The Keys to Estimating Mobility in Urban Areas

Applying Definitions and Measures That Everyone Understands

A White Paper Prepared for the

Urban Transportation Performance Measure Study

by

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SUMMARY
MOBILITY MEASURMENT CONSIDERATIONS

There are several keys to developing and applying mobility measures that are technically useful and generally understandable. Travel time measures are relatively easy to comprehend, but they have not always been used because of data concerns, mandated reporting practices, and other issues. Travel time and speed measures can serve many different uses, communicate to many different audiences, and enhance the ability of project analysis techniques to determine the most appropriate set of policies, programs, and projects for a situation. The important concepts identified in this paper are summarized below.

- Travel time and speed quantities are useful and understandable to a very broad audience and a wide range of uses. They also quantify the effect of the wide range of transportation improvements as well as the land use actions that are being pursued to improve mobility and provide travel and development choices in urban areas.

- Travel time and speed information do not have to be expensive or difficult to collect. There are a variety of automated data collection systems for roadway and transit systems that are being used to improve operations. Additional data collection can be concentrated on the locations with significant mobility problems. The remaining system can be sampled, and a range of analytical methods can be used to estimate travel time quantities.

- The process for selecting mobility measures should identify the decisions that will be made, the alternatives that will be studied, the audiences for the information, the accuracy level needed, and the data that are available or can be estimated. The goal of the mobility measure selection process is to select a set of measures that indicate progress toward the community's vision.

- Outcome measures such as "satisfaction of travelers and shippers with the trip time and cost" cannot be directly measured from system monitoring devices, but performance statistics can be calibrated to traveler satisfaction surveys. The system performance statistics can be updated much more frequently than surveys, in effect providing very useful user satisfaction information from the same data used to operate the system. Automated system monitoring processes provide a rich source of day to day performance information that cannot be replicated by user surveys.

- The concept of target travel conditions is the way to link the user satisfaction survey information with the system monitoring. A matrix of travel rates or travel times can be prepared to represent a community vision encompassing factors that can be seen as conflicting. Issues such as land use, economic development, mobility, environmental features, quality of life, and other concerns can be set against one another by interests opposed to any consensus. The process for getting to such a community consensus can begin with input obtained during long-range plan updates. The expectations for travel conditions vary depending on many factors (e.g., location within the urban area, time of day) that can be included in the set of matrices. Planners, engineers, and other transportation professionals can then use the matrices to identify problem areas, systems, or time periods and prioritize actions to develop a set of projects, programs, and strategies that are targeted to achieving the community vision.

- There is a role for measures based on both free-flow conditions and “target” conditions. Free-flow conditions are good for comparisons in a national context. “Target” values for key performance measures can be used to identify trip patterns that take more time to complete or segments of the transportation system that are not providing the travel time and/or reliability that travelers expect, or the land use or environmental outcomes that neighborhoods desire.

- A complete set of mobility indicators includes an indicator of the variation in travel time. Reliability is a key component of user perception, and is especially important to freight movement and in just-in-time manufacturing processes.

- Travel Time Index, a ratio between the travel time in free-flow conditions or the posted speed limit and peak period conditions, can be used as a multimodal transportation system measure. It can be calculated for a range of area sizes, from individual facilities to corridors and regional systems. It can use information on travel time from continuous system monitors or from estimates developed from computer simulation models and empirical formulas.

- Travel delay and delay per capita are key components of any economic effect analysis. They are also easily communicated to non-technical audiences. They work best in roadway analyses but can be used in multimodal contexts.

- Evolution is the key to incorporating travel time and speed data into mobility measurements. The first steps may include direct travel time and speed measurement for important corridors, along with estimation procedures for the remainder of locations and modes. As more resources and more monitoring equipment become available, the direct data collection can be expanded. User satisfaction surveys can supplement travel speed information. This package of information can identify the threshold for target conditions, identify corridors that need improvement, and analyze alternatives.

