	UT	WA	OR	CA
Average vehicle occupancy												●															
Transit ridership			●	●	●			●	●					●			●				●	●					
Commuter vehicle miles traveled (VMT) saved by transit options										●																	
Average number of workers reaching major employment centers by car or transit in 45 minutes											●																
• Operating cost per unlinked passenger trip by mode • Operating cost per passenger mile by mode	These measures are cost-effectiveness performance measures that evaluate a transit system's ability to transport people in a cost-effective manner										●																
Park-and-ride utilization			●					●							●						●					●	
Cyclist volume																											
Pedestrian volume																											
Transit on-time performance			●	●				●		●																	
Air passenger numbers								●	●																		
Customer satisfaction on airport, transit, roadways, highway rest areas and DOT agencies								●		●									●	●							
Average truck turn-around time at marine terminal								●																			
• Percentage of state-owned roadway centerline miles within urban areas that have sidewalks and percent of sidewalks that meet Americans with Disabilities Act (ADA) compliance								●																			
• Percentage of state-owned roadway with a bicycle level of comfort (BLOC) grade "D" or better and mileage of state-owned highways with marked bike lanes • Percentage of state highway intersections with ADA-accessible pedestrian signals • Performance percent of urban state highway miles with bike lanes and pedestrian facilities in "fair" or better condition								●									●									●	
Percentage of track miles with capacity over 286,000 pounds												●															
Average annual service miles of rural transit fleet												●															
Annual transit vehicle hours												●					●										
Two or more modes serve each passenger terminal															●												
Nonstop air destinations from airport																	●										
Port tonnage																	●										
Percent of population within 20 miles of an airport with paved and lighted runway																	●										
Railroad track speed																	●										
Special transit rides	Average number of special transit rides per each elderly and disabled																									●	
Percent of communities of 2,500 or more with intercity bus or rail passenger service																										●	

Table 2.2 TMA MPO Congestion Management and Operations Performance Measures

TMA MPOs	Travel Time Index/ Reliability	V/C Ratio	Congestion Duration	Speed	Recurring Delay	Other
Atlanta Regional Commission (ARC)	●	●	●			●
Capital District Transportation Committee (CDTC)	●				●	●
Delaware Valley Regional Planning Commission (DVRPC)		●				●
Genesee Transportation Council (GTC)	Under development	●				
Hampton Roads Planning District Commission (HRPDC)		●			Under development	●
METROPLAN ORLANDO	●	●		●	●	●
Metropolitan Transportation Commission (MTC)			●	●	●	●
Mid-America Regional Council (MARC)		●	●			●
North Central Texas Council of Governments (NCTCOG)		●		●	●	●
Pima Association of Government (PAG)	●				●	●
Southeast Michigan Council of Governments (SEMCOG)	●	●		●		
Puget Sound Regional Council (PSRC)	●	●		●		●
Southwestern Pennsylvania Commission (SPC)	●			●	●	●
Wilmington Area Planning Council (WILMAPCO)	●	●		●		●

Source: Cambridge Systematics, *Evaluation of an Objectives-Driven, Performance-Based Approach in Planning for Operations*, prepared for FHWA, March 17, 2010.

2.1 Florida DOT

Based on the initial review of state agencies (as summarized in Table 2.1), it was discovered that Florida DOT has proposed a comprehensive set of mobility performance measures for its performance reporting activities. This made FDOT an excellent candidate for follow-up examination. The 2025 Florida Transportation Plan stated a goal of fostering "a stronger economy through enhanced mobility for people and freight." Mobility was defined as "the ease with which people and goods move throughout their community, state, and world." Supporting this goal, several more specific long-range mobility and economic competitiveness objectives were developed:

- **Mobility between regions, states, and nations**:
  - Provide for smooth and efficient transfers for both people and freight between transportation modes and between the Strategic Intermodal System and other transportation facilities.
  - Reduce delay on and improve the reliability of Strategic Intermodal System facilities.
  - Preserve new capacity on the Strategic Intermodal System for projected growth in trips between regions, states, and nations, especially for trips associated with economic competitiveness.
  - Expand the use of modal alternatives to Strategic Intermodal System highways for travel and transport between regions, states, and nations.
  - Establish statewide criteria for identifying and developing new Strategic Intermodal System facilities where such facilities are needed to connect the economic regions of the state, especially economically distressed areas, in coordination with regional and community visions.
- **Mobility within regions:**
  - Develop regional visions and action plans which integrate transportation, land use, economic, community, and environmental systems to guide transportation decision-making and investments. Focus attention on meeting regional mobility needs transcending traditional jurisdictional boundaries and ensuring connectivity between Strategic Intermodal System, regional, and local facilities.
  - Facilitate economic development opportunities in Florida's economically distressed areas by improving transportation access from these areas to markets in a manner that reflects regional and community visions.
- **Mobility within communities**:
  - Develop multimodal transportation systems to support community visions.
  - Expand transportation choices to enhance local mobility and to maintain the performance of the Strategic Intermodal System and regionally significant facilities.
  - Reduce per capita vehicle-miles traveled by single-occupant vehicles, especially during peak hours of highway use. Ensure the accessibility of the transportation system to all users, including young, elderly, disabled, and economically disadvantaged persons.

In turn, the objectives are supported through mobility performance measures. Four components (attributes) of mobility are considered, along with specific measures useful for **system-level** performance monitoring:

- **Quantity of travel:**
  - Magnitude of use of a facility or service;
  - More people and goods transported the better; and
  - Measures:
    - » Vehicle-miles traveled;
    - » Person-miles traveled; and
    - » Truck-miles traveled.
- **Quality of travel:**
  - Traveler satisfaction with a facility or service;
  - User experience is usually most important to the traveling public; and
  - Measures:
    - » Average travel speed;
    - » Vehicle delay;
    - » Person delay;
    - » Level of service; and
    - » Travel time reliability.
- **Accessibility:**
  - Ease in which travelers can engage in desired activities;
  - It does not matter how good the quality is if it is hard to get there; and
  - Measures:
    - » Proximity to major transportation hubs;
    - » Percent urban miles with sidewalks; and
    - » Percent miles with paved shoulders/bicycle lanes.
- **Capacity Utilization:**
  - Quantity of operations relative to capacity;
  - Indicates how efficiently resources are being used; and
  - Measures:
    - » Vehicles per lane-mile;
    - » Percent of miles heavily congested;
    - » Percent of travel heavily congested; and
    - » Duration of congestion.

A similar set of measures is proposed for the project level, the main difference being the use of the volume-to-capacity (v/c) ratio and levels of service concepts from the *Highway Capacity Manual (HCM)*.

2.2 TRAVEL TIME RELIABILITY PERFORMANCE MEASURES

Definition of Reliability

Travel time reliability relates to the how travel times for a given trip and time period perform over time. For the purpose of measuring reliability, a "trip" can occur on a specific highway section, any subset of the transportation network, or can be broadened to include a traveler's initial origin and final destination. The concepts discussed here apply to all of these units, as long as it is travel time over some distance that is being measured. Measuring travel time reliability requires that a sufficient history be present in order to track travel time performance.

There are two widely held ways that reliability can be defined. Each is valid and leads to a set of reliability performance measures that capture the nature of travel time reliability. Reliability can be defined as:

1. The *variability* in travel times that occur on a facility or a trip over the course of time; and
2. The number of times (trips) that either "fail" or "succeed" in accordance with a predetermined performance standard.

In both cases, reliability (more appropriately, unreliability) is caused by the interaction of the factors that influence travel times: fluctuations in demand, traffic control devices, traffic incidents, inclement weather, work zones, and physical capacity (based on prevailing geometrics and traffic patterns). These factors will produce travel times that are different from day to day for the same trip. The reliability of a facility or trip can be reported for different time slices, e.g., weekday peak hour, weekday peak period, and weekend.

From a measurement perspective, reliability is quantified from the distribution of travel times, for a given facility/trip and time slice, that occurs over a significant span of time; one year is generally long enough to capture nearly all of the variability caused by disruptions. A variety of different metrics can be computed once the travel time distribution has been established, including standard statistical measures (e.g., standard deviation, kurtosis), percentile-based measures (e.g., 95th percentile travel time, Buffer Index), on-time measures (e.g., percent of trips completed within a travel time threshold, and failure measures (e.g., percent of trips that exceed a travel time threshold).

The basic definition of travel time reliability (variability in travel times) can be extended to include the notion of predictability; that is, the probability that a travel time for a facility or trip is within acceptable limits for the traveler, given that travel times are affected by interaction of demand fluctuations, traffic control devices, traffic incidents, inclement weather, work zones, and physical capacity. It also can be used to compare current conditions to history: is the travel time today "typical" of what happens or is it better than usual or near-worst case. However, both of these corollaries are based on establishing the variability over time, as defined by the travel time distribution.

In a broader sense, reliability is a dimension or attribute of mobility and congestion. Traditionally, the dimensions of congestion have been spatial (how much of the system is congested?), temporal (how long does congestion last?), and severity-related (how much delay is there or how low are travel speeds?). Reliability adds a fourth dimension: how does congestion change from day to day?

Recommended Reliability Performance Measures from SHRP 2 Project L03

A more complete discussion of reliability appears in Appendix A. A good summary of the latest thinking about reliability performance measures comes from SHRP 2 Project L03, which examined the potential performance measures used to describe travel time reliability and recommended those in Table 2.3. The recommendations were based on examining measures in use in the United States and other parts of the world. The list includes the Skew Statistic, as proposed by European researchers. The researchers also added the 80th percentile travel time because analysis indicated that this measure is especially sensitive to operations improvements and also has been used in previous studies on the valuation of reliability. The research also demonstrated that the Buffer Index can be an unstable measurement for tracking trends over time due in part to its linkage to two factors that change – average and 95th percentile travel times; if one changes more in relation to the other, counterintuitive results can appear.

Table 2.3 Recommended Reliability Performance Metrics from SHRP 2 L03

Reliability Performance Metric	Definition	Units
Buffer Index (BI)	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time • The difference between the 95th percentile travel time and the median travel time, normalized by the median travel time	Percent
Failure/On-Time Measures	Percent of trips with travel times less than 1.1 * Median Travel Time *or* 1.25 * Median Travel Time Percent of trips with space mean speed less than 50 mph; 45 mph; or 30 mph	Percent
80th Percentile Travel Time Index	80th percentile travel time divided by the free-flow travel time	None
Planning Time Index	95th percentile Travel Time Index (95th percentile travel time divided by the free-flow travel time)	None
Skew Statistic	The ratio of (90th percentile travel time minus the median) divided by (the median minus the 10th percentile)	None
Misery Index (Modified)	The average of the highest 5 percent of travel times divided by the free-flow travel time	None

Source: Cambridge Systematics, Inc. SHRP 2 Project L03 Final Report: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies. Strategic Highway Research Program (SHRP 2), Transportation Research Board, February 2010.

A discussion of these measures follows.

- Planning Time Index and Buffer Index are starting to be used in practice, primarily for performance monitoring applications. A word of caution: SHRP 2 L03 found that the Buffer Index can be an unstable indicator of changes in reliability – it can move in a direction opposite to the mean and percentile-based measures. This is because it uses both the 95th percentile and the median or mean travel time, and the percent change in these values can be different from year to year. Although not specifically tested in L03, the Skew Statistic may also suffer from this phenomenon.
- The 80th percentile travel time has not been widely used. However, SHRP 2 L03 found that can be more sensitive to operational changes than the 95th percentile and recommended its inclusion. Further, one of the more reliable past studies of reliability valuation used the difference between the 80th and 50th percentile travel times as the indicator of reliability.[2]
- The Misery Index, in its current definition, is close to the 97.5 percentile travel time index.

[2] Small, K.A., C. Winston, and J. Yan. (2005) Uncovering the Distribution of Motorists' Preferences for Travel Time and Reliability, Econometrica, 73(4), 1367-1382.

- Standard deviation was not part of the L03 set of measures, but it should be added because of its use in applications:
  - SHRP 2 Projects C04 and L04 use standard deviation as one of the terms in expanded utility functions that are used to predict traveler behavior; and
  - Several past studies of reliability valuation have used standard deviation as the measure that is valued.
- Failure/On-Time measures are defined in two ways: 1) in reference to the median travel time (used to indicate "typical" conditions for a trip); and 2) in relation to predetermined performance standards based on the space mean speed (SMS) of the trip.
  - Because their construction is binary (a trip either "passes" or "fails" the condition), these measures can be insensitive to small changes in underlying performance. Therefore, they have been defined with multiple thresholds so that changes in performance can be more easily detected.
  - The median-based measures are constructed as on-time measures while the SMS measures are constructed as failure measures.

3.0 International Scan of Mobility Measures: Summary

A more detailed discussion of international experience with mobility and accessibility measures is provided in Appendix A. A summary of this experience follows.

Three FHWA international scans were reviewed:

1. *Transportation Performance Measures in Australia, Canada, Japan, and New Zealand*, FHWA, December 2004;
2. *Active Traffic Management: The Next Step in Congestion Management in Denmark, England, Germany, and the Netherlands*, FHWA, July 2007; and
3. *Linking Transportation Performance and Accountability in Australia, Great Britain, New Zealand, and Sweden*, FHWA, April 2010.

In addition to these three FHWA documents, an on-line search also was performed on mobility measures in other countries.

All the transportation agencies use similar sets of measures commonly used in the United States, such as congestion and travel time. Other measures are related to road safety, trip reliability, and accessibility. *Measures of customer satisfaction are also widely used by those agencies*. For example, UK transportation agencies measure time reliability by the average delay experienced in the worst 10 percent of journeys for each monitored route.

Measures relating to freight movement and transit were found in many performance measurement efforts. However, in most cases, performance measurement is implemented within a modally focused agency, so performance measures were targeted at decisions relating to the performance of that modal network. But many agencies are moving away from a traditional mode-centric focus to a broader, more inclusive approach to surface transportation planning in highly congested urban areas, so the examined agencies placed a great emphasis on transit service, rail passenger service, land use integration, and moving people and freight as well as vehicles as they continued to develop their performance measures.

The agencies visited displayed a strong commitment to addressing climate change and sustainability. However, transportation's effect on the environment was not easily captured by the visited agencies. Other measures as travel time reliability and transportation's effect on the environment also were not easily defined by the visited agencies. All these important outcomes that are difficult to measure in the United States were equally difficult in the agencies studied.

The more urbanized agencies in the United Kingdom, Australia, and Sweden were investing considerable effort in measuring real-time highway, transit, and rail operations to improve their operations, travel time reliability, enhance transportation choices, and reduce greenhouse gas emissions.

4.0 Recommended Measures for Mobility Performance Monitoring

4.1 General Discussion: Performance Measures for Managing Mobility-Oriented Programs

Based on the review of current practice, we offer the following guidance for agencies in establishing mobility monitoring programs.

1. **Linkage to Strategic Planning.** Performance measurement is not an end unto itself. Rather, it is used to monitor progress toward achieving the vision, goals, and objectives of an agency or firm. These things are usually specified as part of a strategic planning process that identifies the directions an agency wishes to take in providing transportations services. Figure 4.1 shows an example of how this might work for safety and mobility within a transportation agency.

This simplified example demonstrates that it is critical to determine exactly what an agency wants to achieve. ("Be careful of what you measure – you might just get it.") Note that in this example, only one objective is given as a way to further define the goal of "providing access to jobs, housing, and economic activities." Usually, multiple objectives support one goal; but in this case, if this is the only objective, the emphasis is placed solely on reducing peak congestion, which is only one many factors affecting accessibility; land use patterns, system connectivity, and the very presence of opportunities in the first place (such as jobs) all contribute to accessibility.

Further, it could be argued that accessibility is subsumed by an even higher goal. What matters to travelers may be something different than the time it takes to get to activities. It may be the total cost of getting there (which includes the cost of time as well as out-of-pocket costs), the means of getting there (e.g., nonauto modes), or minimizing external impacts in the process of getting there (e.g., reducing green house gases). It is, therefore, critical to involve stakeholders in the strategic planning process that leads to the system identified in Figure 4.1. The performance measures that arise from this inclusion will be very different from the congestion-based measures now in widespread use. If transportation agencies are to become fully customer-focused, this is the only tact that makes sense. A more complete program based around accessibility to jobs might look like the structure shown in Figure 4.2.

Figure 4.1 Performance Measures Are Used to Monitor Progress Toward Strategic Goals

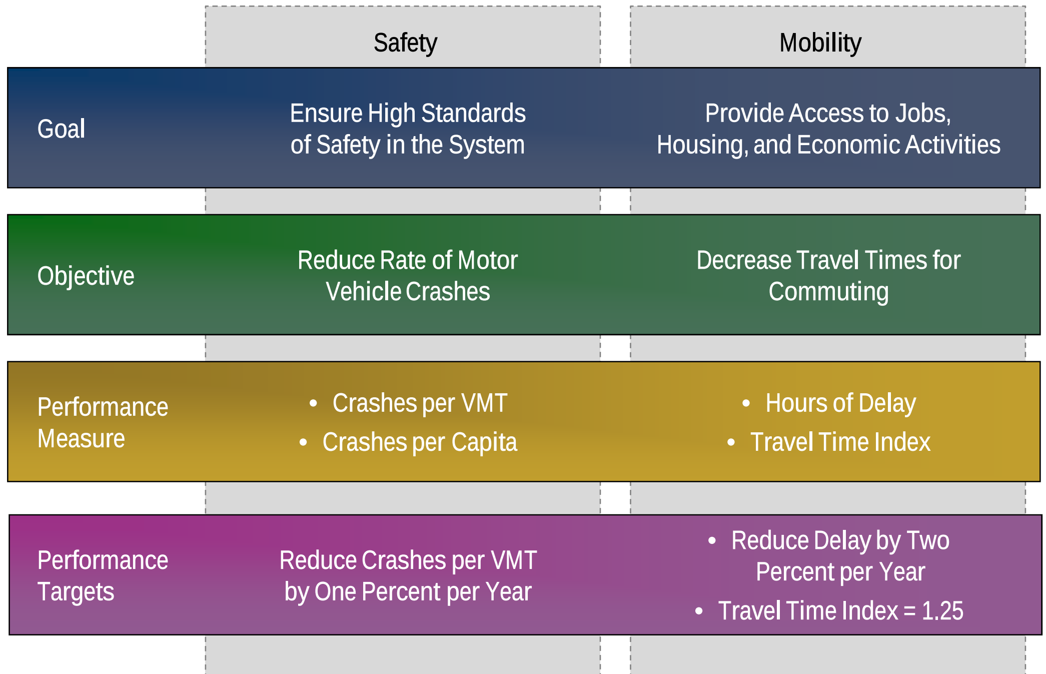
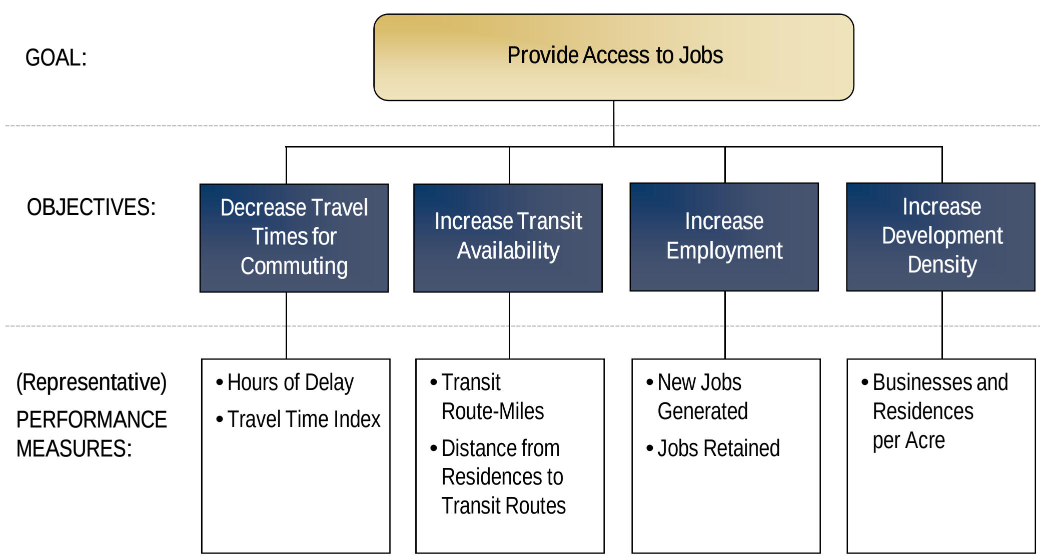


Figure 4.2 Possible Program Structure for an Accessibility Goal



2. **"Mobility" should be the overarching term for the movement of people and freight over the transportation system.** While several taxonomies can be constructed for organizing the concepts used in this project, Mobility is the main feature of interest. Congestion and Accessibility are considered to be features of Mobility.

3. **Travel time as the basis for mobility measures.** Despite the use of capacity-based metrics such as the v/c ratio, a comprehensive mobility measurement program – which includes both historical monitoring and forecasting activities – should rely on measures that are grounded in travel time. Travel time-based metrics are the foundation for all scales of performance – facility, corridor, and areawide spatial scales. They also are a key component of measuring accessibility.

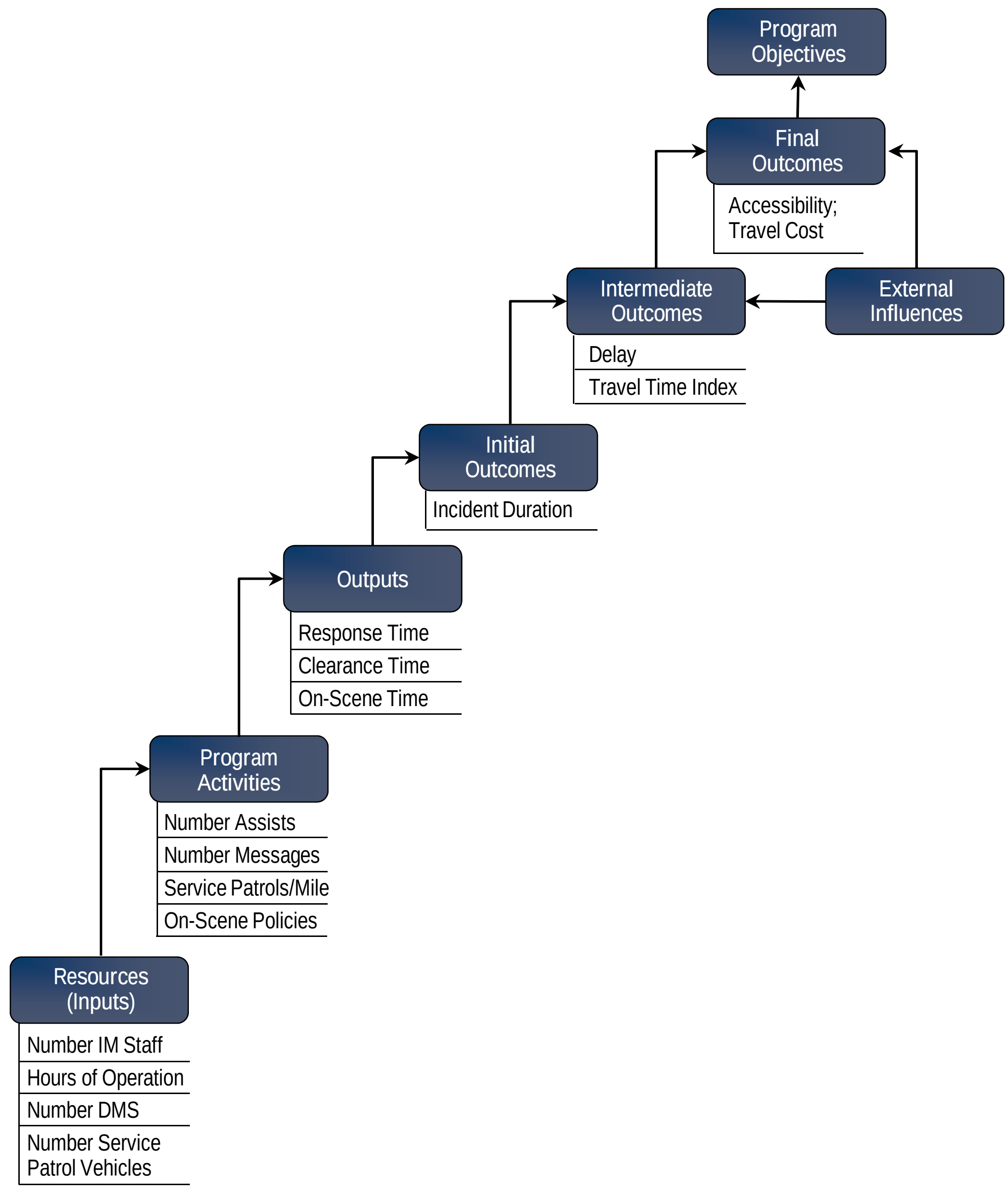
4. **A comprehensive and "linked" mobility performance measurement program.** In the performance measurement literature, measurement programs are established as a series of linked levels, with different performance measures for each level. The so-called "Program Logic Model" has been applied to the programs of many public agencies; Figure 4.3 shows the components of the Model and some example measures for an incident management program. In this context, the previous sections have dealt with measures for the "Final Outcomes" phase for mobility.

   However, it is clear that agencies will require a fully linked mobility performance measurement system to address several emerging issues:

   a. **Explaining outcomes.** Outcomes are required to gauge the impact on system users ("mobility customers"). However, when they are used to track conditions over time, they can only indicate if things are better or worse – but they do not tell us why. We need lower-level measures that relate to the ***investment process itself*** to understand why conditions change, as well as an understanding of external influences (see below). That is, what did we do – and how effectively did we do it – that could have influenced an observed trend. In other words, using a medical analogy, the difference between having a fever (knowing something is wrong) and a diagnosis (knowing what is wrong).

   b. **Performance-based management.** Similarly, we do not manage congestion level – we manage the activities that have an effect on congestion. Therefore, we need to have measures that relate to how effectively we are undertaking day-to-day activities. This is the difference between producing mobility performance reports that highlight changes in outcomes (initial outcomes like congestion level or final outcomes like accessibility/travel cost) and using performance measures to manage our programs. The ideal performance measurement program, then, includes measures at all the levels shown in Figure 4.3.

Figure 4.3 Program Logic Model Adapted for Incident Management



Source: Based on Poister, Theodore H., *Measuring Performance in Public and Nonprofit Organizations*. ISBN 978-0789-4999-0, San Francisco, 2003.

c. **External influences.** Many factors, including those outside the control of transportation agencies – will influence outcomes. In the example shown in Figure 4.3, many other programs will have an effect on congestion in addition to incident management (e.g., roadway capacity expansion, pricing, transit investments). Weather effects are another major external demand with a clear negative effect on performance that need to be identified and reported. More importantly, congestion is strongly influenced by demand (VMT), which is driven largely by economic conditions and land use patterns. These external influences make it difficult to isolate the effect of congestion mitigation programs of all kinds, but it makes it imperative that they be monitored, to provide explanation of trends at a minimum.

d. **Measurement scale and the role of project evaluations.** Largely because of factors external to programs under agencies' control, areawide performance reporting masks underlying problems and makes it impossible to pinpoint emerging problems. Because most congestion mitigation strategies are focused on specific facilities, their effect will be diluted in areawide numbers that include subareas where no improvements have been made and congestion has grown worse. Areawide performance is useful for high-level decisions about the size and nature of programs but not for targeting specific problems or assessing specific solutions. For this reason, it is very important to monitor mobility at a much smaller scale; the corridor level or "typical commute path" is a logical place to start. Further, to help control for the effect of external influences and areawide "dilution," *evaluations of completed projects using the same set of performance measures as for areawide reporting* will provide a different view of mobility trends.

e. **Cost-effectiveness and efficiency measures.** Both of these measures weave in the notion of costs. Cost-effectiveness measures relate the cost of investments to the change in outcomes; an example is the cost per change in delay or accessibility. Efficiency measures relate the cost of investments to outputs; an example is the cost per increase in capacity. Cost-effectiveness measures have been used in transportation as a basis for comparing alternatives within a specific project (e.g., different designs, transit versus highway improvements), but for the most part, we have shied away from using them to report global performance. However, with the urgency to make every investment dollar count and the *push for increased transparency in government, the transportation profession can no longer avoid using cost-based performance measures*. At a minimum, cost-based measures can be used in project evaluations (what actually happened) in addition to project planning (what we expect to happen).

f. **User cost measures.** There has been a growing interest in translating the rather dry mobility measures into costs incurred by users as a means of communicating the consequences of poor mobility and the positive effect of transportation investments. As with cost-effectiveness and efficiency measures, most of the profession's experience with these measures has been at the project planning stage. However, the Texas Transportation's Institute *Urban Mobility Report* has used user costs at the system (global) level for many years. Recently, AASHTO has defined several potential user cost mobility measures for performance-based management of transportation programs, including:

i. Travel delay per commuter;

ii. Annual passenger vehicle delay cost; and

iii. Annual commercial delay cost.

GDOT has also defined user cost measures as part of their strategic planning process.[3] These measures are:

iv. Annual congestion cost; and

v. Supply chain costs by corridor (sum of: congestion cost, direct inventory cost, and obsolescence cost).

5. **Facility-based versus trip-based mobility.** Largely due to data availability, transportation performance programs have focused on what happens on the facility, yet our customers view their experience in relation to the entire trip. The data to monitor entire trips by travelers is on the horizon; it is likely that within the next five years, these data will be available mainly from private vendors of travel time information. The issue then becomes: *how do investment and policy decisions change if they are based on trip performance rather than facility performance?* A major issue is that when trips are monitored over time, we measure not only system condition but how travelers adjust their lifestyles to congestion. That is, over time, travelers will change their places of residence and work to adapt to congestion and many other societal and economic factors, so these responses become part of the measurement. So, trip-based mobility performance is starting to measure the interaction of transportation and spatial development patterns. Actually, there is no need to pick facility or trip measures as the "best" way to measure mobility – we need both to gain a complete picture of mobility. Moreover, the same data and travel time-based measures can be used to develop both types of measures.

6. **Accessibility as an integrated transportation-land use measure.** Trip-based mobility measures are the starting point for accessibility measures, but they are blind to trip purpose or opportunity; they just measure the performance of trips within a given time window. Accessibility measures layer on the trip purpose or type of destination represented by the trip and are meant to measure the ease of reaching opportunities – goods, services, activities, and other destinations. Three factors affect accessibility: 1) congestion (or impedance); 2) transportation system connectivity; and 3) land use patterns. Thus, accessibility measures capture all four of these simultaneously; it is still important to understand the contribution of components, especially mobility as this is under more direct control of transportation agencies and easier to communicate to a general audience for a greater range of purposes. Note the

[3] Georgia Department of Transportation, *Statewide Strategic Transportation Plan, 2010-2030*, June 2, 2010, http://www.it3.ga.gov/Documents/Final-SSTP.pdf.

accessibility can apply to the ease of getting to activities (such as jobs, recreation, shopping) or aspects of the transportation system itself (freeways, transit route, bike facilities).

7. **Managing programs with mobility performance measures.** With the data now available, agencies can report mobility performance for a large part of their transportation systems. However, this is only a first step. It is important to report performance for a number of reasons: to demonstrate knowledge of where the problems are, transparency in programs, and identifying the effects of investments. The next level is to use performance information to manage programs. This can take the form of directing individual investments and defining program structure and size. Very little experience exists in this area and as a result, this study did not investigate how agencies could manage with mobility measures. In fact, the issue is much broader than just mobility and includes all other functional areas of concern to transportation agencies (e.g., safety, pavements, bridges, maintenance).

4.2 Recommended Mobility Measures

As a starting point for organizing mobility measures, the four categories used by Florida DOT are used. A fairly long list of measures is recommended for use by agencies (Table 4.1). However, many of the measures are derived from the same underlying data – travel time measurements at very small spatial levels are the basis for all of the measures except VMT/demand. These are the common measures that should be reported by all agencies. Additional measures can be added for an agency's own use. The list is focused on ***outcome***-related measures; a wide variety of ***output*** and ***input measures*** should be developed to support these outcome measures, as supported by Figure 4.3.

It must be pointed out that for the immediate future, most of the activity in mobility performance measurement will be focused on the facility level, because most continuous travel time measurements are being made or compiled at the that level. However, we expect that data capable of measuring travelers' entire trips will become available shortly, and agencies should be planning for its use in performance monitoring.

For the "Quality of Travel" category, trip-based based measures are meant to handle the multiple aspects of travel. That is, they can be applied without regard to mode, or can be developed for each mode individually.

Table 4.1 Recommended Mobility Performance Measures

Category	Measurement Scale	Geographic Scale		
		Facility	Corridor	Areawide
Quantity of Travel	Facility-Based	Total VMT Truck VMT Total PMT SOV PMT HOV VMT Transit PMT	Total VMT Truck VMT Total PMT SOV PMT HOV VMT Transit PMT	Total VMT Truck VMT Total PMT SOV PMT HOV VMT Transit PMT
	Trip-Based	N/A	N/A	N/A
Quality of Travel	Facility-Based	HCM-based LOS Vehicle Delay Person Delay Travel Time Index Planning Time Index Percent On-Time	HCM-based LOS Vehicle Delay Person Delay Travel Time Index Planning Time Index Percent On-Time	HCM-based LOS Vehicle Delay Person Delay Travel Time Index Planning Time Index Percent On-Time
	Trip-Based			Travel Time Index Planning Time Index Percent On-Time
Accessibility	Facility-Based	N/A	N/A	N/A
	Trip-Based			Cumulative Opportunity Index
Capacity Utilization	Facility-Based	Density Demand-to-Capacity Ratio Duration of Congestion Spatial Extent of Congestion	Duration of Congestion Spatial Extent of Congestion	Duration of Congestion Spatial Extent of Congestion
	Trip-Based	N/A	N/A	N/A

Quantity of Travel

Facility-Based Measures (developed at the facility, corridor, and areawide levels, unless otherwise noted):

- Vehicle miles of travel (total and truck); and
- Person miles of travel (total and separately by mode).

Quality of Travel

Facility-Based Measures (developed at the facility, corridor, and areawide levels, unless otherwise noted):

- Level of service: An indicator of the quality of traffic flow on a **facility**, as defined by the *Highway Capacity Manual.*
- Delay:
  - Travel time (vehicle-hours and person-hours) in excess of what would have occurred under free-flow conditions.
  - Vehicle delay: Travel time (vehicle-hours) in excess of what would have occurred under free-flow conditions.
  - Person delay: Travel time (person-hours) in excess of what would have occurred under free-flow conditions.
- Travel time index:
  - Actual travel time (or travel rate) divided by the free-flow travel time (or travel rate).
- Reliability measures:
  - Planning time index (95^{th} percentile travel time divided by the free-flow travel time);
  - Percent On-Time – Percent of trips that occurs at or above a reference speed. (The recommended reference speed is 70 percent of the free-flow speed for a facility.)

Trip-Based Measures (subarea and areawide only):

- Travel time index; and
- Reliability measures:
  - Planning time index;
  - Percent On-Time – Percent of trips that occur at above a reference speed.

Accessibility (Areawide Only)

These measures are based on the work of El-Geneidy and Levinson,[4] and were selected because of their historical precedent and their relative ease of explanation. The focus is on jobs, but opportunities beyond jobs may be added (e.g., access to health care, recreation), but the work trip is the one most affected by congestion and, therefore, of greater interest to transportation agencies.

- Recommended Measure – Cumulative opportunity: number of jobs within 20 and 30 minutes of travel time by income range:
  - $C_i = \sum O_j B_j$
  - Ci = Opportunities (jobs) reachable from zone i
  - Oj = Opportunities (jobs) at zone j
  - Bj = A binary value equal to 1 if zone j is reachable within a predetermined time from zone i, otherwise equal to 0
- Supplemental Measure – Gravity-based accessibility index for jobs:
  - $A_i = \sum O_j * \exp(x * C_{ij})$
  - A_i = Accessibility at a given zone, i
  - O_j = Opportunities, in this case jobs, at a particular zone, j
  - C_{ij} = The travel time to get from zone i to zone j
  - x = coefficient

The two above measures should be calculated separately for auto and transit travel.

Capacity Utilization

- Vehicles per lane-mile (density): Used primarily for rural uninterrupted flow **facilities**.
- Demand-to-capacity ratio: The travel demand attempting to use a **facility** during a given timeframe divided by the physical capacity of the facility.
- Duration of congestion: Number of minutes a **facility** operates below a threshold space mean speed, travel rate, or travel time.

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[4] El-Geneidy, Ahmed M., and Levinson, David M., *Access to Destinations: Development of Accessibility Measures*, prepared for Minnesota Department of Transportation, Report No. MN/RC-2006-16, May 2006.

- Spatial extent of congestion:
  - Directional-miles of roadway within a predefined area and time period, for which average travel times are 30 percent longer than unconstrained travel times; **areawide only.**

5.0 Assessing Alternative Methods for Measuring Regional Mobility in Metropolitan Regions

5.1 Scenarios for Using Mobility and Accessibility Measures

Transportation agencies have a number of common applications that will benefit from the use of these mobility and accessibility performance measures. This section identifies many of these common applications and describes the most useful measures and information gained from using the measures.

The scenarios addressed in this Guideline fall into three general categories and are listed below:

Major Investment

The major investment scenarios involve physical changes to the infrastructure and require analysis over a long timeframe of up to 30 years. While the improvements may be confined to a limited area, the impacts are likely to be felt over a wider area, requiring a regional analysis to assess the full impacts. Generally regional or subregional travel demand models are used for this purpose. Three scenarios that fall into the major investment category are:

1. Conducting an Alternatives Analysis for Multimodal Capital Investment;
2. Analyzing an Integrated Corridor Management project; and
3. Evaluating a Corridor Improvement project.

Operations

The operational scenarios involve actions within existing rights-of-way or minor changes to the infrastructure. Increasingly, they involve the use of technology to improve the capacity and efficiency of the existing system. Analysis of these improvements often involves peak-period microscopic traffic analysis models. In other cases, operational models such as the ITS Deployment Analysis System (IDAS) that use data from travel demand models to assess operational impacts can be used. Three scenarios that fall into the operations category are:

1. Selecting Traffic Operations Improvement alternatives;
2. Optimizing Arterial Signal Timing; and
3. Evaluating Ramp Meter Operations.

System Performance and Management

The most common use of some of the newer performance measures discussed above, such as travel time index and congestion duration, is in documenting system performance. Many state DOTs have initiated performance measure reports, including summary "dashboards" which are intended to inform the public about agency activities and their impacts. These reports represent a first step in using the data to help make investment decisions. For example, detailed delay data, combined with classification counts, can help agencies to identify corridors where delays to freight traffic are having major impact on shipping costs, and ultimately on economic development:

- Conducting Transportation Agency Performance Management; and
- Prioritizing Transportation Agency Capital Programs.

Performance measures will vary based on the scenario or project being evaluated, the scale of the proposed project and the availability and cost of processing the data. Many of the measures are similar to each other so in some cases it becomes a matter of which are easier to calculate or easier to explain to the audience.

5.2 Performance Measures

The performance measures that will be tested are described below. In addition to the recommended measures from Section 4.0, a few additional measures have also been included. The applicability to use facility or trip-based analyses is noted for each measure. Most of the facility measures can be calculated from field data using a variety of data collection methods. Trip-based speed measures cannot currently be measured in the field; they can only be estimated from model output. Trip-based measures are calculated by aggregating facility-based measures over the entire duration or length of the trip, not just the portion that occurs on a given facility. While cell phones with GPS capability make the availability of this information a potential reality, privacy concerns and the related issue of demographic breakdown must be addressed before this will become widely available. The legal and institutional barriers in this are significant.

Facility-Based Measures

Travel Time Delay. Delay is very useful for assessing alternatives or conducting evaluations. Also the public easily understands delay without a detailed description of the measure. Vehicle delay and person delay have different uses as described below. (Facility)

Vehicle Travel Time Delay. Vehicle delay is obtained from sensor data along instrumented roadways or probe data where available. Vehicle delay data will allow direct travel time comparison among roadways in a corridor and also among transit types, such as bus, bus rapid transit (BRT), light rail or heavy rail alternatives. The vehicle travel time delay provides information about the operating characteristics of the autos and transit vehicles using the corridor facilities, not the person travel time in those vehicles. Also direct travel time is only available where the facilities are monitored, not on unmonitored facilities. Model delay may also be obtained from the regional travel demand models.

Person Travel Time Delay. Person travel time delay is normally obtained by multiplying the vehicle travel time delay by the number of occupants in each vehicle. Since the precise auto vehicle occupancy is not known, the vehicle occupancy is assumed from data collected occasionally for travel demand model calibration. The person delay will have the effect of weighting the comparison between modes, giving more weight to transit since the transit vehicles carry many times more people than autos. Model delay may also be obtained from the regional travel demand models.

Travel Time Index. The travel time index (TTI) is the ratio of prevailing travel time to the free-flow travel time. The TTI measure takes into account the different base travel time of freeways and arterials so that the comparison is normalized. (A TTI value of 1.30 indicates that a 20-minute trip in free-flow conditions takes 26 minutes in the peak period). Transit travel times can be compared as long as the travel times can be collected or modeled (Facility and Trip).

Space Mean Speed. Space mean speed provides a measure of distance per time unit, e.g., miles per hour, rather than time per a given distance. The measure is useful when comparing average speed among alternatives.

Buffer Index. The Buffer Index provides an indication of the travel time reliability of a roadway. The measure indicates the amount of extra time a traveler should allow (above the average travel time) when traveling a particular road segment if the traveler wants to be on time for 95 percent of the trips. (A BI value of 40 percent indicates that a traveler should allow 40 percent more travel time than average to arrive on-time for an important trip). This measure is useful to inform the user about the impacts of events such as crashes, weather, and special events on a road segment. Reliability measures have only been obtained from field data. They cannot be modeled using conventional four-step travel demand models. They may be estimated from calibrated traffic simulation models with detailed crash, vehicle breakdown, and other incident data.

Planning Time Index. The Planning Time Index is similar in purpose to the Buffer Index. They both provide an indication of the travel time reliability of a roadway but the PTI indicates the amount of time the 95th percentile trip in a particular road segment will take over the free-flow travel time. (A PTI value of 1.80 indicates that a traveler should allow 80 percent more travel time than in free-flow conditions to arrive on-time for an important trip). This measure is useful to inform the user about the impacts of events such as crashes, weather, and special events on a road segment. Reliability measures are obtained from field data, or can be modeled as specific incident or event scenarios that might be modeled using microscopic simulation tools.

Percent On-Time. Percent On-Time indicates the percent of times a trip on a particular road segment is completed within a set reference time or speed. It is best used as a travel time reliability measure. This measure requires volume data, which precludes probe data from being used by itself. This measure is more difficult to calculate than the other speed-based measures.

Vehicle Miles of Travel. VMT indicates the amount of travel in a corridor, but does not provide any information on the quality or performance of the travel. VMT is applicable only to roadways not transit (though Bus or Rail VMT might be important for transit operators). In most cases, VMT is not useful when considering facilities in a single corridor but is helpful when evaluating areawide travel, comparing corridors or examining multiyear trends.

Person Miles of Travel. PMT also indicates the amount of travel in a corridor, but includes transit and other modes. PMT is useful in a corridor alternatives analysis because it allows comparison of usage between the various modes and transit types.

Density. Density measures the number of vehicles per lane per mile. Density data provides an indication of vehicular traffic flow and congestion on a roadway segment. This measure is only useful for vehicle traffic on roadways. The measurement of density requires that roadways be instrumented or that aerial photography be used.

Level of Service. Level of service indicates the quality of service provided to the traveler. It is the translation of numerical performance results into a letter grade system designed to indicate to decision-makers and the public a general quality of service provided by the facility. Density, speed, and delay are used together in the appropriate HCM table to determine the LOS letter grade. Level of service is useful in that models provide that output and the modeled LOS can be compared for any roadway or transit facility in the corridor and LOS can be compared for future model projections for any alternative.

Demand-to-Capacity Ratio. Demand-to-capacity ratio is based on the entire vehicular demand trying to use a short section of roadway during a given time period, compared to the section's capacity. Field measurement of demand is difficult in oversaturated conditions as some of the demand will be "stored" in a queue and, therefore, not measured during the time period. However, models can estimate the Demand-to-Capacity ratio and the modeled demand can be compared for any roadway or transit facility in the corridor and demand can be compared for future model projections for any alternative.

Duration of Congestion. Duration of congestion indicates the amount of time a roadway or transit facility operates below a threshold speed. It is useful to provide information on the scale of congestion on different facilities. Duration of congestion can be determined on roadways that are instrumented with sensors or from probe data if speed is used as the congestion measure, or estimated from transportation planning models that allow for peak spreading.

Spatial Extent of Congestion. Spatial extent of congestion indicates the length of roadway that is operating below a threshold speed during a period of time. It is useful to provide information on where congestion occurs. Extent of congestion can be determined on roadways that are instrumented with sensors or which have probe data available, as well as by models.

Trip-Based Measures

Trip-based measures are facility-based measures aggregated or averaged over the entire duration/length of the trip, not just the portion that occurs on a given facility. In general, they are measured the same way as the facility-based measures described above. The measures most relevant to trip-based analysis include:

- Travel Time Index;
- Space Mean Speed;
- Buffer Index;
- Planning Time Index; and
- Percent On-Time.

Accessibility Measures

Opportunity Accessibility Index. The Opportunity Accessibility Index (OAI) indicates the level of access to activities, such as jobs, provided by transportation modes to/from locations in a region. This index has two components, the number of job opportunities within a travel time range and a function that reflects travel time between home and work locations. Goals of a potential improvement or project may include making economic opportunities more available to specific populations; for example providing service that allows inner city residents to reach available jobs in the suburbs or providing improved access to land that is available for housing or commercial activity. A higher OAI for a zone indicates there are more jobs closer to homes than in zones with lower OAI values. The measure shows the effect of transportation improvements as well as land use densification and diversification programs. The measure is estimated from model output and has been used in transportation planning applications, but is not widely used as a performance measure or as a decision-making tool. Roadway and transit trips are calculated separately.

Tabular Summaries

Table 5.1 summarized the measures described above, current and potential sources of data and their uses.

Table 5.1 Summary of Mobility/Accessibility Performance Measures

Measure	Field Data or Model	Currently Available	Uses
Facility-Based Measures			
Vehicle Miles of Travel	Model	Yes	Compare roadway alternatives
Person Miles of Travel	Model	Yes	Compare auto and transit modes
Density	Field data	Yes	Compare roadway alternatives and identify traffic operations improvements
Level of Service	Model	Yes	Compare roadway alternatives and identify traffic problem locations
Demand-to-Capacity Ratio	Model	Yes	Compare roadway alternatives and identify traffic problem locations
Travel Time Delay	Field data	Yes	Compare auto and transit modes
Vehicle Delay	Field data	Yes	Compare auto and transit modes
Person Delay	Field data	Yes	Compare auto and transit modes
Travel Time Index	Field data	Yes	Compare roadway alternatives
Space Mean Speed	Field data	Yes	Compare roadway alternatives
Buffer Index	Field data	Yes	Compare roadway alternatives and identify traffic operations improvements
Planning Time Index	Field data	Yes	Compare roadway alternatives and identify traffic operations improvements
Percent On-Time	Model	Yes	Compare roadway alternatives and identify traffic operations improvements
Duration of Congestion	Field data	No	Compare roadway alternatives and identify traffic problem locations
Spatial Extent of Congestion	Field data	No	Compare roadway alternatives and identify traffic problem locations
Trip-Based Measures			
Travel Time Index	Model	No	Compare auto and transit modes
Space Mean Speed	Model	No	Compare auto and transit modes
Buffer Index	Field data	No	Compare roadway alternatives and identify traffic operations improvements
Planning Time Index	Field data	No	Compare roadway alternatives and identify traffic operations improvements
Percent On-Time	Model	No	Compare roadway alternatives and identify traffic operations improvements
Accessibility Measure			
Cumulative Opportunities	Model or Data	Partially	Compares the level of access to activities provided by transportation modes

Tables 5.2 and 5.3 provide an assessment of which measures would be most effective in analyzing the eight scenarios described in Section 2.0. Measures in Tables 5.2 and 5.3 are grouped by category and in general, analysts would probably want to limit primary or secondary measures to one in each category. An important exception would be for agencywide performance measurement and evaluation of capital programs. These systemwide scenarios would justify a larger number of performance measures.

Both primary and secondary measures are identified since they are interchangeable in many cases. In general, however, the assessment is based on the likely goals and objectives of the project. An example can be seen in the first row of Table 5.2 for the scenario of a multimodal capital investment. The measure of Person Miles of Travel (PMT) is considered a primary measure since a major goal of the multimodal investment would provide travel opportunity for those who may not have an option. Another objective could be to reduce automobile vehicle miles of travel (VMT) but since this objective would be lower-priority VMT would be considered a secondary measure. A similar example can be shown in the scenario "Evaluating a Corridor Improvement." A facility-based measure of vehicle travel time delay provides a good measure of how well the improvement meets its objectives. Travel time index would be a secondary measure since the corridor may be relatively short in length and only serve a small portion of total trips. Thus, a high TTI may overstate the impact of the improvement for individual motorists.

In some scenarios, more than one measure is noted as primary or secondary for an analysis type. In most analyses, the measurement program would choose one or two of the possible performance measures based on audience understanding and previous experience. Use of many of the measures is relatively new. As they are used more frequently for different applications it will be helpful to document how effectively different measures communicate information to technical personnel, decision-makers and the general public.

Table 5.2 Facility-Based Measures for Scenarios

	Facility-Based Measures												
	Average Delay		Average Speed		Reliability			Explanatory		Traditional			
Scenario	Vehicle Travel Time Delay	Person Travel Time Delay	Travel Time Index	Space Mean Speed	Buffer Index	Planning Time Index	Percent On-Time	VMT	PMT	Density	LOS	Demand to Capacity Ratio	Congestion Duration
Alternatives Analysis for Multimodal Capital Investment		P	P		P			S	P		S	S	P
Analyzing an Integrated Corridor Management Project		P	P		P	S	S	P			P	P	S
Evaluating a Corridor Improvement Project	P		S		S			P			P	S	S
Selecting Traffic Operational Improvement Alternatives	P			P	S	P					S		P
Optimizing Arterial Signal Timing	P		P							S	P	S	
Evaluating Ramp Meter Operations	P		P	S			S	S			P	S	
Conducting Agency Performance Measurement	P	P	P		S	S	S	P	P		S		P
Prioritizing Agency Capital Programs	P	P	S		S	S	S	P	P		S	S	P

P = Primary Measure.

S = Secondary Measure.

Table 5.3 Trip-Based and Accessibility-Based Measures for Scenarios

	Trip-Based Measures					Accessibility-Based Measure Cumulative Opportunities
	Average Speed		Reliability			
Scenario	Travel Time Index	Space Mean Speed	Buffer Index	Planning Time Index	Percent On-Time	Number of Jobs within X Minutes
Alternatives Analysis for Multimodal Capital Investment	P	S	P			P
Analyzing an Integrated Corridor Management Project	P	S	P	S	S	S
Evaluating a Corridor Improvement Project	S		S			S
Selecting Traffic Operational Improvement Alternatives		P	S			S
Optimizing Arterial Signal Timing	S	P	S			
Evaluating Ramp Meter Operations	P	S	S			
Conducting Agency Performance Measurement	P		S	S	P	P
Prioritizing Agency Capital Programs	S	S	S	S	S	P

P = Primary Measure.

S = Secondary Measure.

5.3 Scenario Descriptions

The following section briefly describes the scenarios listed above and the sources of data that could be used to support the performance measures recommended in Tables 5.2 and 5.3 above.

Scenario 1: Conducting an Alternatives Analysis for Multimodal Capital Investment

Description. A regional MPO is proposing to add a light rail line along a 15-mile radial corridor. The FTA funding application process requires an alternatives analysis that includes a no-build alternative, a TSM alternative (low-cost improvements) and any valid alternatives that includes various modes and transit types.

Assumptions. The region has a continuing freeway traffic monitoring program and there are parallel arterial routes under signal system central control. One arterial corridor has some speed and volume data available.

Recommended Measures. The analysis of the measurement needs indicate that the facility-based measures would provide the most helpful information when conducting an Alternatives Analysis. Trip-based travel time index and buffer index measures would be helpful in determining the reliability impact of the investment but the new operating scenarios would have to be modeled. The OAI accessibility measure described above would also be useful in this scenario since a likely objective is to provide better access to jobs and commercial activity. Most travel demand models used by larger MPOs can provide this measure.

Scenario 2: Analyzing an Integrated Corridor Management Project

Description. A state DOT is proposing an Integrated Corridor Management Program that will involve both capital investment and operational strategies in a major freeway corridor. The freeway is heavily congested while two parallel arterials experience a moderate amount of congestion. An express transit service will be implemented on the major corridor freeway with some widening and realignment to accommodate stops. The freeway already has a full detection and surveillance system with several DMS at key locations. This system will be upgraded and CCTV will be installed at key intersections along the parallel arterials. A combination of detectors and probe data will be used to report speeds on the parallel arterials. Blank-out signs will be added to points on both the freeway exits and the arterials to guide traffic between parallel facilities. These signs will be used during construction and during major incidents to reroute traffic.

Assumptions. The region has a continuing freeway traffic monitoring program and the parallel arterial routes are under signal system central control. Both arterial corridors will have speed and volume data available. Transit vehicles traveling both the Freeway and the parallel arterials will have AVL equipment and report travel times through the transit dispatch center to the Traffic Management Center.

Recommended Measures. Facility-based measures summed across the corridor would provide the most useful measures of effectiveness. Since a major goal of the ICM project is to improve reliability by providing users with the most efficient route, delay reduction measures and travel time and buffer indices would all be very helpful in evaluating the improvement. Measures such LOS would be helpful in identifying any bottlenecks that may continue after the improvement. Modeling of trip-based measures, including vehicle delay and the buffer index would be helpful in evaluating the impact of the project.

Scenario 3: Evaluating a Corridor Improvement Project

Description. A state DOT is proposing to upgrade a major arterial corridor in a fast-growing suburban area. The project will involve capital investment in grade separation of several intersections and deployment of an ITS system, including CCTV, detection, and some DMS.

Assumptions. The region has a continuing freeway traffic monitoring program and there are parallel arterial routes under signal system central control. Both arterial corridors will have speed and volume data available. Transit vehicles traveling both the freeway and the parallel arterials will have AVL equipment and report travel times through the transit dispatch center to the Traffic Management Center.

Recommended Measures. Facility-based measures summed across the corridor would provide the most useful measures of effectiveness. Since a major goal of the ICM project is to improve reliability by providing users with the most efficient route, delay reduction measures and travel time and buffer indices would all be very helpful in evaluating the improvement. Measures such LOS would be helpful in identifying any bottlenecks that may continue after the improvement. Modeling of trip-based measures, including vehicle delay and the buffer index would be helpful in evaluating the impact of the project.

Scenario 4: Selecting Traffic Operations Improvement Alternatives

Description. Several options have been proposed to improve traffic flow on a congested major arterial that is owned by the state DOT but operated and maintained by a County Public Works Department. In addition to peak-hour congestion, the arterial experiences a higher than average rate of intersection crashes. Alternatives include some minor intersection modifications such as added turn lanes and driveway consolidations, signal upgrades and improved timing and installation of CCTV which would be tied into a regional Traffic Management Center. Other options include implementation of service patrols and software integration of the signal control system and ITS system. The budget does not allow for implementation of all of these options so a program of priorities must be developed.

Assumptions. Some data are available from detectors but overall volume and speed data in the corridor are limited. The two agencies will implement a data collection program to help guide the process but need to know how they will measure the effectiveness of the various options first.

Recommended Measures. Facility-based measures summed across the corridor would provide useful measures of effectiveness. Vehicle delay is the most effective measure for use in this situation, while space mean speed would also be helpful since it provides a measure of the distance that can be covered within a certain period of time. Reliability measures are also important to analyze the effect of operational improvements in situations where crashes are a problem. No empirical data are available to calculate trip-based measure but origin-destination data from models could be used to estimate space mean speed to help gauge the impact of the corridor improvement on certain major origin-destination pairs.

Scenario 5: Optimizing Arterial Signal Timing

Description. A proposal has been developed to optimize signal timing on a major arterial corridor. No capital improvements are planned other than upgraded signal equipment. Studies have shown that signal timing does not reflect current traffic patterns and that traffic flow improvements could be realized, especially during peak periods. The corridor also serves traffic for a number of special events, where flow and time-of-day patterns do not match those normally found in the corridor. The operating agency needs to know what investments in signal equipment, software, and operations personnel will be most cost-effective.

Assumptions. Data are available from corridor detectors and there is some probe data available as well. Intersection counts are not up to date and will have to be collected. It is anticipated that a traffic microsimulation model will be used to estimate the benefits of improved signal timing along the corridor.

Recommended Measures. Facility-based measures summed across the corridor would provide the most useful measures of effectiveness. The measures would include vehicle delay, space mean speed and the buffer index or planning time index as a measure of reliability. More traditional traffic engineering metrics, including level of service and density will also be helpful in evaluating the impact of various improvement strategies.

Scenario 6: Evaluating Ramp Meter Operations

Description. The state DOT is considering a proposal to install ramp meters on a section of freeway, which has experienced rapid traffic growth and is becoming increasingly congested at peak periods. This segment of road has become less reliable as it approaches capacity and both primary and secondary crashes have increased. There is a parallel service road along the freeway for part of the corridor and a parallel arterial within a half mile along the full length of the section.

There are ramp meters along the same freeway closer to the City Center and a control system is in place for the region. The DOT needs to understand the costs and benefits of the deployment, as well as the impacts on both the service road and the parallel arterial, which is owned by the county.

Assumptions. The freeway and service road are monitored with detection and CCTV and the data archived. Data on the parallel arterial are more limited. There is also a good database on the existing ramp metering system as well as volumes and speed on the parallel service road. It is anticipated that both microscopic and mesoscopic models to evaluate the impacts.

Recommended Measures. Facility-based measures summed across the corridor would provide the most useful measures of effectiveness. Aggregate vehicle delay across the three parallel roadways will be a useful measure (because diversion is an important element). The buffer index or planning time index along the corridor will be helpful in evaluating the impact on reliability. Level of service measures on all three roadways will be helpful as well. Trip-based vehicle delay would be helpful as well but will need to be developed from travel demand models, increasing the scope of the analysis.

Scenario 7: Conducting Agency Performance Measurement

Description. The state DOT is enhancing its performance measurement requirements to incorporate measures of mobility and reliability into the planning process and to help identify the benefits of a recently expanded ITS system. The agency is looking for measures that can be supported with existing and proposed data collection and can be easily understood by the public.

Assumptions. Major urban freeways are monitored through an ITS system using detection and CCTV. There are several relatively sophisticated arterial management systems that provide data adequate to estimate travel times on several major arterial corridors. For areas outside those covered by ITS, however, the DOT plans to rely on a recently executed probe data contract that will cover all freeways and major arterials around the state. Most of the larger transit systems are equipped with passenger counters and AVL data that can be used to estimate travel times and passenger volumes. The state DOT operates a data warehouse that collects and analyzes travel time and incident data.

Recommended Measures. While many agencies are producing estimates of measures such as reliability travel time index and buffer index, they are still in the early stages of determining what measures resonate with decision-makers and the public. Multimodal measures such as travel time, speed, person delay and the travel time and buffer indices appear to be useful and understandable. Following these measures from year to year is also important in helping to estimate and demonstrate the benefits of various investments that are made for both capital and operations improvements. The OAI Accessibility measure would also be useful in describing the overall impact of an agency's transportation program.

Scenario 8: Prioritizing Agency Capital Programs

Description. The state DOT and MPOs use various subsets of the measures described above to help prioritize capital projects. Two deficiencies identified in the process are: 1) use of inconsistent measures depending on the project; agencies would like to standardize measures to the extent possible; and 2) measures used for capital planning do not do a good job of incorporating reliability.

Assumptions. Major urban freeways are monitored through an ITS system using detection and CCTV. There are several relatively sophisticated arterial management systems that provide data adequate to estimate travel times. For areas outside those covered by ITS, however, the DOT plans to rely on a recently executed probe data contract that will cover all freeways and major arterials around the state. Most of the larger transit systems are equipped with passenger counters and AVL data that can be used to estimate travel times and passenger volumes. In order to standardize measures, agencies also require a method of extrapolating from facilities where good data sources exist to those where it does not.

Recommended Measures. Vehicle delay and person delay appear to the best measures to incorporate into capital planning efforts. VMT and PMT are also helpful companion measures in determining whether additional demand is being effectively accommodated. The OAI Accessibility measure would also be useful in describing the overall impact of an agency's capital investment program, particularly where economic development and access to jobs are important goals.

Scenario 9: Measuring Performance of Adding Roadway Capacity

Description. The state DOT and the MPO have programmed adding lanes to an arterial road in the urban area. The agencies need to measure the performance of the project to determine the effectiveness of the money spent on the project. Additionally, the agencies plan to use the results to evaluate future roadway capacity projects at other locations in the region.

Assumptions. The arterial roadway that will be widened by the capacity project did not have instrumentation in place to measure speed or travel time prior to project implementation. In order to assess performance, a "before/after" study will be conducted. The state DOT funded several portable Bluetooth readers and Video Image Detection (VID) cameras to collect travel time and volume data before the construction phase was initiated and during construction. The project plans included permanent installation of VIDs throughout the corridor to collect speed, travel time, and volume after the project is complete.

Recommended Measures. Facility-based measures calculated along the corridor would provide the most useful measures of effectiveness. The measures would include travel time, vehicle delay, space mean speed and the buffer index or planning time index as a measures of reliability. Additionally, volumes are a useful measure to assess latent demand caused by the improvement. More traditional traffic engineering metrics, including level of service and density will also be helpful in evaluating the impacts of the capacity increase.

5.4 Methodology for Testing Scenarios

Two potential methodologies for incorporating reliability into the planning and operational scenarios discussed above are documented here. The first methodology combines regional travel demand model data with operational data. This method would be used for larger regional and corridor projects that require a long forecast horizon. The second methodology involves use of operational data combined with either growth factors, or microscopic/mesoscopic models with the choice depending on the specific alternative being evaluated.

Method 1 – Travel Demand Model and Operational Data

This method could be applied to scenarios that involve capital investment in infrastructure or operational alternatives that are regional in scope. The steps involved would include:

1. A regional or subregional travel demand model would be used to estimate existing travel conditions. Base traffic and transit conditions are estimated using the model.
2. Operational data are reviewed and compiled for the corridor(s) or subarea under study. This would include detector data probe data, incident data, and transit/maintenance vehicle AVL data. Transit AVL data can be used to estimate delay for transit passengers and as supporting data in estimating overall vehicle/person delay. Traffic count data may be used to supplement this information as well. Logical segments are identified and matched with those in the model.
3. Incident data and speed data are used to calculate the nonrecurring delay on the segments being analyzed. Nonrecurring delay is also estimated. Since only nonrecurring delay is estimated through the model, the estimates made through the operational data and those made through the model are compared and reconciled.
4. A relationship between recurring and nonrecurring delay is established to help forecast the impact of the proposed improvement on nonrecurring delay. Research studies offer some data with which to estimate these relationships.
5. The new alternative(s) is coded into the travel demand model and run. The change in recurring delay is calculated based on the difference between the base run and the alternative. The relationships established in Task 4 can be used to estimate nonrecurring delay for the alternative scenarios. This can be used for either base year changes or future forecasts.

6. The nonrecurring delay estimates can be used with other model output data to estimate various performance measures such as travel time index or buffer index. The complexity of the calculations will vary depending on the size of the area and the number of facilities involved.

Method 2 – Simulation Models and Operational Data

This method could be applied to scenarios that involve operational improvements that are limited in scope. The steps involved would include:

1. Base traffic and/or transit conditions are estimated using a microscopic or mesoscopic model. Recurring delay is calculated using the model.
2. Operational data are reviewed and compiled for the corridor(s) under study. This would include detector data probe data, incident data and transit/maintenance vehicle AVL data. Transit AVL data can be used to estimate delay for transit passengers and as supporting data in estimating overall vehicle/person delay. Traffic count data and turn movement data may be used to supplement this information as well. Logical segments are identified and matched with those in the model.
3. Incident data and speed data are used to develop several scenarios of nonrecurring delay and test them in the model. The model results are then compared with the actual operational data to determine and compared. The results are then reconciled.
4. Based on the test scenarios a relationship is established to use in estimating nonrecurring delay. For example, a tabular format may use the following information.

Table 5.4 Tabular Format Example

Roadway Characteristics	Number of Lanes Closed	Length of Closure	Time of Day	Recurring Delay (from Model)	Nonrecurring Delay (Calculated from the Other Variables)
Urban Arterial – Two lanes per direction					
Urban Arterial – One lane per direction					
Suburban Arterial – Three lanes per direction					

The rows in this table are only examples; other categories that can be supported by the data could also be included.

1. The relationship established in Task 4 can be used to estimate nonrecurring delay for the proposed alternatives. This can be used for base year alternatives or future forecasts.

2. Impacts of ITS improvements can be developed using factors from FHWA ITS Benefits/Cost Database or IDAS model. If there are local studies, these can be used as well. The estimated nonrecurring delay can then be reduced depending on the options run.

The nonrecurring delay estimates can be used with other model output data to estimate various performance measures such as travel time index or buffer index. The complexity of the calculations will vary depending on the size of the area and the number of facilities involved.

6.0 Application Guidelines

The application guidelines are presented in detail in Section 5.0. Below is a general discussion of how performance measures should be applied in practice.

Performance measures and performance data provide valuable information in assessing corridor alternatives. However, each performance measure provides information on only one or two dimensions of corridor performance. Thus, it is important to identify the "dimensions" of performance and the corresponding performance measures most important for the particular application. The paragraphs below describe how performance measures may be used in the regional transportation planning process and which measures are useful and which measures are not useful in the process, depending upon the specific application.

Performance measures should address the need of the specific application to which it is being applied. Applications may range from specific, short-term improvements such as retiming of signals or ramp meters, all the way up to regional or statewide performance measurement summaries. In between are capital investments in regional/subregional ITS systems or corridor projects that may impact multiple facilities across a wider geographic area. The smaller projects are primarily concerned with facility operation and performance while projects of larger scale are more likely to be concerned with the traveler's viewpoint, i.e., "how much time is saved from the average trip?" These can be defined as "facility-based measures," which measure the performance of a specific facility or network, without identifying individual travel patterns. "Trip-based measures" involve the impact on individual trips or groups of trips that are likely to involve multiple facilities. While some of the same measures are used in both, they answer different questions. For example, an improvement concentrated on a specific facility may result in a significant and measurable performance improvement on that facility. If most of the trips that occur on the facility are only on it for a short segment, however, the improvement to trip times may be limited. Additional discussion of these concepts is found later in this document.

The travel time-based measures, such as the Travel Time Index, Space Mean Speed, Buffer Index, Planning Time Index, and Percent On-Time are all based on speed data provided by roadway sensors or probes. This data is commonly available for the freeways in many large regions. Arterial speed data is not generally available in most regions, and this is being recognized as a data gap and state and local governments are initiating activities to obtain arterial corridor speed data.

The available field-collected data is facility-based data. Trip-based data is not available except for a few datasets collected for research purposes. Current methods of trip-based data collection involve tracking of people with GPS or cell phone GPS devices. Google and several cell phone companies are collecting anonymised data that currently is link-based but in the future could be trip-based. There are serious privacy concerns with tracking of individuals, which severely limits the use of existing technology. In the future, there may be methods developed that will provide a higher level of comfort to the public, allowing more extensive collection of trip-based measure.

An additional measure which does not fit in either of the above categories involves accessibility, a measure not largely used in most regions. It is a model-based measure that requires extensive data processing to calculate the measure. The measure addresses an important transportation and land use issue – the ability to move between home and work in a relatively short time. While urban residents care about this issue, the measure has not been easily communicated to general audiences except in the analysis of specific projects where accessibility is used to map the differences between alternatives. The remainder of this paper includes a set of potential scenarios in which performance data could be used for capital and/or operational planning, a description of performances and their applicability to specific scenarios and finally, two alternative methods for applying performance measures to the analysis/evaluation of planning and operational scenarios.

7.0 Investigation of Agencies That Have Advanced Mobility Performance Monitoring Programs

7.1 INTRODUCTION

Based on the earlier surveys of agencies, five were selected for follow-up based on the research team's assessment of their mobility performance monitoring programs. These agencies were selected because it was felt that they had the most advanced programs in terms of identification of measures, reporting, and use of the measures in agency activities. The agencies are:

- Maricopa Association of Governments (MAG);
- Puget Sound Regional Council (PSRC);
- Metropolitan Washington Council of Governments (MWCOG);
- Houston-Galveston Area Council (HGAC); and
- Florida DOT.

After investigation, MAG, PSRC, FDOT, and MWCOG proved to have advanced mobility performance monitoring programs. HGAC has not yet worked mobility performance measures into their activities. It should be pointed out that all regional planning agencies use mobility performance measures when conducting special analyses and in long-range transportation plan development. However, this project is interested in the monitoring of current performance on an ongoing basis. A summary is provided below.

- Accessibility is described both in terms of **access to opportunities**, especially employment, and **system access** (access to the transportation system, especially transit). The two concepts are quite distinct; but in both cases, they recognize that transportation is a service provided to consumers (travelers). Accessibility to opportunities has not yet moved into monitoring programs but is a criterion used in the modeling done in support of long-range transportation plans.
- MAG has developed the first cost-effectiveness measures that we have in practice: trips served per dollar invested and travel time savings per dollar invested. However, they have not yet moved this routine reporting of

performance but rather use it on a case-by-case basis, presumably as an evaluation measure on specific projects.

- Regional agencies are becoming interested in new sources of data, especially travel time data from private vendors. For the development of mobility measures, this greatly expands the roadway coverage (including signalized highways) compared to relying on freeway detector data.
- Mobility monitoring in Florida occurs at both the statewide level and at the local level:
  - Statewide: Travel time measurements on a statewide basis are not currently available, although the Department is looking into private vendor travel time data for this purpose. Currently, traffic count, traffic mix, geometric, and operating data are used to synthesize travel times.
  - Local: Both the MPOs and FDOT District operations personnel are involved in mobility monitoring. The District personnel use data from their roadway surveillance systems to measure travel times and produce metrics. By virtue of their CMPs, the MPOs are also involved in mobility monitoring, but the exact procedures vary for agency to agency.

The following questions were reviewed for each candidate planning area:

- **Question 1 –** Why use performance measures for mobility monitoring?
- **Question 2 –** How was the performance measures used?
- **Question 3 –** What are the experiences learned from using the performance measures: positive, negative, and what are the problems?
- **Question 4 –** What are the data and analytical challenges associated with using the performance measures?

7.2 Maricopa Association of Governments (MAG)

Question 1

The Maricopa Association of Governments (MAG) has developed a Performance Measurement Framework to illustrate the most important characteristics associated with the status of surface transportation in the region (Table 7.1). The **purpose** of this framework is to:

- Enhance planning and programming decision-making processes by enabling MAG to better monitor and evaluate progress toward the achievement of strategic goals;

Table 7.1 MAG Performance Measurement Framework

Focus Area/Mode	Limited Access Highways (GP)	HOV Lanes	Arterials	Transit	Freight	Bicycle/Pedestrian (Nonmotorized)
Travel Time, Delay, and Reliability	Mean and 80th-90th Percentile and Point-to-Point Travel Times	Mean and 80th-95th Percentile and Point-to-Point Travel Times	Mean and 80th-95th Percentile and Point-to-Point Travel Times	Point-to-Point Travel Times	Point-to-Point Travel Times	
	Congestion – Spatial and Temporal	Congestion – Spatial and Temporal	Congestion – Spatial and Temporal	Congestion – Spatial and Temporal		
	Travel Time Variability	Travel Time Variability	Travel Time Variability	On-Time Performance		
Incident Management	Incident Clearance Time		Incident Clearance Time			
Mobility – Throughput (People/Freight)	Volume (Person and/or Vehicle)	Volume (Person and/or Vehicle)	Volume (Person and/or Vehicle)	Ridership – by Mode	Freight Volume	*Bicycle/Pedestrian LOS*[a]
	On-Ramp Queue Size		Intersection LOS – based on V/C	Peak Hour Load Factor (Average Load Factor on Express bus/freeway BRT)	*Commodity flows from, to, within, and through the region, by mode*	*Per capita miles traveled*
	Lost Productivity		Signal Cycle Failures/ Intersection Queue Size			
	Per Capita VMT		Per Capita VMT	Boardings per Revenue Mile		
Safety and Security	Crash/Injury/Fatality Rate		Intersection Crash Ranking	Crash Rate	Crash/Injury/Fatality rates for large truck involved crashes on the freeway system	Crash Totals for the Region
			Crash/Injury/Fatality Rate	Transit Crime Rate (Safety Incidents per 100K vehicle miles)	Crash/Injury/Fatality rates for large truck involved crashes on the arterial system	*Number of Schools participating in Safe Routes to Schools program*
System Accessibility and Modal Options				Percent of Park-and-Ride Capacity Used	*Percent of freight terminals/intermodal facilities (air, rail, and truck cargo) located within 5 miles of a freeway*	*Sidewalk and/or Bicycle Network Completeness*
				Vehicle Revenue Miles of Service		*Availability of Safe Street Crossing Facilities for Access to Transit Stops*
				Percent of population residing within ¼ mile of local bus and ½ mile of LRT/Express Bus		*Bicycle Storage Facilities*
				Transit share of travel (by Mode)		Bicycle/Pedestrian share of travel
System Preservation	*Bridge/Pavement Condition Rating*	*Bridge/Pavement Condition Rating*	*Bridge/Pavement Condition Rating*			
Environmental Preservation	*Air Quality Index*	*Air Quality Index*	*Air Quality Index*	*Air Quality Index*	*Air Quality Index*	*Vehicle Emissions Reduced by Pedestrians and Bicycle Users*
Quality of Life	*Customer Satisfaction*	*Customer Satisfaction*	*Customer Satisfaction*	*Customer Satisfaction*	*Customer Satisfaction*	*Customer Satisfaction*
	Participation in MAG Region Trip Reduction Program		Participation in MAG Region Trip Reduction Program	Participation in MAG Region Trip Reduction Program		Participation in MAG Region Trip Reduction Program
Cost-Effectiveness	*Trips served/Time Savings per dollar invested*	*Trips served/Time Savings per dollar invested*	*Trips served/Time Savings per dollar invested*	*Trips served/Time Savings per dollar invested*	*Trips served/Time Savings per dollar invested*	

Yellow = Data is available.
Orange = Some data is available, but additional refinement and/or data collection is needed prior to use.
Red = Limited or no data available, or significant additional refinement/analysis is needed prior to use.

It is recommended that those performance measures which are *italicized and underlined* be reported only infrequently for the purpose of assessing behavioral and systemic changes occurring over.

[a] Level of Service (LOS) measures are best used in assessing the need for planning-related improvements and are, therefore, best suited for use as part of an agency's Congestion Management Program.

- Provide the tools necessary to better understand regional trends in transportation system performance; and
- Provide a factual basis to better inform policy-makers based on objectives-based, performance-driven planning.

Question 2

Performance Measures are used in the planning and programming processes of MAG. The two examples are: 1) the development of the MAG Regional Transportation Plan (RTP) which included a performance-based planning and programming process; and 2) the Congestion Management Process.

The RTP process established goals, objectives, and performance measures for developing various options and evaluating potential scenarios to be included in the Plan. A number of the goals and objectives adopted relate to the performance of the system as a whole as well as the individual components of the systems across all modes. MAG has established an ongoing Transportation System Performance Monitoring and Assessment Program. The program is applied to all modes of transportation in the area, including: limited access highway and HOV lane performance, arterial performance, transit system performance, bicycle and pedestrian performance and quality of life performance. The table below listed the performance measures used for each mode of transportation.

These criteria were applied in the development of the **RTP** to evaluate alternatives and establish implementation priorities. They can also be applied in the future to evaluate potential adjustments to the priority of corridors, corridor segments, and other transportation projects and services.

- **Facility/Service Performance Measures –** Facility performance measures focus on the amount of travel on specific facilities, the usage of transportation services, the degree of congestion, and other indicators of the level of service as provided:
  - Accident rate per million miles of passenger travel;
  - Travel time between selected origins and destinations;
  - Peak-period delay by facility type and geographic location;
  - Peak-hour speed by facility type and geographic location;
  - Number of major intersections at level of service "E" or worse;
  - Miles of freeways with level of service "E" or worse during peak period;
  - Average Daily Traffic on freeways/highways and arterials;
  - Total transit ridership by route and transit mode; and
  - Cost-effectiveness: trips served per dollar invested.

- **Mobility Measures –** Mobility measures focus on the availability of transportation facilities and services, as well as the range of service options as provided:
  - Percentage of persons within 30 minutes travel time of employment by mode;
  - Jobs and housing within one-quarter-mile distance of transit service;
  - Percentage of workforce that can reach their workplace by transit within one hour with no more than one transfer;
  - Per Capita Vehicle Miles of Travel (VMT) by facility type and mode;
  - Households within one-quarter mile of transit;
  - Transit share of travel (by transit submode); and
  - Households within five miles of park-and-ride lots or major transit centers.

The MAG Performance Report is based on observed data sets and constitutes a fundamental tool in the **Congestion Management Process** evaluation process. Not only does it establish benchmarks for evaluating current year performance and congestion levels but, in time, will allow for historic archiving facilitating trend analysis.

Question 3

No information found.

Question 4

The MAG developed a performance measurement **web-based tool** which provides access to all performance measures developed by MAG in 2008 and 2009. Measures are based on multimodal observed data on a system and corridor scale. This tool will serve as the current and future repository of MAG's Performance Measurement Program. New measures and performance analysis will be posted on the site as new data becomes available. This tool is linked internally to the MAG Transportation Data Management System.

The optimum combination of accuracy and detail for performance measurement is based on real time, observed data sources. This data provides the information to assess the principal operating characteristics of the current transportation system and to establish a historical record that tracks performance trends over time. The specific parameters observed vary by the transportation mode and must take into consideration the **practicality and expense** of collecting data on a continuing basis. The latter factor is particularly important if a historical record is to be established that allows effective analysis of performance trends. A large amount of data is collected annually in the MAG region related to the movement of people, goods, and services. Data from the Arizona Department of Transportation's (ADOT) Freeway Management System (**FMS**) is collected continuously from sensors and other systems that detect and record the movement of vehicles across a large portion of the MAG region. As the FMS system continues to grow, it will allow the use of these data for future **reliability** performance calculations. In addition, traffic data is collected on **arterial** roadways through both permanent and temporary counting stations deployed by a variety of MAG member agencies.

For roadway systems, typical data collected to assess current performance includes: vehicle counts at a sample of locations; vehicle densities along various roadway segments; speeds and point-to-point travel times; intersection queue lengths and delays; and number and types of accidents.

In the near future, MAG is anticipated to contract with **private data collection sources** to supplement the arterial and freeway observed data. This will allow the current data archive to be more geographically comprehensive and enable MAG to perform analysis on system and corridor performance from **real-time** data sources.

References

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7.3 PUGET SOUND REGIONAL COUNCIL (PSRC)

Question 1

In PSRC's *Transportation 2040* plan, it is stated that:

> Performance monitoring completes the link between plan policies and an investment strategy designed to implement those policies. Through evaluation of transportation metrics over time, the region can be sure that **investments are achieving desired outcomes**. In order to perform this function properly, the region will need to fully develop transportation performance measures that address the region's goals.
>
> Performance measures provide policy-makers and the public a framework for evaluating progress toward implementing adopted regional policies. These measures were established by describing desired policy outcomes and identifying measurable indicators for each outcome. If desired, the region could also set future targets for these indicators. Measures need to be both complex and flexible enough to reflect changing and uncertain conditions in the real world, but simple and reliable enough to allow both comparison and **sustained data collection** into the future.

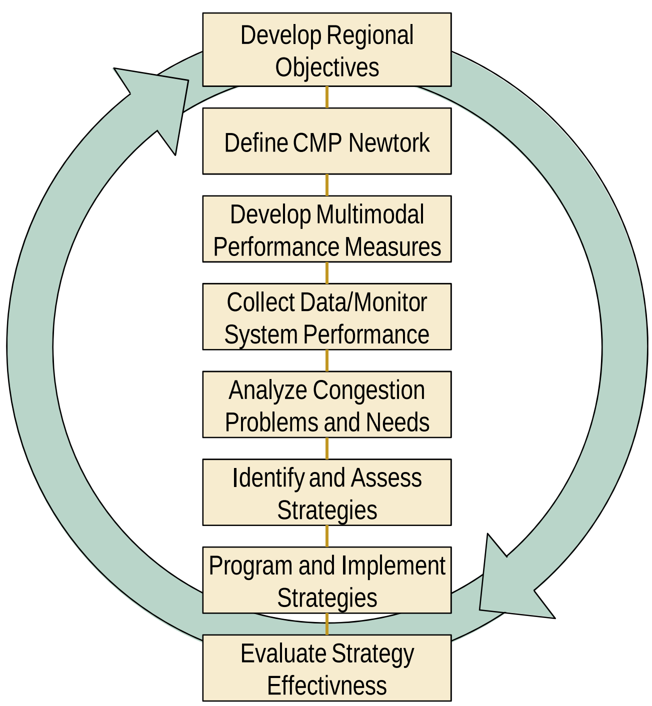
Question 2:

PSRC addresses performance monitoring in the following areas:

1. **Congestion relief and mobility** for all transportation modes;
2. **Accessibility** to transportation choices;
3. Greenhouse gas and other emissions;
4. Water quality;
5. Land use and regional development patterns (as laid out in VISION 2040);
6. The extent and application of tolling and user fees;
7. Public and private expenditures for transportation and regional transportation funding capacity; and
8. Transportation project completion and program implementation status.

For congestion and mobility monitoring, the performance measures used are: **travel mode splits, travel times, delay, traffic volumes, transit boarding, and total and per capita vehicle-miles traveled**. The process of congestion management is shown in the Figure 7.1.

Figure 7.1 Elements of the Congestion Management Process



Source: FHWA. Data Congestion Management Process: A Guidebook. July 22, 2010.

As part of the monitoring and congestion management process, the SMART (**S**afe and **S**ustainable, **M**ultimodal, **A**ccessible, **R**eliable, **R**esilient, **T**echnology) corridor report sought to report on these measures and apply other lessons learned during the *Transportation 2040* plan update process. Transportation system performance measures detailed in SMART Corridor reports include (but are not limited to) **travel times, levels of service, transit congestion, ferry statistics, and park-and-ride utilization**. For the roadways, PSRC adopted the WsDOT's method to identify chokepoints and bottlenecks. HPMS data was used to locate the roadways that were estimated to be operating at **under 70 percent of the posted speed limit** during peak periods.

Question 3

Positive. By establishing how the region has changed its transportation system over time it can, in conjunction with performance metrics assessed over the same time period, help to answer the question of which actions are best achieving the region's goals. It also assists in monitoring the progress of the plan's financial strategy by establishing what investments have been realized and at what cost.

Negative. Data to support this monitoring commitment is not consistently available. Given the current reality of limited resources for enhanced data collection, PSRC will continue to work closely with regional planning partners to align the mutual existing resources in a way that will enable the realization of this monitoring commitment. To this end, it will be necessary for the region to develop additional resources and mechanisms for interagency cooperation. This work is underway within the region's Congestion Management Process. PSRC anticipates building upon this effort, VISION 2040 implementation actions, and other monitoring efforts to realize these goals.

Question 4

Data challenge. In order to monitor transportation system performance, PSRC relies heavily on the data collection efforts of their partner agencies and project implementers. Many of their stakeholders produce comprehensive annual reports and collect significant amounts of information related to the condition and performance of their assets and services. Complicating efforts to collect standardized data is the multitude of software and methodologies used to track these issues in various areas of the region. Further, some agencies undertake monitoring efforts that others do not, and some have implemented more reliable and efficient means of collecting data which leads to a more robust data set. These efforts produce widely different data products (at times not compatible) and make comparison between agencies difficult. PSRC is committed to an effective regional transportation monitoring system and will work with stakeholders to enhance and expand data collection efforts that will facilitate meaningful and efficient analysis.

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http://psrc.org/transportation/t2040/t2040-pubs/final-draft-transportation-2040.

http://psrc.org/assets/3544/1Final_CMP.pdf.

7.4 METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS (COG)

Question 1

The COG believes that "a performance measure, or indicator, is a means to gauge and understand the usage of a transportation facility, or the characteristics of particular travelers and their trips."

Also, as required by the Federal regulations that the Congestion Management Process (CMP) should include:

> *Definition of congestion management objectives and* ***performance measures*** *to assess the extent of congestion and support the evaluation of the effectiveness of congestion reduction and mobility enhancement strategies for the movement of people and goods.*

Question 2

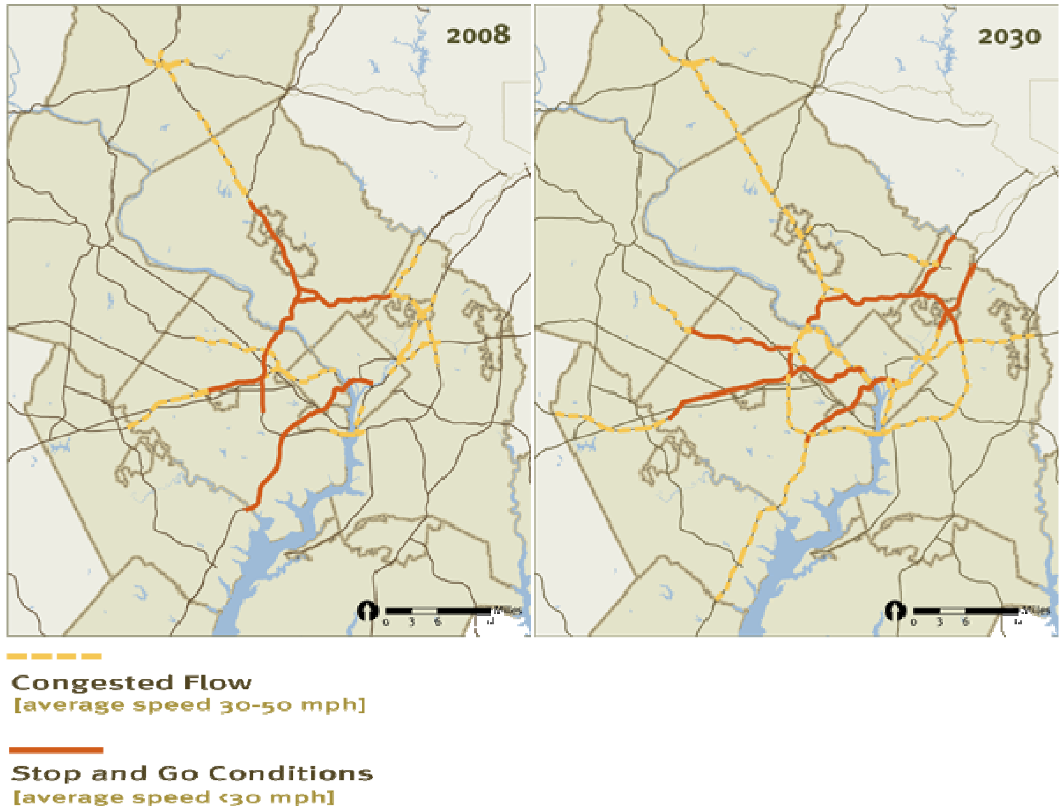
The COG assesses the performance of its **Constrained Long-Range Plan (CLRP)** in the following areas:

- Metropolitan Growth;
- Travel Demand;
- Congestion;
- Air Quality: Mobile Source Emissions;
- Job Accessibility;
- Activity Clusters; and
- Environmental Justice.

In the travel demand, transit work trips, vehicle work trips, **VMT, VMT per capita**, lane-miles, lane miles of congestion (a.m. rush hour) are the performance measures used among others.

In the Congestion performance, **average speed** was used to estimate the performance. Two levels of speed were used to describe congestion (as shown in Figure 7.2): 1) congested flow, average speed between 30-50 mph; and 2) stop-and-go conditions, average speed less than 30 mph.

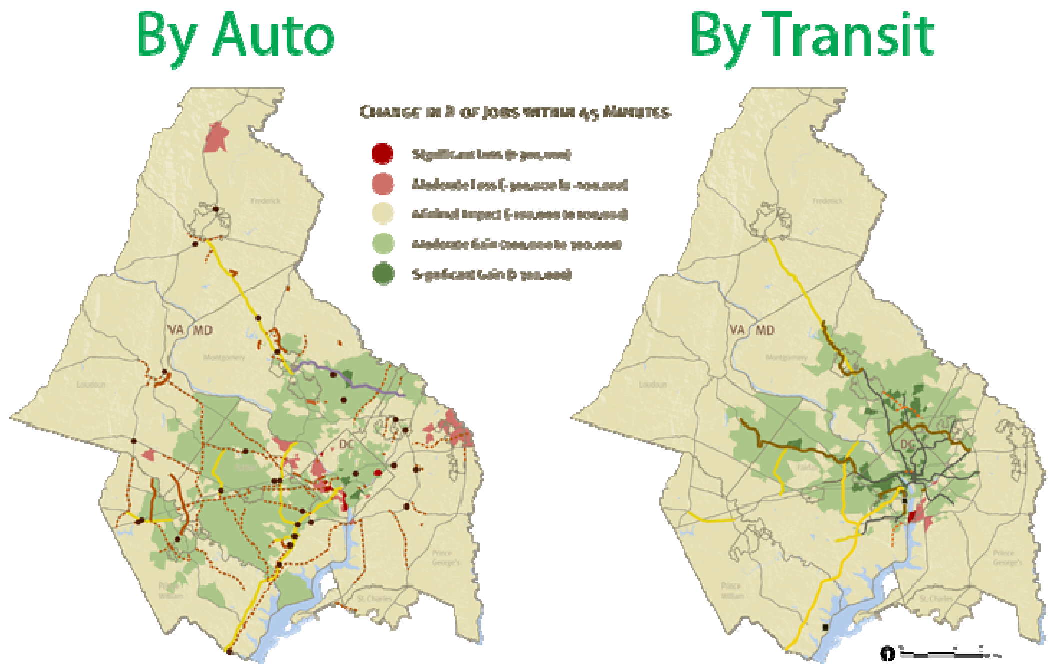
Figure 7.2 Two Levels of Speed Used to Describe Congestion



In the Job Accessibility, the way used to measure the performance of the plan is by **accessibility to jobs** by auto, transit, and walk-access transit. Figure 7.3 shows the change from 2010 to 2030, either positive or negative, in the number of jobs within **45 minutes** of the households in that area.

With the 2009 plan, the average number of jobs accessible to a given household by automobile is expected to rise slightly between 2010 and 2030. Average accessibility by transit is also forecast to increase, but more significantly than by auto. However, overall accessibility by transit will still remain less than by auto.

Figure 7.3 Change in Number of Jobs within 45 Minutes of Household
2010-2030



The Congestion Management Process (**CMP**) Technical Report serves as a background document to the official **CLRP**, providing detailed information on data, strategies, and regional programs involved in congestion management. The **CMP** has four components as described in the CLRP:

1. Monitor and evaluate transportation system performance;
2. Define and analyze strategies;
3. Implement strategies and assess; and
4. Compile project-specific congestion management information.

The selected CMP performance measures as originally identified in *The 1994 CMS Work Plan* are listed below:

- Data for direct assessment of current (or future background) conditions:
  - Traffic volumes;
  - Facility capacity;
  - Speed;
  - Vehicle density;
  - Vehicle classification;
  - Vehicle occupancy; and
  - Transit ridership.

- Calculated performance measures/indicators for congestion assessment:
  - Volume-to-capacity (V/C) ratio;
  - Level of service;
  - Person miles of travel/vehicle miles of travel;
  - Truck hours of travel;
  - Person hours of delay/vehicle hours of delay;
  - Modal shares;
  - Safety considerations;
  - Vehicle trips; and
  - Emissions reduction benefits.

Since the development of the above CMP performance measures in 1994, there has been an evolution towards more **traveler-oriented** metrics in conveying congestion and related information to the general public. Some of the measures are leveraged by emerging highway performance monitoring activities such as the **I-95 Corridor Coalition's Vehicle Probe Project** that provides probe-based continuous monitoring. Earlier in this report, the following four measures were used, with the first two quantifying congestion and the latter two travel time reliability. The newly developed Strategic Plan for the Management, Operations and Intelligent Transportation Systems (MOITS) Program adopted **travel time index, buffer time index, and planning time index** as three **regional indices** of travel conditions and traveler's experience.

- Travel time index;
- Mile-hour of congestion;
- Planning time index; and
- Buffer time index.

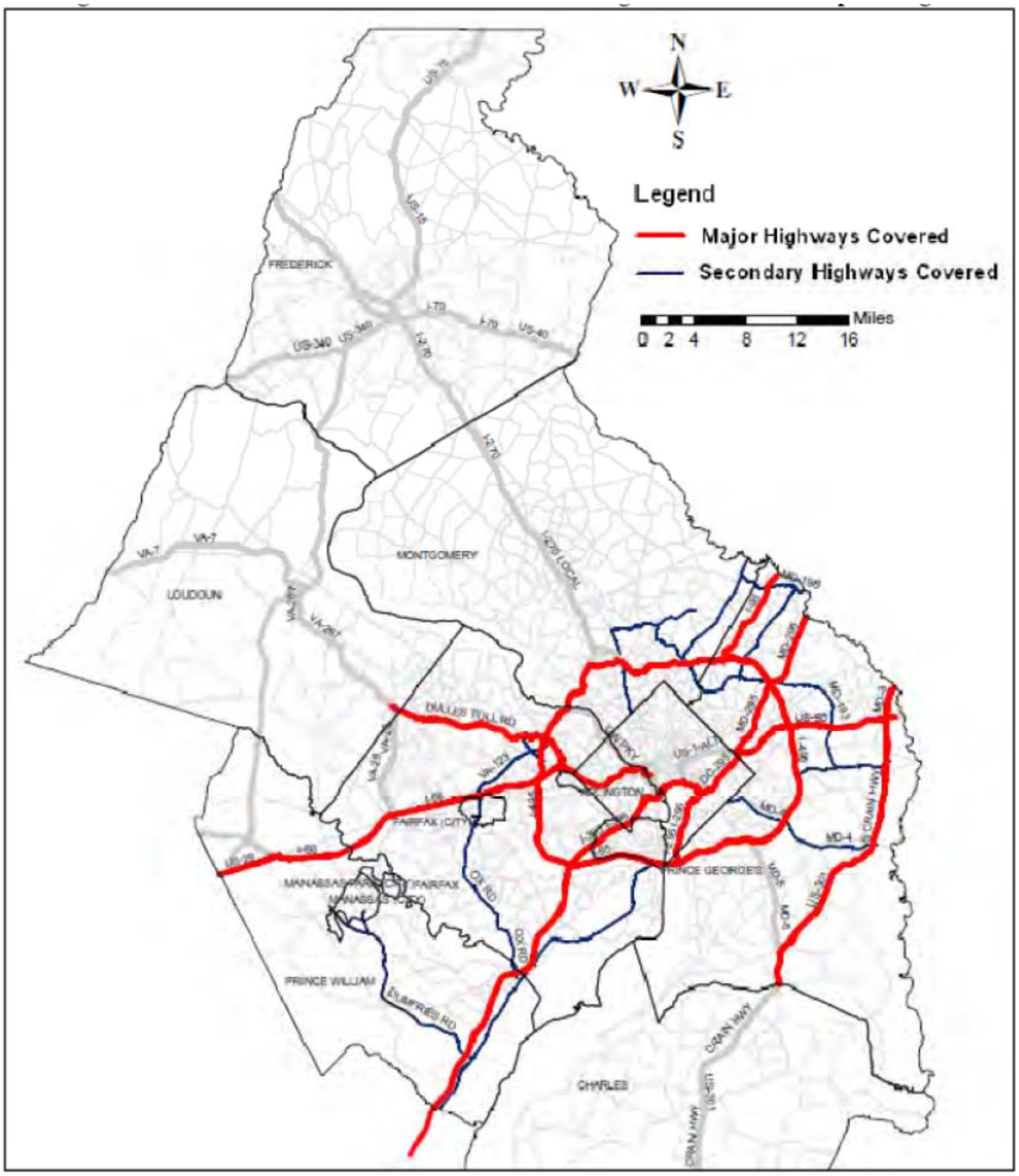
Question 4

The COG Region's freeway monitoring program is mainly based upon a comprehensive **aerial photography survey** of the region's freeway system conducted by **Skycomp, Inc.** A.m. and p.m. peak periods congestion is monitored once every **three** years since 1993 and the most recent survey was conducted in spring 2008.

In addition to the aerial photography program, since July 1, 2008, a number of the region's freeways (198 centerline miles, as shown in Figure 7.4) have also been covered by and **probe-based** continuous monitoring data made available through the **I-95 Corridor Coalition's Vehicle Probe Project**. The two most significant advantages of this new innovative data source are that it provides continuous (24/7/365) monitoring, and that it reports segment-based **speeds and**

travel times, which are more **accurate** than estimates from speeds measured by **location-fixed sensors**.

Figure 7.4 I-95 Corridor Coalition/INRIX Data Coverage in the National Capital Region



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http://www.mwcog.org/clrp/.

http://www.mwcog.org/clrp/elements/cmp/files/CMP_Tech_Report_2010%20FINAL_09032010.pdf.

7.5 HOUSTON-GALVESTON AREA COUNCIL

How performance measures are used in transportation planning process and mobility analysis was not written extensively in HGAC's documents. Here are few applications found from the planning documents.

In the 2035 Regional Transportation Plan (RTP) update, vehicle-miles traveled (VMT), the number of vehicle-hours traveled (VHT), and average driving speeds the delay and delay cost was used to summarize the systemwide benefits of the plan.

Another example of the use of performance measures is that **Travel Time Savings** is used as one of the evaluation criteria in the Galveston-Houston Mobility Corridor Alternatives Analysis**.** This is measured by the average travel time per passenger for each alternative. Travel times, for specific trips from origin to destination, are compared for each alternative.

By reviewing the planning documents, it seems that the performance measures have not been used extensively in the HGAC's planning process.

References

http://www.h-gac.com/taq/plan/default.aspx.

http://www.galvestonrailstudy.com/index.html.

7.6 FLORIDA DOT

The interview included the original four review questions plus several supplemental questions:

- **Question 1 –** Why use performance measures for mobility monitoring?
- **Question 2 –** How were the performance measures used?
- **Question 3 –** What are the experiences learned from using the performance measures: positive, negative, and what are the problems?
- **Question 4 –** What are the data and analytical challenges associated with using the performance measures?
- **Question 5 –** Has the agency done any target setting, and if so, how?
- **Question 6 –** Does the agency routinely evaluate completed projects for mobility impacts? If so, does the agency have a standard set of procedures?
- **Question 7 –** How is mobility performance integrated into the Congestion Management Process? If so, how is this influencing investment decisions?
- **Question 8 –** Can the agency estimate the cost of establishing and running their mobility performance programs (i.e., actual dollar cost or staff hours)?

Question 1: Why use performance measures for mobility monitoring?

The State of Florida has developed a set of Mobility Performance Measures to answer the following questions:

- How do we improve transportation to serve people and commerce I Florida?
- What are we getting back from our investment in transportation?
- Are we investing in transportation as efficiently as possible?

Question 2: How were the performance measures used?

FDOT reports performance along the following dimensions:

- Quantity;
- Quality;
- Accessibility; and
- Capacity utilization.

The following is a description of FDOT's performance measures:

- **Quantity measures**
  - *Vehicle-miles traveled* – Total vehicle miles of travel on the state highway system or various subcomponents of it.
  - *Person-miles traveled* – Total person miles of travel on the state highway system or various subcomponents of it.
  - *Truck-miles traveled* – Total vehicle miles of travel by heavy vehicles on the state highway system or various subcomponents of it.
  - *Transit ridership* – Total number of persons traveling on scheduled fixed route public transit bus or rail services.
- **Quality measures**
  - *Average travel speed* – Average daily speed of vehicles on the state highway system or various subcomponents of it.
  - *Vehicle delay* – Number of vehicle hours of travel at speeds less than FDOT's speed threshold for the state highway system or various subcomponents of it.
  - *Person delay* – Number of person hours of travel at speeds less than FDOT's speed threshold for the state highway system or various subcomponents of it.
  - *Level of service* – Highway Capacity Manual level of service for the state highway system or various subcomponents of it.

  - *Travel time reliability* – Percent of on-time vehicle arrivals during the peak travel hours for the State's freeway system or various subcomponents of it.

- **Accessibility measures**

  - *Proximity to major transportation hubs* – Currently under development. Conceptually: percent of State's population within a selected distance of major airports, seaports, and rail hubs.

  - *Percent urban miles with sidewalks* – Percent of urban nonfreeway miles in the state highway system in areas of 5,000 or more population with sidewalks.

  - *Percent urban miles with paved shoulders/bicycle lanes* – Percent of urban nonfreeway miles in the state highway system in areas of 5,000 or more population with at least four feet of paved and delineated shoulder width for bicycle travel.

- **Capacity utilization measures**

  - *Vehicles per lane-mile* – Average density of vehicles during the peak hour of travel on the state highway system or various subcomponents.

  - *Percent of miles heavily congested* – Percent of centerline mile on the state highway system or subcomponents of it that operate at LOS D, E, or F during the peak travel hour.

  - *Percent of travel heavily congested* – Percent of VMT traveled for each segment of the state highway system or subcomponents of it that operate at LOS E or F.

  - *Duration of congestion* – Average number of hours per day that roads on the state highway system or subcomponents of it operate at LOS E or F, weighted by lane-miles.

Each mobility measure is calculated and reported annually at the following levels:

- State.

- Specific area types:

  - All counties with one million or more population;

  - All other urbanized areas with at least 50,000 population; and

  - All rural areas.

The primary use of mobility performance measures by FDOT senior management has been for reporting mobility trends of the highway system and to illustrate additional resource needs. Hence, performance measures can help to provide a rationale for allocating public funding for transportation.

What is important is that the performance measures cover the important issues without being too overwhelming: too few performance measures will give an incomplete picture of how the transportation system is performing, while too many performance measures can dilute the picture.

Question 3: What are the experiences learned from using the performance measures: positive, negative, and what are the problems?

FDOT's experience has been positive. From the viewpoint of technical staff, some type of monitoring is needed to keep track of how the transportation as a whole is performing. There is, however, a potential for some dissatisfaction within some operational units if it is perceived that the performance measures do not adequately address their concerns.

Question 4: What are the data and analytical challenges associated with using the performance measures?

Most performance measures are calculated from existing data. For example:

- FDOT has about 300 permanent counters throughout the State.
- Coverage counters are used at about 5,000 to 6,000 locations. These collect data for 24 to 48 hours and are deployed one to four times per year. They provide volume estimates for each highway segment.
- Results from the 1995 National Transportation Survey are used to estimate average vehicle occupancies.
- Average travel speeds are calculated using speed-volume relationships from the Highway Capacity Manual and FDOT's Quality/Level of Service (Q.LOS) Handbook and from geometric characteristics of highway segments.
- FDOT's Roadway Characteristic Survey is used to develop information on geometric characteristic of road segments.

There have been some technical issues that needed to be resolved. For example, the HCM method for estimating delay is based on a reference free-flow travel time; but free-flow time is seldom, if ever, experienced on signalized arterials. And at high traffic volumes, predicted speeds can drop to near zero. FDOT got around this problem by using an approximate 20 mph speed threshold for calculating delay and using an approximate 5 mph floor for predicted speeds.

Travel time reliability is a fairly recent performance measure that could not be readily forecasted using existing methods. FDOT and the University of Florida developed a travel time reliability model for the State's freeway system to address this issue.

Question 5: Has the agency done any target setting, and if so, how?

Yes. Target setting is done by the policy unit in FDOT.

Question 6: Does the agency routinely evaluate completed projects for mobility impacts? If so, does the agency have a standard set of procedures?

Evaluation is typically not done for most projects. But for high-visibility projects such as the I-95 express lanes, monitoring and evaluation are key project components.

Question 7: How is mobility performance integrated into the Congestion Management Process? If so, how is this influencing investment decisions?

Congestion management is more within the domain of MPOs rather than the State. The FDOT office for performance measures coordinates with MPOs in instances where the State can help out. But most congestion management assessments are based primarily on straightforward LOS analyses and standards.

Question 8: Can the agency estimate the cost of establishing and running their mobility performance programs (i.e., actual dollar cost or staff hours)?

It may be possible to do so, but staff who work on performance measures also work on reporting for HPMS. Hence, it is difficult to separate out costs.

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8.0 The Next Level of Performance Measurement – What Does the Future Look Like?

8.1 Introduction

This section offers some ideas that agencies should consider in adapting to the rapidly changing landscape for mobility performance measurement. It also identifies several issues that will have to be resolved as mobility performance measurement becomes more sophisticated. Specifically, this section inquires: what are the key elements of future practice and what should be investigated to adapt current mobility performance measurement activities to the future?

8.2 Developing and Reporting Accessibility Measures

Background

The current state of the practice for mobility performance measurement is almost entirely focused on reporting facility performance, largely because of data availability. However, given current trends in technology and in the private sector provision of data, we fully expect data to become available shortly that will allow direct measurement of trip performance, and by extension, of accessibility. (In the interim, models can be used to synthesize trip-based performance.)

Accessibility is defined as the ease of reaching valuable destinations. Highways, railways, and other transportation infrastructure provide accessibility that affect location decisions (Hansen 1959, Patton and Clark 1970, Levinson 2008). Accessibility weights opportunities (e.g., the quantity of an activity as measured by employment) by impedance (e.g., a function of travel time or cost).

Accessibility applies within cities and between cities. The matrix depicted in Table 8.1 suggests one way of organizing accessibility measures. Most focus in the planning community has been on access for passengers to various daily activities. But access from a city to other cities is important in explaining the growth of areas as a whole; furthermore, industry depends on easy access to goods both within the metropolitan area (to distribute to customers and suppliers) and to other cities.

Table 8.1 Potential Framework for Organizing Accessibility Measures

	Intrametropolitan						Intermetropolitan
Passenger		Car	Bus	Bike	...	Walk	
	Jobs						
	Stores						
	...						
	Workers						
Freight							

Accessibility is comprised of two components: 1) the presence of opportunities; and 2) the ease with which those opportunities can be obtained or "reached." Thus, measuring accessibility goes beyond simply the performance of the transportation system – it also measures how users interact with the landscape of opportunities. Accessibility can be improved by improving the movement between opportunities or by moving opportunities closer to users. Because transportation is a derived demand – people engage in it not for its own sake but because it allows access to opportunities – accessibility is a key indicator of the quality of life for a transportation agency's customers. It is not a replacement for measuring the performance of the transportation system, but an adjunct to it.

Data for Accessibility Measurement

Accessibility measures can be computed assuming first there is land use data at the level of interest (e.g., jobs, residents, workers, stores, etc., by zone), and second that there are point-to-point travel times.

Most planning agencies will have estimates of the first from a variety of sources, including Census, Longitudinal Employment Household Dynamics data (LEHD), parcel files, and other data sets.

Point-to-point travel times are readily estimated from regional travel demand models, and are produced as a standard output at the resolution of the model (e.g., hourly, or at least peak hour and off-peak). Many other capacity/delay models that use regional travel demand model outputs can further refine these point-to-point estimates. Better than modeling (at least for the current period), these data can also be measured in cities that have robust traffic data collection efforts. This is especially true on freeways, where DOTs often collect traffic data for freeway traffic operation efforts (e.g., ramp metering). Arterial traffic data is archived in some cities (and should be archived in all), and can be used to estimate travel times on signalized facilities.

Newer technologies are making what was once difficult to measure now much simpler. Data from GPS systems by vendors such as TomTom, Inrix, and Navteq provide good coverage of travel speeds on the road network, and are being archived historically at a detail sufficient for future accessibility measurements. These measures can further be differentiated by time of day, so that morning, midday, afternoon, and free-flow accessibility measures can be obtained. With the datasets from GPS vendors, mean and standard deviation of travel times on a link basis should also be able to be estimated, so that in addition to an average (mean) accessibility, the reliability of accessibility can be measured. These data sets are not free, but they are often purchased by state DOTs and metropolitan planning organizations for other purposes, and can be used for accessibility calculations.

Cell phone tower triangulation has been tried, but is generally not as accurate as GPS data, which is becoming ubiquitous. Other technologies, such as Bluetooth signal capture and data fusion, and toll road transponder tracking have been suggested, but are likely to be more expensive than the now widespread GPS databases.

The explosion of data from the private sector that has occurred in the past few years and shows no signs of abating has raised concerns about the availability of bandwidth. It appears that the bandwidth issues/concerns that have traditionally been troubling for transportation applications is quickly something that technology is addressing. Given the recent explosion in wireless capabilities (WiMax, 3G/4G, LTE technologies) and the significant adoption (or movement to) wired/FO Ethernet in 10Mb/s, 100 Mb/s and 1 Gb/s flavors, it appears that the basic bandwidth needs of transportation/traffic should be adequately handled with current and near future technologies. The technology capability is for the most part outpacing industry bandwidth needs at this point. The main issue – at least in the short term – is the cost of these technologies: do agencies want to buy the technology at market cost?

Accessibility Measures

What is a good performance measure for accessibility?

Key to the particular pursuit of measuring and furthering accessibility is that the measures be clearly understood by both residents and decision-makers (Levinson and Krizek, 2008). Toward this end, we suggest that five criteria be satisfied. We label these the "Five Cs:"

1. **Cumulative –** Accessibility measures need to scale well. They need to apply to a particular address, a neighborhood, or an entire region.
2. **Comparable –** Accessibility measures need to inform multiple modes on the same continuum and on the same scale. In other words, it is ideal to have the associated varying networks, varying travel speeds, and varying impedance functions be as consistent as possible. Comparing an accessibility measure for walking that focuses particular attention on experiential elements (e.g., urban design amenities) with an accessibility measure for auto-based solely on travel time presents outstanding challenges.

3. **Clear –** For the measures to have appeal to various constituents, they need to be understood by them. They need to be transparent in terms of where the data came from, how they were calculated, and what they mean. Politicians and citizens have a hard time relating to phenomena such as log-sum measures or negative exponential distance decay curves.
4. **Comprehensive –** Accessibility measures need to be able to clearly capture just certain domains of interest – jobs or restaurants, for example – or be able to aggregate different types of land uses.
5. **Calculable –** It is best for measures to employ data that are readily available, available for an entire metropolitan area.

The above criteria ultimately rule out some academic measures that have appeared in the literature over the past decades.[5] Satisfying the above Five Cs of effective accessibility measures leads us to recommend the cumulative opportunity measures of accessibility.

Several advantages of this measure for this purpose stand out. It is a straightforward measure for people to understand; the number of destinations within a set amount of travel time is a concept most can relate to. It scales well; it can be used in a straightforward manner for a single point or an entire metropolitan area. It compares well; it can be used in the same manner to compare different modes, different neighborhoods, and even different metropolitan areas.

Within the framework described above, accessibility is typically described by the following equation:

$$A_i = \sum_{j=1}^{J} O_j f\left(C_{ijm}\right)$$

Where:

- A_i = Accessibility from a zone (i) to the considered type of opportunities (*j*).
- O_j = Opportunities of the considered type in zone j (e.g., employment, shopping, etc.).
- C_{ijm} = Generalized (or real) travel time or cost from *i* to *j* by mode *m.*
- f (C_{ij}) = Impedance function. In cumulative opportunities measures, the impedance function is a binary expression that takes on the value of 1 if the C_{ij} is below a threshold, and 0 if the cost is above a threshold.

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[5] In some of the literature, e.g., accessibility will be defined as the logsum resulting from a destination or mode choice model. Unlike the cumulative opportunities measure, this is hard to explain to the public or policy-makers, though may present a more accurate relative comparison between places. There are also gravity measures. These are reviewed in Handy and Niemeier (1997), among others.

Weighted averages of local measures can be computed:

$$A_a = \frac{\sum_{i=1}^{I} A_i P_i}{\sum_{i=1}^{I} P_i}$$

- A_a = Accessibility Measure (for a particular area such as a neighborhood, district or even metropolitan area).
- P_i = Weight (e.g., population of the disaggregate unit area).

To this point, we have said almost nothing about mode of travel. Cumulative opportunities accessibility measures can be computed separately for each mode of travel (e.g., driving alone, carpool, transit, walking, biking), and even separately for those using HOT lanes and untolled lanes. The accessibilities between modes are directly comparable.

Monitoring Trends in Accessibility

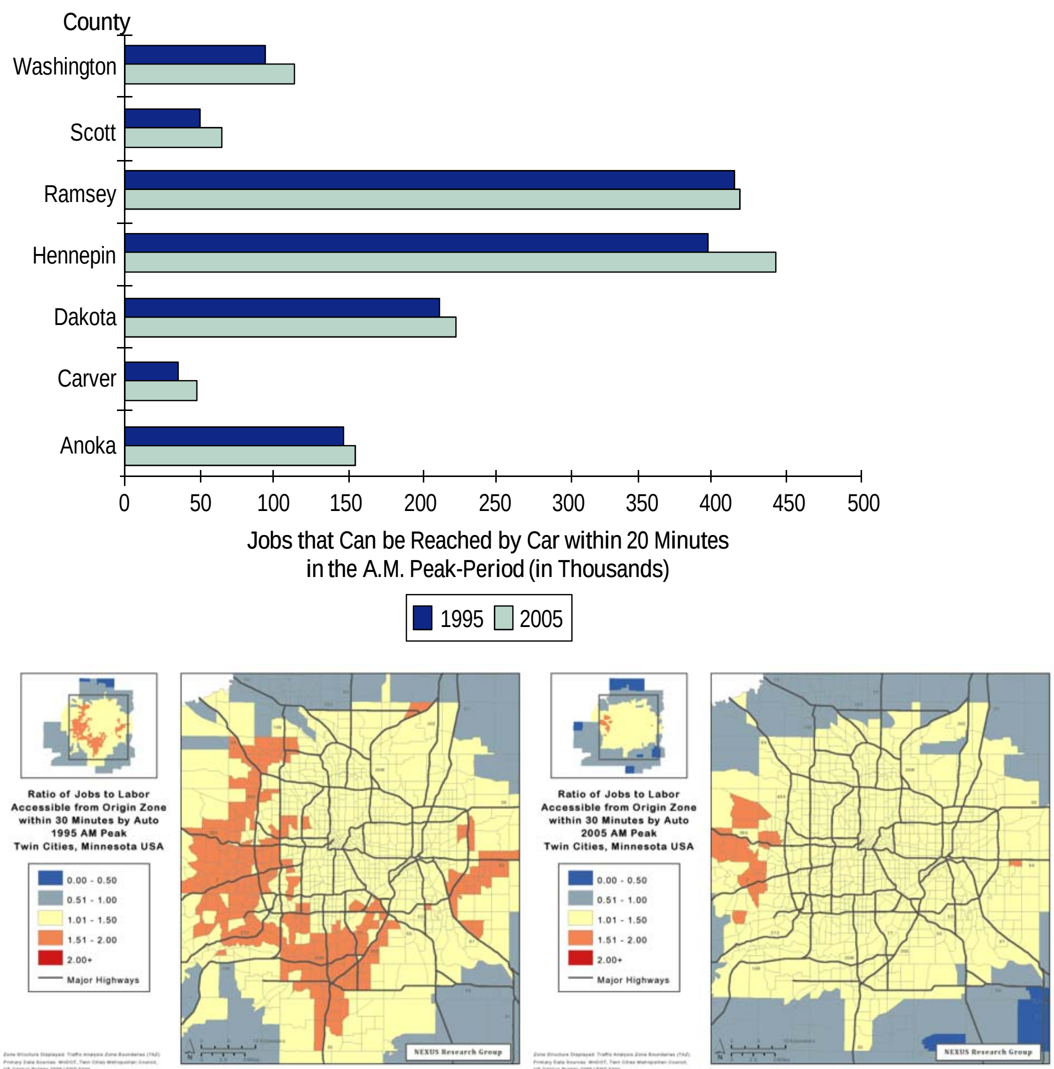
Accessibility may rise or fall independent of congestion levels, as it depends on both congestion and land use patterns. If the city is getting denser (more activities per unit area) more than it is getting slower (due to congestion), we expect accessibility to rise. If it is getting slower more than it is getting denser, we expect accessibility to fall.

Table 8.2 Accessibility and Congestion

		Road Speed	
		Increasing	Decreasing
Development	Increasing	Accessibility Rising	Depends
Density	Decreasing	Depends	Accessibility Falling

Thus, this is an empirical question that might vary by city. The Twin Cities of Minneapolis/St. Paul saw rising congestion for the period from 1995 to 2005, yet as we show in Figure 8.1 (Marion and Levinson, 2010), accessibility generally rose over this period for all seven counties in the metropolitan area. This was due primarily to land use changes, an increasing population and number of jobs (particularly in the 1995-2000 period) resulted in greater accessibility. We can also see that the region became more balanced, the ratio of accessibility to job divided by the ratio of accessibility to workers became closer to 1.

Figure 8.1 Person Weighted Accessibility



One key finding of the Twin Cities study is that nearly the entire region became more accessible in absolute terms over the period under study. The greatest growth occurred in faster-growing, suburban parts of the region. This trend was observed when measuring access to both jobs and workers, suggesting that between 1995 and 2005 both households and employers were decentralizing. Levels of accessibility converged over time, leading to a "flattening" of accessibility across the region. Locational responses by households and firms, particularly the clustering of activities in certain locations, more than offset the negative impact of the deterioration of network performance.

Special Populations

Accessibility can be computed for the population as a whole, as shown above, or for specific groups. There are a number of ways of classifying transportation disadvantaged. Those with low incomes, who are physically or mentally challenged, who do not speak English, are among those groups. Other groups are not inherently disadvantaged, but may have a greater share of their members who are. For instance, while a fully capable newly retired senior citizen is not disadvantaged, someone who a senior may be more likely to have physical difficulties preventing them from driving, or driving at night, or resulting in some other constraint on their ability to reach destinations. These problems are likely to increase as the share of seniors in the population grows. In a recent study (Wasfi, et al., 2012), 17 percent of seniors reported being unable to make a trip they wanted to.

Fan, et al. (2012) examined the effect of new transit service on access to jobs for low-income groups in Minneapolis. This research found that a new LRT line along with a high-frequency bus network significantly improved access to jobs in parts of Minneapolis and St. Paul. The ability to reach destinations is clearly limited without a car compared to with, so understanding the accessibility differences associated with reliance on public transport, taxis, or paratransit is important.

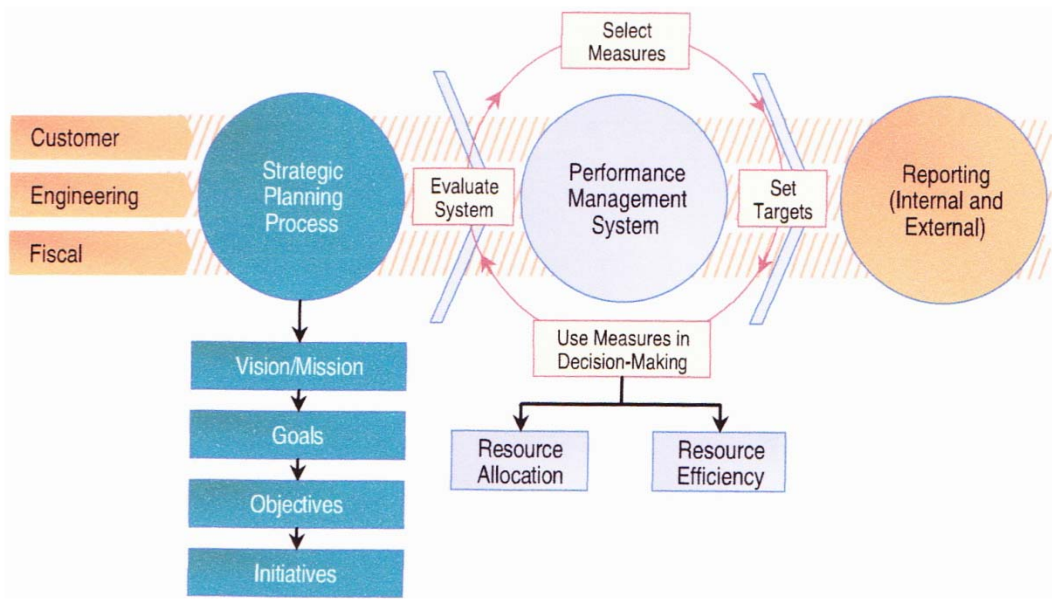
8.3 Fitting Mobility Performance into the Agencywide Context: Performance Management and the Congestion Management Process

Performance Management. The continuous process of improvement driven by assessing, reporting, and acting on the performance of the system – is becoming a guiding principle for making transportation investments. Performance management provides the basis for this process by helping transportation agencies make decisions based on objective data, communicating results to executives and the public in a meaningful way, and providing the key inputs that can and should be used to establish priorities. The private sector has a long history of successfully managing their businesses by tracking performance, evaluating whether particular strategies worked well, and funding those activities that have produced the best results.

Preliminary discussions on Federal transportation reauthorization indicate that Congress is expected to include performance management as a requirement for Federal funding. Even without a Federal requirement, performance management provides transportation agencies with the same kind of rigor used widely by the private sector in delivering services. At the same time, several internal factors are driving the movement for performance management, including the need to target scarce resources to the most pressing problems, the demand by decision-makers and the public for increased accountability and transparency, and evaluating how well past investments have performed. As a major focus area of state departments of transportation (DOT), it is imperative that these principles be applied to mobility.

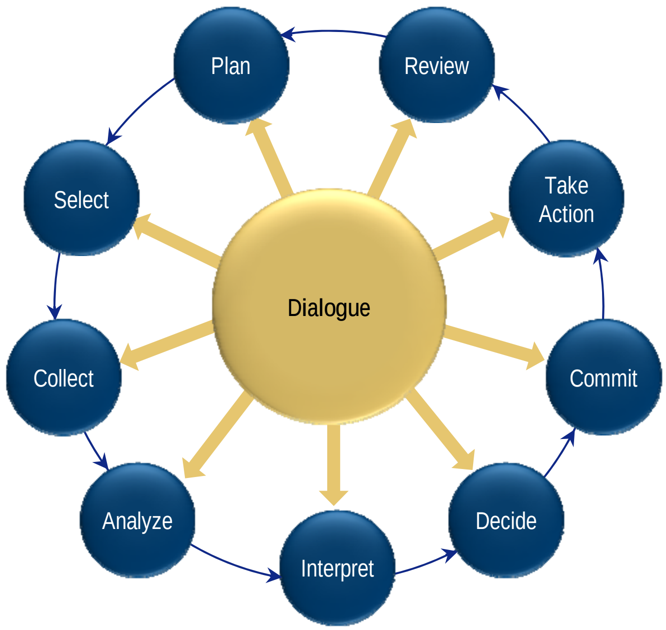
As shown in Figure 8.2, performance management is built around developing and applying performance measures. But just as project investments and program development change in response to performance, so too should the performance measurement program. Experimentation and adjustment will always be required to keep the mobility performance measurement responsive to changing data sources, communication to a wide variety of audiences, and investment needs (Figure 8.3.)

Figure 8.2 The Performance Management Process



Source: Cambridge Systematics, Inc. and High Street Consulting, "Transportation Performance Management: Insights from Practitioners," *NCHRP Report 660*, Transportation Research Board, 2010.

Figure 8.3 The Performance Measurement Process Should Be Continuously Evolving



Source: Spitzer, Dean, "Transforming Performance Measurement," 2007.

A **Congestion Management Process** (CMP) is required in metropolitan areas with population exceeding 200,000 (Transportation Management Areas, (TMA)). FHWA guidance on the CMP includes:

- A congestion management process (CMP) presents a systematic process for managing traffic congestion and provides information on transportation system performance. Features of a CMP include:
  - Measurement of multimodal transportation system performance;
  - Identification of the causes of congestion;
  - Assessment of alternative actions;
  - Implementation of cost-effective actions; and
  - Evaluation of the effectiveness of implemented actions.

At the core, a CMP should include a data collection and monitoring system, a range of strategies for addressing congestion, performance measures or criteria for identifying when action is needed, and a system for prioritizing which congestion management strategies would be most effective.[6]

[6] http://plan4operations.dot.gov/congestion.htm.

The CMP is the logical place where the mobility performance recommendations in this report can be implemented. For transportation planners, it represents a major shift in focus from the long term to the near term in terms of addressing mobility problems. It also implies that the performance measurement activities of multiple agencies must be coordinated. This includes the regional planning agency responsible for the CMP as well as operations, transit, and land use regulatory agencies.

8.4 Explaining Outcomes and Diagnosing Mobility Problems

Evaluations of Implemented Strategies

Performance measurement will increasingly be used beyond reporting and will be nested within an increasing number of agency activities. These will be oriented at understanding why mobility, reliability, and accessibility changed, what agency actions and external conditions affected the change and how do "before" conditions compare to "after" conditions. This will require obtaining the proper data, using that data in ways to measure or estimate the appropriate measures and linking data from several data sets together to understand the results (for example, linking incident descriptions with travel time data to understand the role of collisions and rapid removal programs in reducing congestion).

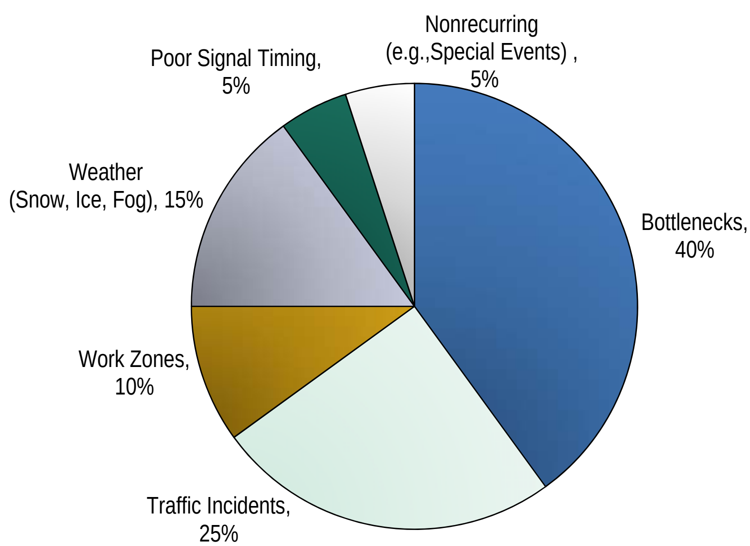
Traditionally, a lot of planning and analysis goes into the front end of projects, they are implemented, but we rarely go back to see how they perform. In a customer-focused environment, however, it is critical to **evaluate constantly how well services are being delivered**, and to devise ways to improve delivery. Therefore, a formal evaluation process is seen as a key feature of a mobility performance program. Evaluations should be routine – not special undertakings – and having an established mobility measurement program enables this. For example, continuously collected mobility performance data means that special data collection efforts do not have to be made. Evaluations enable agencies to learn from successes as well as failures, and successful strategies can be highlighted as a public relations tool.

The important changes in agency practices and procedures will come from using the information developed from better data and more complete diagnoses. The changes in procedures and practices will be influenced by understanding of the effect of ***external factors*** and how they interact with agency practices and investments. Accounting for the influence of external factors on measured performance is therefore critical for the evaluation process. VMT, or other indicator of demand, is clearly the most immediate influencing factor on mobility performance, but it in turn also has determinants: settlement patterns, economic conditions, availability of alternate modes, and demographic structure of the population to name a few.

Deconstructing Congestion: Congestion by Source

In order to target strategies effectively, knowing what the causes of congestion or general mobility problems are is required. This is true whether a highway segment, corridor or region is being considered. The question usually asked is "how much of total delay is related to the underlying causes of congestion?" More broadly, it can be expressed as the "congestion pie," which assigns the relative contribution of each of congestion's recurring and nonrecurring components. FHWA has developed its own version of the congestion pie and has used it for several years in framing the congestion problem (Figure 8.4). The relative percents are based on a single study that used modeling methods for the country as a whole – urban and rural, freeway and nonfreeway, conditions are combined.[7]

Figure 8.4 Relative Sources of Congestion



Source: http://ops.fhwa.dot.gov/congestion_report/congestion_report_05.pdf.

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[7] Chin, et al., *Temporary Losses of Highway Capacity and Impacts on Performance*, prepared for FHWA, 2004, http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.

NCHRP Project 3-68 undertook an analysis using empirical data from Seattle rather than modeling, and compared it to other studies that had been completed at that time (Table 8.3).[8]

Table 8.3 Results from Previous Studies Identifying Congestion by Source

	Study			
Statistics	Dowling Associates	NCHRP 3-68 (CS and Dowling Associates)	Kwon, et al.	CDTC
Metro Area	Los Angeles	Seattle	San Francisco	Albany
Routes	I-10	I-405, I-90, SR 520	I-880	I-87, I-90
Freeway Miles	10 miles	42 miles	45 miles	15 miles
Amount of Data	7 days	4 months	6 months	1 year
Total Delay				
Recurring Delay	69%	71%	80%	72%
Nonrecurring Delay	31%	29%	20%	28%[b]
Nonrecurring Sources				
Percent Incident	31%	16%[a]	13%	28%
Percent Work Zone	0%	0%	0%	Not studied
Percent Weather	0%	9%	2%	Not studied
Percent Special Events	0%	Not studied	5%	Not studied
Percent High Volume	Not studied	4%	Not studied	Not studied

[a] Includes two percent opposite direction rubbernecking.

[b] Assigned all delay under an incident condition to incidents, rather than setting a "recurring baseline."

More recently, SHRP 2 Project L03 used extensive data of urban freeways in Seattle to derive the following contributions:

- Incidents – 28.5 percent;
- Rain – 13.1 percent;
- Construction – 1.0 percent; and
- Recurring/Bottleneck – 57.4 percent.

[8] Cambridge Systematics, Inc., et al., *Guide to Effective Freeway Performance Measurement*, NCHRP project 3-68, Transportation Research Board, August 2006, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w97.pdf.

Several caveats should be noted about the above congestion by source studies:

- What sources of nonrecurring congestion are included in each study. No study was able to incorporate all the potential sources.
- All of the studies used data from freeways that experience a significant amount of bottleneck-related (recurring) congestion. As bottleneck conditions worsen, they will tend to dominate delay from a percentage viewpoint. The increased "baseline" congestion will also cause an increase in nonrecurring congestion, all other things equal, but since recurring congestion happened more of the time, on a percentage basis it will be higher.
- The studies took place in corridors where operations strategies already were in place, so some of the nonrecurring delay is masked.
- The occurrence of work zones during the relatively brief study periods is mostly nonexistent.

Besides fusing disruption data (e.g., TIM data) with travel time data, the main analytic challenge facing these types of studies is deciding how to assign causation to a source. For instance, during peak periods, some amount of recurring delay will almost always exist in corridors with bottlenecks. The method must account for "what would have happened in the absence of the disruption" otherwise the disruption's delay contribution will be overemphasized. A recent study by Kwon and others approached the problem by using regression analysis.[9] The study used a 30-mile section of I-880 in the Bay Area and found that traffic accidents contributed 15.1 percent to total congestion during a.m. and 25.5 percent during p.m., and that most of the remaining congestion came from the recurring bottlenecks. These percentages are in line with the other studies.

Clearly, additional research is needed on this topic and a standard method for computing congestion by source would be useful for agencies around the country to use. In the interim, agencies can use one of the references provided above and develop their own diagnostic tools. One such tool is the "Reliability Profile" shown in Figure 8.5 for conducting highway section analysis. It combines the basic travel time-based metrics with characteristics of disruptions to provide analysts with the nature of congestion.

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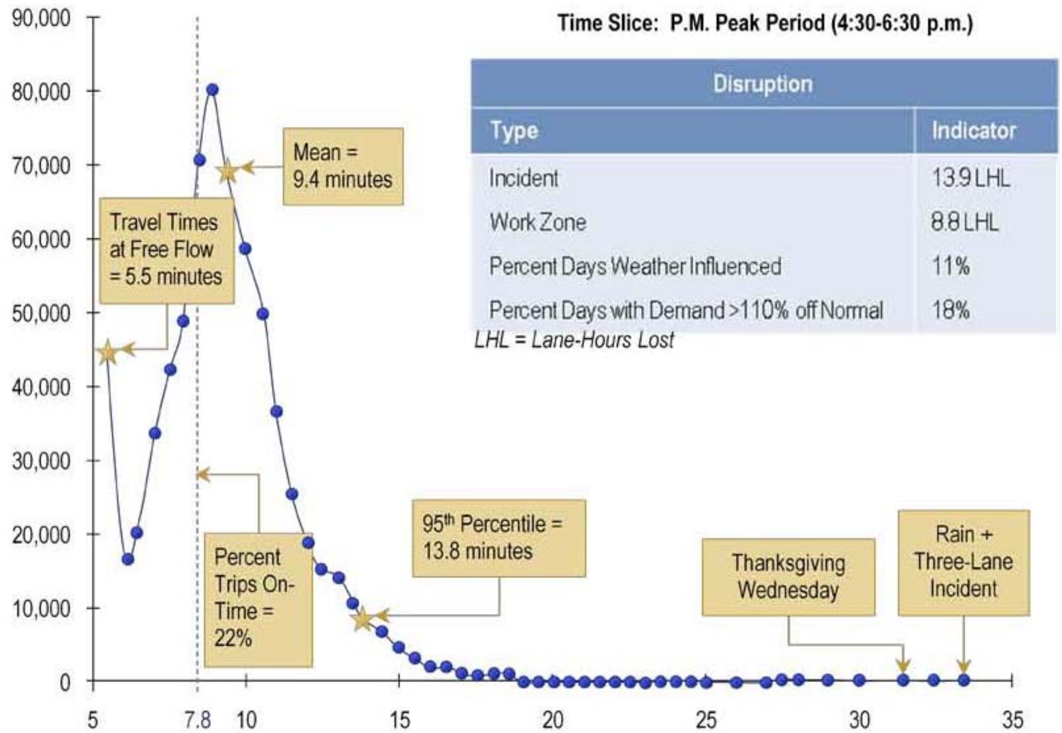
[9] Kwon, Jaimyoung, et al., Decomposition of Travel Time Reliability into Various Sources: Incidents, Weather, Work Zones, Special Events, and Base Capacity, paper submitted at TRB Annual Meeting, January 2011.

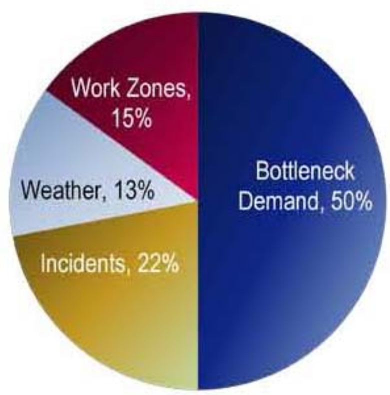
Figure 8.5 Prototype of the "Reliability Profile"
Corridor: I-75 Northbound
I-285 to Roswell Road



Disruption	
Type	**Indicator**
Incident	13.9 LHL
Work Zone	8.8 LHL
Percent Days Weather Influenced	11%
Percent Days with Demand >110% off Normal	18%

LHL = Lane-Hours Lost

Incident Analysis			
		Duration (minutes)	
Category	Number	Mean	95th Percentile
All	94	32.1	75.5
Lane-Blocking	90	32.4	75.5
Large Truck	2	20.3	38.6



8.5 INCORPORATING COST-RELATED MEASURES

Many private sector performance measurement processes – as well as some public sector processes – include aspects of cost and return on investment. These can be cost-efficiency measures (cost per output produced) or cost-effectiveness (cost per outcome achieved). Cost-efficiency measures would be applied at the activity level (e.g., field incident management activities) while cost-effectiveness measures would accompany outcome measures based on travel time-based metrics. Cost-effectiveness measures can be used to choose or prioritize projects or to evaluate; for example, the cost of an hour of delay reduction or some unit of improvement in accessibility. The cost quantities will be for both agency costs and user costs; a comprehensive set of metrics would also include personal travel and freight travel cost measurements. These cost measures will be incorporated in several types of analysis at different points from the initial project decision to implemented project evaluation process.

A major drawback to using cost-related measures for mobility is that external factors outside of the direct control of an agency can have a profound effect on outcomes. Demand, a strong determinant of both average congestion level and reliability, is subject to changes in the socioeconomic character of a region. Some method for controlling for changing demand patterns when tracking annual changes or performing before/after evaluations must be developed. Modeling the effect seems to be the best way to achieve this in the interim.

8.6 Making Decisions Based on Both Facility and Trip Measures

A comprehensive mobility measurement program will involve using a combination of mobility, reliability, and accessibility measures, because they all inform analysts about the nature of mobility in a region. With new data sources being available, it will be much easier to do both facility- and trip-based analyses and incorporate a broader range of concerns. Even though the same mobility metrics can be applied to the performance of both facilities and trips, the nature of the measurements are different.

Facility measurement describes the nature of congestion to which users are exposed. Trip measurement includes factors in addition to congestion exposure – how users interact with entire landscape. With regard to trips, users are generally free to change departure times and routes, and in some cases, destinations and modes as well. Further, over time, however, trip purposes and destinations change. What will result are multiple definitions of what a “trip” is, even though it may be measured with the same metric. For example, a work trip could start at the same time every day, use auto only, and use the same route every day. Alternately, these factors can vary to different degrees. For the purpose of monitoring changes that are important to users, it is recommended that a trip defined it two ways:

1. **Loosely Defined –** A trip for a given purpose can be initiated at any time and by any mode or route. Essentially, this is the same definition used in travel surveys.
2. **Strictly Defined –** A trip for a given purpose is initiated at a fixed time or small time interval, and uses either a specific mode or a specific route.

As trip-based performance becomes more commonplace, reliability-related metrics that measure on-time performance or lateness will become more meaningful, because users perceive at least a rudimentary schedule associated with their trips. However, deciphering what every individual's implied schedule is for a trip will require additional research. A simple approach is to use the mean or median travel time, or some multiple of it, as was presented earlier in this report. For nonauto modes, where published schedules exist, this problem does not exist. It may be necessary to expand the list of reliability metrics when these measurement issues are resolved. For example, the notion of ***schedule delay***, the amount of time a trip is completed early or late relative to the expected schedule, may be used, especially, if research indicates that this component is the most highly valued component of reliability.

Finally, there is the issue of directing Mobility-Related Programs with Performance Management. Performance management is currently receiving much attention by the transportation profession. Much of this emphasis is self-initiated by transportation agencies as they adopt a customer-oriented focus, and strive for accountability and transparency in transportation investment decisions. There is also a great deal of interest at the Federal level as well. As of this writing, it is uncertain if the Federal interest will take the form of Congressionally-imposed regulations on the management of Federal transportation programs, but performance management in some form is being discussed intensely.

However, especially with regard to mobility, the profession has little experience in managing mobility programs with performance measures. Historically, agencies have used performance measures to identify needs (usually through the use of models rather than direct mobility measurements) and to assess impacts of project alternatives. But, monitoring the systemwide effect of mobility programs has been elusive. As data and monitoring systems become more sophisticated and ubiquitous, tracking trends will become easy to accomplish, but several "so what?" questions remain. That is, we may have the ability to monitor changes, but how do we use that information in an actionable way?

- How large should a mobility program be? What overall level of investment is required to make progress toward performance targets? Agencies have competing needs to address – what are the implications of emphasizing one program area over another?
- Perhaps more so than other program areas, changes in mobility performance are affected by forces external to a transportation agency's control. Primary among these is demand growth, either brought about by general economic conditions or in a more localized fashion due to land use changes. While demand growth certainly affects other program areas (e.g., safety, pavements, it is particularly egregious for mobility because of the well-documented nonlinear effect that demand growth has under already congested conditions. Other factors such as major weather and special events may also skew mobility measurements in a particular year.

- Given the above, how strictly do we manage to outcomes? Should we manage to lower level output-oriented measures (e.g., performance at the project level) or do we somehow qualify or adjust outcome targets to account for external influences?

8.7 Standard Procedures for Computing Performance Metrics

This report has recommended a core set of mobility performance measures to be used in the near term. However, merely specifying a metric does not ensure compatibility across areas. With the vast amount of data now available, there are many ways to take low-resolution travel time measurements and turn them into performance metrics. Specifically, temporal and spatial aggregation must occur and other data must be used as reference points (e.g., the selection of free-flow speeds) or in transforming the travel time data (e.g., volume used to weight measurements). Therefore, a strong need exists to develop standard procedures for computing performance metrics from “raw” measurement data. A formal standard could be developed, such as through a standards development organization like ASTM or AASHTO, or a set of guidelines can be produced, but having procedures that all agencies can follow will foster comparisons between areas.

A. Mobility Performance Measures in Current Practice

A.1 Travel Time Reliability Performance Measures

Nevada DOT

Nevada DOT's Integrated Transportation Reliability Program (ITRP) aims to implement new and innovative programs to prevent congestion and improve reliability. As part of the program, the DOT will coordinate with statewide stakeholders to develop strategies to improve travel time reliability in Nevada. Las Vegas' Traffic Incident Management Coalition brought southern Nevada emergency response and transportation agencies together to enhance emergency response to the over 15,000 traffic crashes that occur each year in the Las Vegas valley. The group established collision clearance time goals to restore road travel following traffic crashes.[10]

The ITRP proposed five travel time reliability measures for freeways and arterials in Las Vegas based on the MPO's Freeway Arterial System of Transportation (FAST) program findings. The measures include:

1. Variability based on normalized standard deviation;
2. Analysis of variance;
3. Average time mean estimation;
4. Reliability as a measure of nonfailures; and
5. Information theory-based approach.

Freight Reliability

Many states that have large freight corridors and commercial traffic also track freight performance measures. While shippers and manufacturers are concerned about delivery time, unloading capacity, and inventory requirements, a system reliability performance measure can be a useful component of a freight

[10] Nevada DOT, *Statewide Integrated Transportation Reliability Program: Executive Summary Presentation*, Kimley-Horn and Associates, Inc., 2009, http://www.kimley-horn.com/projects/NevadaITRP/images/pdfs/Program%20Abstract.pdf.

performance measure set. Reliable travel times allows shippers and operators to plan better and to meet service commitments and customer expectations. Shippers also can help improve reliability by implementing strategies to reduce the number of commercial collisions and breakdowns.[11]

In 2007, the Washington State Legislature initiated one of the first state truck performance measure projects in the United States.[12] By accurately tracking truck trip travel times and network reliability, the Truck Freight Performance Measure project placed the State of Washington in a better position for:

- **Future Federal Freight Funding Requests –** Most of the concepts put forth in Federal transportation bill proposals include some requirements for performance measures;
- **Increasing Public Accountability to Citizens –** Tracking truck freight performance before and after projects are constructed explains the value of their investments; and
- **Making the Most Productive Investments of State Dollars –** Quantifying delay at truck freight bottlenecks allows the State to identify key problems and prioritize project funding.

North Dakota State University Department of Civil Engineering conducted a comprehensive study of freight performance measures addressing all modes and facility types for the Minnesota DOT.[13] The study found that freight operators and shippers need a reliable travel time window within which delivery can be expected. They deal with travel time contingencies as a matter of business, but travel time reliability is important. The Minnesota Statewide Transportation Plan included freight reliability performance measures in general but noted that additional work was required to analyze and deploy them.

Lam, et al. investigated the impact of travel time reliability on freight truck route choice and total travel time.[14] The study found that the total travel time of the vehicle fleet increased as drivers required more reliable travel time because drivers took more circuitous but more reliable paths. To draw these conclusions, the

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[11] Performance Measures to Improve Transportation Planning Practice: A Peer Exchange, Transportation Research Circular Number E-C073, Washington, D.C., May 2005.

[12] Washington Department of Transportation, Washington State Truck Freight Performance Measure Research: Interim Report, March 17, 2010.

[13] Varma, Amiy, *Measurement Sources for Freight Performance Measures and Indicators*, Department of Civil Engineering – North Dakota State University. Research performed for Minnesota Department of Transportation, July 2008. http://www.lrrb.org/PDF/200812.pdf.

[14] Lam, W.H.K., C. Chen, K.S. Chan, and A. Ren. *Optimizing Vehicle Fleet Management with Travel Time Reliability Constraint*, Journal of Transportation Systems Engineering and Information Technology, Volume 5, Number 5, October 2005.

study set travel time reliability goals for just-in-time ready-mix concrete delivery (i.e., the concrete must arrive on time for a given percent of trips) modeled travel choice.

Recommended Reliability Performance Measures from SHRP 2 Project L03

SHRP 2 Project L03 examined the potential performance measures used to describe travel time reliability and recommended those in Table A.1. The recommendations were based on examining measures in use in the United States and other parts of the world. The list includes the Skew Statistic, as proposed by European researchers. The researchers also added the 80th percentile travel time because analysis indicated that this measure is especially sensitive to operations improvements and also has been used in previous studies on the valuation of reliability. The research also demonstrated that the Buffer Index can be an unstable measurement for tracking trends over time due in part to its linkage to two factors that change – average and 95th percentile travel times; if one changes more in relation to the other, counterintuitive results can appear.

Table A.1 Recommended Reliability Performance Metrics from SHRP 2 L03

Reliability Performance Metric	Definition	Units
Buffer Index (BI)	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time • The difference between the 95th percentile travel time and the median travel time, normalized by the median travel time	Percent
Failure/On-Time Measures	Percent of trips with travel times less than 1.1 * Median Travel Time *or* 1.25 * Median Travel Time Percent of trips with space mean speed less than 50 mph; 45 mph; or 30 mph	Percent
80th Percentile Travel Time Index	80th percentile travel time divided by the free-flow travel time	None
Planning Time Index	95th percentile Travel Time Index (95th percentile travel time divided by the free-flow travel time)	None
Skew Statistic	The ratio of (90th percentile travel time minus the median) divided by (the median minus the 10th percentile)	None
Misery Index (Modified)	The average of the highest 5 percent of travel times divided by the free-flow travel time	None

Source: Cambridge Systematics, Inc. SHRP 2 Project L03 Final Report: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies. Strategic Highway Research Program (SHRP 2), Transportation Research Board, February 2010.

A.2 International Scan of Mobility and Accessibility Measures

Three FHWA international scans were reviewed:

1. *Transportation Performance Measures in Australia, Canada, Japan, and New Zealand*, FHWA, December 2004;
2. *Active Traffic Management: The Next Step in Congestion Management in Denmark, England, Germany, and the Netherlands*, FHWA, July 2007; and
3. *Linking Transportation Performance and Accountability in Australia, Great Britain, New Zealand, and Sweden*, FHWA, April 2010.

In addition to these three FHWA documents, an on-line search also was performed on mobility measures in other countries.

All the transportation agencies use similar sets of measures commonly used in the United States, such as congestion and travel time. Other measures are related to road safety, trip reliability, and accessibility. ***Measures of customer satisfaction are also widely used by those agencies.*** For example, UK transportation agencies measure time reliability by the average delay experienced in the worst 10 percent of journeys for each monitored route.

Measures relating to freight movement and transit were found in many performance measurement efforts. However, in most cases, performance measurement is implemented within a modally focused agency, so performance measures were targeted at decisions relating to the performance of that modal network. But many agencies are moving away from a traditional mode-centric focus to a broader, more inclusive approach to surface transportation planning in highly congested urban areas, so the examined agencies placed a great emphasis on transit service, rail passenger service, land use integration, and moving people and freight as well as vehicles as they continued to develop their performance measures.

The agencies visited displayed a strong commitment to addressing climate change and sustainability. However, transportation's effect on the environment was not easily captured by the visited agencies. Other measures as travel time reliability and transportation's effect on the environment also were not easily defined by the visited agencies. All these important outcomes that are difficult to measure in the United States were equally difficult in the agencies studied.

The more urbanized agencies in the United Kingdom, Australia, and Sweden were investing considerable effort in measuring real-time highway, transit, and rail operations to improve their operations, travel time reliability, enhance transportation choices, and reduce greenhouse gas emissions.

Tables A.2 through A.8 summarize the mobility measures adopted by various international transportation agencies. A brief discussion of use by selected agencies follows the tables.

Table A.2 Mobility Measures in British Columbia

Agency	Performance Measures	Note
British Columbia Ministry of Transportation	Percent of urban vehicle-kilometers traveled in congested conditions	
	Commercial trucking travel time between economic gateways	Transportation's role in fostering economic growth is a key policy direction of the ministry.
	Higher user satisfaction with existing ministry services and delivery processes	Using surveys to pinpoint those aspects of dissatisfaction that the ministry could address (e.g., maintenance and snow removal efforts).
	Annual total duration of unplanned closures greater than 30 minutes for all numbered highways	This measure is directly linked to the ministry's and police agency's ability to remove incidents from the road network.
TransLink – The Greater Vancouver Transportation Authority	Congestion	A congestion measure is not yet part of the TransLink scorecard. A study on congestion costs is underway to examine a variety of ways that congestion measures could be defined, ranging from total social cost of congestion to facility delay indicators.
	Multimodal	Consensus is good on what is important within modal categories, but across modes little agreement exists on how multimodal performance should be measured.

Table A.3 Mobility Measures in Japan

Agency	Performance Measures	Note
Japan – Road Bureau, Ministry of Land, Infrastructure, and Transportation (MLIT)	• Time loss due to traffic congestion • Percent of ETC use • Hours of roadwork • Percent of traffic diverted to expressways • Percent of roads with access to airports/ports • Percent of main cities connected to national road • Percent of people having safe drive into city of less than 30 minutes • Percent of barrier-free main roads near transit terminals with more than 5,000 passengers • Level of road user satisfaction	Data collection methods include traditional roadside surveys, automated traffic counters, ultrasonic loop detectors, floating cars, and an evolving program to use probe vehicles for determining travel time. Japan has about 5,000 GPS probe vehicles, most of which are buses. This data can be turned into real-time arrival information for transit riders, operations control for bus managers, and road performance measurement for the Road Bureau.
	Community Design	MLIT participates in large-scale, multiuse development projects with a significant transportation component.

Table A.4 Mobility Measures in Australia

Agency	Performance Measures
Australian Transport Council (ATC)	• A.M. peak actual travel speed – urban • P.M. peak actual travel speed – urban • A.M. peak lane occupancy rate (persons/lane/hour) • P.M. peak lane occupancy rate • Off-peak lane occupancy rate • All-day lane occupancy rate • Operating costs per kilometer • Cost per ton-kilometer for freight • User satisfaction index • Total kilometers traveled by jurisdiction of registration, normalized for economic activity • Total road ton-kilometers traveled, normalized for economic activity Note: Austroads methodology for determining travel time measurements focused on a congestion indicator (minutes per kilometer) and a travel time variability measure.
Main Roads, Queensland	• Travel speed variability (urban) • Average duration of incident delays • Network reliability • User satisfaction index • Percent of level of stakeholder satisfaction in selected topics • vehicle-kilometers, travel speed, and congestion index • Lane occupancy rate • Percent of network that is multimodal • Percent of stakeholder satisfaction with corridor management • Percent of variability of travel time
Transport Queensland	• Community satisfaction with public transport services • Average private vehicle occupancy rates on key major urban routes • Public transit patronage trend for buses, rail, and regulated air and taxi services • Patronage trend in the corridor impacted by the South East Busway • Travel times on select transport corridors during peak hours of buses compared to autos • Proportion of Queensland's public transport services that are wheelchair accessible • Number of rail corridor sublease integrity breaches • Level of coordinated and integrated public transport services in southeast Queensland

Agency	Performance Measures
Rail, Transport Queensland	• Average trains per week (number) • Capacity use (percentage) • Average below rail delays (minutes) • Total below rail delay events (number) • Below rail track availability (percentage) • TSR variance against threshold (percentage) • OTCI last recorded number (number)
Roads and Traffic Authority (RTA), Sydney, New South Wales	• Number of incidents on the road network • Time taken to respond to and clear incidents on the network • TMC telephone call statistics for the average 3,000 calls per day (e.g., number of calls responded to within 30 seconds, with a target of 75 percent answered within 30 seconds and 95 percent answered within 60 seconds) • Provision of bus lanes/transit lanes/transit ways in kilometers • Enforcement of bus priority lanes • Provision of bicycle ways in kilometers • Number of minutes without signal detection capability • Development of pedestrian facilities and access plans Note: Sydney Coordinated Adaptive Traffic System (SCATS) was developed by RTA to provide coordinated traffic signal strategies for the road network. For other modes of transportation, SCATS is used to monitor and manage bus reliability. Bus lane monitoring is used to measure bus travel speeds, and vehicle occupancy data is collected as well.

Agency	Performance Measures
Department of Infrastructure, Melbourne, Victoria	Access and Mobility • Public transport – Percent of motorized trips in Melbourne – Compliance with law requiring access to the public transport system and vehicles for disabled persons – Response times for taxis for the disabled – Reliability of service provision and customer services (level of fully operating ticketing machines) – Customer satisfaction – Network average speed for trams and buses • Road congestion delays on urban arterial roads Rural and Regional Development • Proportion of specified roads developed for minimum safe travel time • Public transport – Reliability of service provision – Customer satisfaction – Compliance with law requiring access to the public transport system and vehicles for disabled persons Seamless Freight and Logistics System • Freight productivity – Share of freight tonnage transported to and from Victoria's commercial ports by rail – Freight rates for containers by road and rail – Freight rates for specified commodities – Container movements to and from freight terminals (percent empty vehicles and percent empty container slots on vehicles) • Freight Infrastructure – Percent of travel undertaken on "smooth" roads – Rail track condition (network temporary speed restrictions) – Percent of arterial road network accessible to legal freight vehicles – Traffic delays because of congestion on urban arterial roads

Agency	Performance Measures
VicRoads, Melbourne, Victoria	• Urban and rural actual travel time (minutes per kilometer), time nominal travel time (minutes per kilometer), congestion (minutes per kilometer), and variability of travel time (percentage) • Road use for people (person-kilometers) • Freight (ton-kilometers) Note: Reducing travel times (increasing speeds) would be rewarded with bonuses. VicRoads agreed to spend AU $15 million (U.S. $11 million) a year for two to four years for bottleneck removals. The franchisee would pay VicRoads AU $3.6 million (U.S. $2.6 million) a year for each 1 kilometer per hour average speed increase on trams. VicRoads is using ITS applications most effectively as a source of data for performance indicators, and is developing additional applications that could be important in the future.

Table A.5 Mobility Measures in New Zealand

Agency	Performance Measures
Transit New Zealand	Travel Time Use Austroads definition and methodology Customer Satisfaction Percent of satisfied ("good" or "better") users for overall network, traffic flow, road safety, road surface, road markings, rest areas, and environment
Ministry for the Environment	• G1: Change in Level of Road Congestion over Time – Ratio of measured journey time to free-flow journey time over a sample of urban peak-hour journeys, for cars, buses, and rail. • G26: Transport Cost Index – For car ownership (purchase and annual charges and per-kilometer equivalent); car use (additional per-kilometer costs); public transport costs (bus, rail, per kilometer); parking costs per day (CBD).

Table A.6 Mobility Measures in Great Britain

Agency	Performance Measures
Department for Transport	Mobility Measures • Private road vehicles – Person journey times – Reliability is measured by the standard deviation of travel time • Public transport journeys – Reliability is defined as the difference between travelers' actual and timetabled arrival times Reliability Ratio = Value of SD of travel time/Value of travel time or Reliability Ratio = Value of SD of lateness/Value of lateness Note: The agency believes it is one of the few, if not the only agency, to actively track reliability performance on a daily basis across an entire national network. Accessibility Measures • Accessibility to school education • Accessibility to further education • Accessibility to work • Accessibility to a hospital • Accessibility to a doctor • Accessibility to a supermarket/food store

Table A.7 Mobility Measures in Sweden

Agency	Performance Measures
Swedish Road Administration	Measures the travel times to major towns for rural residents and reports changes over time.

Table A.8 Mobility Measures in the Netherlands

Authors	Performance Measures
Stephan Krygsman, Martin Dijsta, Urban and Regional Research Centre Utrecht (URU), Utrecht University, P.O. Box 80115, 3508 TC, Utrecht, The Netherlands Theo Arentzeb, Eindhoven University of Technology, Eindhoven, The Netherlands	Interconnectivity Ratio Multimodal public transport: an analysis of travel time elements and the interconnectivity ratio, Transport Policy, Volume 11, Issue 3, July 2004, pages 265-275. Access and egress are the weakest links in a public transport chain and determine the availability and convenience of public transport. This paper used a comprehensive travel-activity diary to collect detail travel time estimates. The interconnectivity ratio is defined as the ratio of access and egress time to total trip time. For most multimodal trips, the ratio falls within a modest range of 0.2 to 0.5. Note: Literature review has not found any agency that adopted interconnectivity ratio as a performance measure.

Discussion

Transport Coordination Plan (TCP) for Queensland 2008-2018

http://www.tmr.qld.gov.au/~/media/2e112627-8161-4135-9e5d-ef327fc58675/transport%20coord%20plan.pdf.

Ten objectives have been defined that respond to the challenges and opportunities facing the transport system. These objectives will be relevant in any operating environment that unfolds in Queensland over the life of the TCP. They will contribute to sustainable use of the transport system and help to meet the government's key outcomes and priorities. The objectives and associated performance measures that relate to mobility and accessibility are:

- **Make the most of the existing transport system.** Balancing demand and supply of infrastructure and services to maximize efficiency.

  Performance indicators:

  - Level of congestion in urban areas; and
  - Travel reliability.

- **Integrate transport planning and land use planning.** Matching transport and land use patterns to enhance livability and trade.

  Performance indicators:

  - Accessibility to transport services, markets, social opportunities, and desired destinations.

Brief Review of Some Relevant Worldwide Activity and Development of an Initial Long List of Indicators, Sustainable Transportation Performance Indicators

Project. Richard Gilbert and Hélène Tanguay, June 2000, http://cst.uwinnipeg.ca/documents/STPI%20Phase%201%20report.PDF.

New Zealand

In 1996, the New Zealand Ministry for the Environment published a document entitled National Environmental Indicators: Building a Framework for a Core Set that proposed a program to establish a core set of nationally standardized indicators to help in the assessment of the state of the environment and in the monitoring of outcomes related to environmental policies and key legislation. In 1997, another document, The State of the New Zealand Environment was launched by the Ministry, stressing this time the need for better information about the effects of our activities on the environment. New Zealand's environmental indicators program was initiated following the publication of this last document. In June 1999, *Proposals for Indicators of the Environmental Effects of Transport* was published by the New Zealand Ministry of the Environment as a result of the environmental indicators program initiative.

The congestion/mobility indicators listed were as follows:

- **G1: Change in Level of Road Congestion over Time –** Ratio of measured journey time to free-flow journey time over a sample of urban peak-hour journeys, for cars, buses, and rail; and
- **G26: Transport Cost Index –** For car ownership (purchase and annual charges and per-kilometer equivalent); car use (additional per-kilometer costs); public transport costs (bus, rail, per kilometer); parking costs per day (CBD).

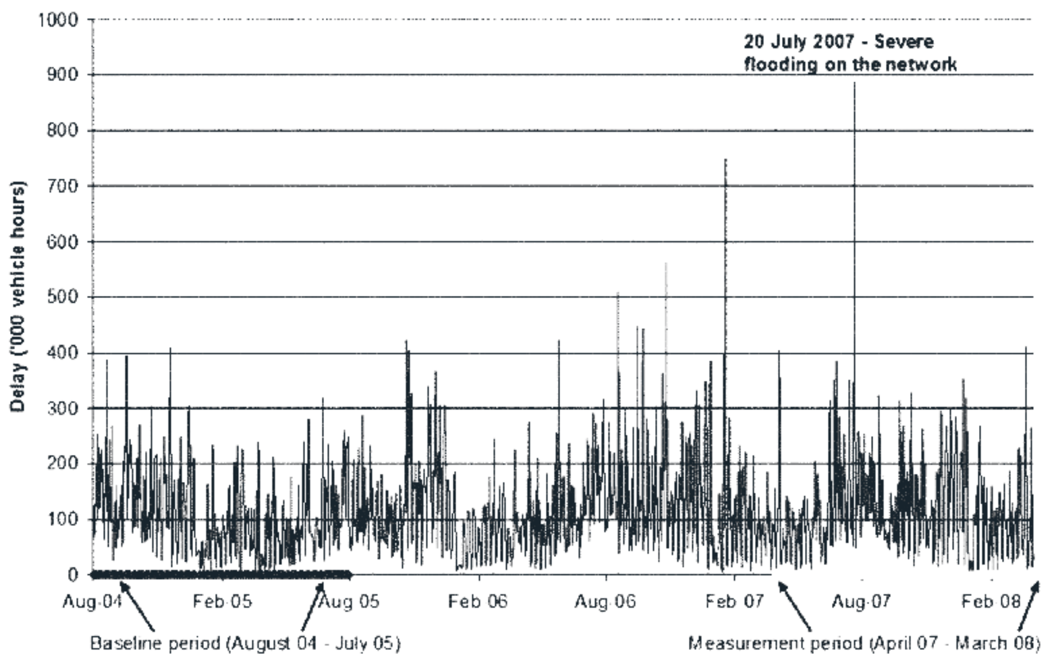
Great Britain's Highway Mobility Monitoring

The British, in particular, have invested considerable effort in measuring reliability on high-volume national routes. The Highways Agency (HA) of Great Britain identified a Strategic Road Network of 2,700 kilometers (1,678 miles) of motorways and 4,350 kilometers (2,703 miles) of other trunk routes. It divided those routes into 103 sections with 2,500 total links. The HA actively tracks reliability performance on a daily basis across this network.

The HA Traffic Information System database holds the average journey time traffic flow of every link of that network for every 15-minute time period. The travel speed and reliability data come from several sources, including inductive loops, traffic (*license*) plate cameras, and global positioning system (GPS) tracking systems. The data are compiled into ongoing travel speed data and compared to a 2004 baseline.

From the data, officials measure the amount of delay on the most congested 10 percent of the network. Reliability is measured as average vehicle delay on the slowest 10 percent of the journeys. The slowest 10 percent of journeys are selected for each 15-minute departure time between 6:00 a.m. and 8:00 p.m. for each day of the week on 95 of the 103 routes on the Strategic Road Network. Figure A.1 was used to illustrate the use of reliability measure to identify the effect of weather.

Figure A.1 Great Britain's Delay Tracking Chart Showing Weather Effects



British officials said their network reliability program has improved their understanding of system performance and led to increased evaluation of intervention strategies. But they acknowledged they are not completely satisfied with their program and want to improve it. They noted that measuring reliability is difficult because of shortcomings in data, definitions of what reliability is, and the lack of sensitivity to intervention strategies. The results of their interventions and measurement revealed that for a 10-mile (16-kilometer) journey, a motorist undertaking one of the 10 percent slowest journeys would be subject to 3.4 minutes of delay, compared to 3.9 minutes before the interventions. Such metrics are difficult to explain to the public, they said. Such small differences in average travel time could be attributed partially to a reduction on overall demand, especially during the economic downturn. They are pleased that their system responded to the Treasury requirement that they uniformly measure and improve travel time on the major highway network. But they also acknowledged that explaining the results of the reliability measure to the public and decision-makers is difficult, and this is the focus for improvement.

Australian Mobility Monitoring

Australia's challenges include addressing a growing population and existing congestion problems. The transportation plans in most regions include investments in both road and public transportation capacity and operating improvements. The plans and reporting for both modes include reliability as an element of concern, but there is no indication that near-term or long-range investment plans are tied to specific reliability performance measures.

- **New South Wales Region –** The New South Wales Roads and Traffic Authority measures reliability by monitoring morning and evening average travel times on its seven most important urban routes. It has invested considerably in both operational and capital improvements to sustain travel times as the population grows. One improvement from the 1970s was the Sydney Coordinated Adaptive Traffic System. The computerized traffic control system is used to adapt signal timing to changes in traffic flow. Linking the traffic signals allows the optimization of traffic flow in the regional system.
- **Queensland Region –** The Queensland Department of Transport and Main Roads has a strategic plan with a focus on maximizing the efficiency of the transportation network. In doing so, they combined the city and suburban traffic operations units into regional traffic management centers that coordinate the region's urban traffic signals and several local transit bus providers. This multimodal approach is extended into the draft long-range plan – Connecting South East Queensland 2031. Travel reliability (as measured by daily tracking of morning and evening speeds on key corridors) and traffic management is referred to as a priority as the agency moves to increase person movement capacity.
- **Victoria Region –** Victoria produces an annual report on the performance and management of its freeway and arterial network. It has monitored travel performance on its network since 1994. It reports travel speeds, travel volumes, tram speeds and reliability, journey trends by bicycling, and traffic volumes. The report feeds into its travel time reliability measures, which influence investment in projects and programs to improve reliability. Their long-range plans (Victorian Transport Plan) and their current improvement program (the $30 million *Congestion Improvements Program* is an element of the $113 million *Keep Melbourne Moving* program) both have significant recommendations on improving road and transit service reliability.

Swedish Mobility Monitoring

The Swedish Road Administration (SRA) includes travel reliability in a large set of transportation performance measures. Travel times and speeds are tracked on major routes in the three major cities (Stockholm, Malmo, and Goteborg) and on routes to towns for rural residents. The SRA reports are designed to connect the performance of the system with "the steps taken in each area to improve traffic flow and reliability and report on planned improvement strategies for the next year." The rural reporting includes the effect of seasonal weather problems and summarizes the reports with the number of residents who saw increases or improvements in travel times to towns.

A.3 ACCESSIBILITY PLANNING METHODS

From: New Zealand Transport Agency Research Report 363, 2008. This report summarized accessibility in the context of transportation planning in England, Southern California, and The Netherlands. It then gave a synopsis of where accessibility planning in New Zealand was heading. A summary of their findings from the three case study locations is provided in Table A.8.

In addition to the three areas listed in Table A.9, the Georgia DOT (GDOT) has recently defined accessibility measures in their Strategic Transportation Plan.[15] Under the objective of: "Improved access to jobs, encouraging growth in private-sector employment, work force," are two specific accessibility measures:

- Percent of population within 30-45 minutes drive of employment center.
- Percent of population that can reach an employment center via transit within 30-45 minutes.

Table A.9 Summary of Accessibility Planning in Practice

Criteria	England	Southern California, United States	The Netherlands
Accessibility Planning Type	Comprehensive	Limited	Regulatory
Driver	Social exclusion	Transport Equity	Reduce car mobility Ensure access to economic activity centers
Spatial Focus	Urban and rural areas	Urban and rural areas	Urban areas only
Organizational Responsibility	Local application National guidance, standards, and monitoring	Regional design and application National monitoring	Local application Provincial and national monitoring
Used for Area Transport Plan Development	Yes – Local transport plans	Yes – Regional transportation plans	Yes – Land use plans
Assessment	Continuous in line with planning cycle One-off as required for projects	Individual, but repeated on a three-yearly planning cycle	One-off, but repeated as necessary
Process	Five-stage assessment using indicators and stakeholder input	Analysis of plan impacts on accessibility using indicators and stakeholder input	Allocation of accessibility rating to areas based on their location and use

[15] Georgia Department of Transportation, *Statewide Strategic Transportation Plan, 2010-2030*, June 2, 2010, http://www.it3.ga.gov/Documents/Final-SSTP.pdf.

Criteria	England	Southern California, United States	The Netherlands
Standardized Indicators of Accessibility	Yes – A range of standard national “core” indicators Local indicators supplement these as required	Yes – Selected locally to comply with national policies	No
Accessibility Focus	Education, work, medical, and food shopping	Jobs and “opportunities”	Business location
Modal Focus	PT Bicycle Walking	Car PT	Car PT
Used for Project Evaluation	Yes	No	No

Source: Chapman, Susan, and Weir, Doug, Accessibility Planning Methods, NZ Transport Agency Research Report 363, 2008, http://www.nzta.govt.nz/resources/research/reports/363/docs/363.pdf.

Comprehensive Accessibility Planning: England

Indicators: “Core,” or national, indicators and local indicators support accessibility planning in England. Core indicators are standard measures, established by the Department for Transport (DFT) to measure and compare accessibility across Local Transport Authorities (LTA) on a national basis. Indicators have been calculated based on journey time by car, public transport, cycling, and walking. There are six categories of core indicators, based on the journey purpose types:

1. Accessibility to school education;
2. Accessibility to further education;
3. Accessibility to work;
4. Accessibility to a hospital;
5. Accessibility to a doctor; and
6. Accessibility to a supermarket/food store.

Indicators are calculated for a “main” population group and a particular “risk” group within each category, with the exception of the further education category where only a main population group is examined. The risk groups provide a proxy for individuals/groups considered vulnerable to accessibility-related social exclusion.

Thresholds used are based on travel time by public transport during the morning peak period (7:00 to 9:00 a.m.). For this purpose, “public transport travel time” is defined as being either the travel time by a public transport mode (e.g., bus) inclusive of walk time to/from stops, by flexibly routed services available to the public, or the corresponding walk time (i.e., it is assumed that people will walk if that travel time is quickest).

Regulatory Accessibility Planning: The Netherlands

The Netherlands' approach to accessibility planning is very different from those employed in England and the United States. It uses a measure known as the ABC location policy to classify land in urban areas according to its accessibility, with the goal of optimizing land use in relation to public transport supply and demand for car use. It aims to reduce avoidable car mobility and ensuring access to economic activity centers. The approach is encapsulated by an alternative name for the process – "the right business in the right place."

The policy, which came into force in 1989, has two key concepts:

1. **The Proximity Principle –** The grouping of trip origins and destinations as close together as possible; and
2. **Accessibility Profiles –** The locating of businesses (and urban developments) in the right places in terms of transport needs.

The core element of the ABC location policy is classification of locations and businesses according to their access requirements. Locations are graded according to their accessibility by public and private transport, which creates an "accessibility profile," while businesses are graded according to their access needs and modal shift potential, creating a "mobility profile."

The location accessibility profiles are graded A, B, or C:

- "A" locations are highly accessible by public transport, and tend to be located at major public transport nodes such as central stations in large urban areas;
- "B" locations are reasonably accessible by both public transport and car, and are typically located on both public transport and road corridors; and
- "C" locations have poor public transport accessibility, but tend to be located on main roads so are easily accessible by car.

The business mobility profiles are assigned to classes of business and relate to:

- Site work intensity (the number of workers by surface unit);
- The mobility of employees (dependence on the car for business activities);
- Visitors' intensity (the number of visitors by surface unit); and
- Dependence on the transport of freight.

The ABC policy aims to match accessibility profiles to mobility profiles, i.e., it seeks to locate each business at a location with an accessibility profile that matches its mobility characteristics. It does this by directing businesses that are looking for new sites to locations with matching accessibility profiles, and by improving the accessibility of locations to match the mobility profiles of existing businesses. Shops are ideally located in "A" areas, offices in "A" and "B" areas, while "C" areas are only intended for use by transport activities or land-intensive activities. Limiting the available parking places at "A" and "B" locations enforces the policy.

New Zealand Practice

Accessibility is an issue of concern for New Zealand policy-makers and is being considered to varying extents by a range of organizations across government. However, the current approach to accessibility is somewhat piecemeal, largely uncoordinated and mainly focuses on monitoring rather than active assessment and planning.

Ministry of Transport: The Ministry also has recently led development of a range of key indicators of access to the transport system, as part of the Transport Sector Strategic Directions 2006-2009 (TSSD) Transport Monitoring Indicators Framework (TMIF) project. These accessibility indicators are being populated with data and cover:

- The affordability of transport;
- Accessibility of community resources;
- Access to a motor vehicle;
- Travel perceptions; and
- Accessibility of public transport.

The recommended core indicator categories are based on the English and Southern Californian accessibility planning indicators and cover the journey purpose types similar to the UK system discussed above. Accessibility-related issues and community outcomes also were considered when recommending the following core indicator categories as relevant to New Zealand:

- Accessibility to school education (primary and secondary schooling);
- Accessibility to further education;
- Accessibility to work;
- Accessibility to a hospital;
- Accessibility to a doctor or primary health organization (PHO); and
- Accessibility to a supermarket (urban) or food store (rural).

Given the remoteness of some rural communities and residents, measuring access to additional or different activity centers in these areas may be more appropriate, for example:

- Accessibility to a petrol station;
- Accessibility to a pharmacy;
- Accessibility to a bank, post office, or financial services facility;

- Accessibility to a social services office (Heartland Services; Work and Income; Accident Compensation Corporation; Child, Youth, and Family; etc.); and
- Accessibility to public transport (including rural school and hospital board buses, etc.).

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