The overriding conclusion from any investigation of mobility measures is that there is a range of uses and audiences. No single measure will satisfy all the needs, and no single measure can identify all aspects of mobility—there is no “silver bullet” measure. Mobility is complex and in many cases requires more than one measure, more than a single data source, and more than one analysis procedure. Mobility measures, when combined in a process to uncover the goals and objectives the public has for transportation systems, can provide a framework to analyze how well the land use and transportation systems serve the needs of travelers and businesses and provide the basis for improvement and financing decisions. Exhibit S-1 provides a quick reference to selected mobility measures discussed in more detail in this report.

Exhibit S-1. Quick Reference Guide to Selected Mobility Measures.

INDIVIDUAL MEASURES[1]	
Delay per Traveler	$\text{Delay per Traveler (annual hours)} = \dfrac{\left(\text{Actual Travel Time (minutes)} - \text{FFS or PSL Travel Time (minutes)}\right) \times \text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy (persons/vehicle)} \times \dfrac{250\text{ weekdays}}{\text{year}} \times \dfrac{\text{hour}}{60\text{ minutes}}}{\text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy (persons/vehicle)}}$
Travel Time	$\text{Travel Time (person – minutes)} = \text{Actual Travel Rate (minutes per mile)} \times \text{Length (miles)} \times \text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy (persons/vehicles)}$
Travel Time Index[2]	$\text{Travel Time Index} = \dfrac{\text{Actual Travel Rate (minutes per mile)}}{\text{FFS or PSL Travel Rate (minutes per mile)}}$
Buffer Index[2]	$\text{Buffer Index (\%)} = \left[\dfrac{\text{95th Percentile Travel Time (minutes)} - \text{Average Travel Time (minutes)}}{\text{Average Travel Time (minutes)}}\right] \times 100\%$
AREA MOBILITY MEASURES[1]	
Total Delay	$\text{Total Segment Delay (person-minutes)} = \left[\text{Actual Travel Time (minutes)} - \text{FFS or PSL Travel Time (minutes)}\right] \times \text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy (persons/vehicle)}$
Congested Travel	$\text{Congested Travel (vehicle-miles)} = \sum \left(\text{Congested Segment Length (miles)} \times \text{Vehicle Volume (vehicles)}\right)$
Percent of Congested Travel	$\text{Percent of Congested Travel} = \left[\dfrac{\sum_{i=1}^{m}\left(\left(\text{Actual Travel Time}_i\text{ (minutes)} - \text{FFS or PSL Travel Time}_i\text{ (minutes)}\right) \times \left(\text{Vehicle Volume}_i\text{ (vehicles)} \times \text{Vehicle Occupancy}_i\text{ (persons/vehicle)}\right)\right)_{\text{Each congested segment}}}{\sum_{i=1}^{n}\left(\text{Actual Travel Rate}_i\text{ (minutes per mile)} \times \text{Length}_i\text{ (miles)} \times \text{Vehicle Volume}_i\text{ (vehicles)} \times \text{Vehicle Occupancy}_i\text{ (persons/vehicle)}\right)_{\text{All segments}}}\right] \times 100$
Congested Roadway	$\text{Congested Roadway (miles)} = \sum \text{Congested Segment Lengths (miles)}$
Accessibility	$\text{Accessibility (opportunities)} = \sum \text{Objective Fulfillment Opportunities (e.g., jobs), Where Travel Time} \leq \text{Target Travel Time}$

[1]"Individual" measures are those measures that relate best to the individual traveler, whereas the "area" mobility measures are more applicable beyond the individual (e.g., corridor, area, or region). Some individual measures are useful at the area level when weighted by PMT (Passenger Miles Traveled) or VMT (Vehicles Miles Traveled).

[2]Can be computed as a weighted average of all sections using VMT or PMT).

Note: FFS = Free-flow speed, PSL = Posted speed limit.

ACKNOWLEDGMENTS

This is the second report of a research study that builds on past urban congestion reports. The goals of this new study are to examine the issue of mobility measurement and the presentation of information to a wide range of audiences. This report identifies a number of key issues and provides guidance on the state of the practice. Additional information developed in the course of the study with the help of the Steering Committee will improve this information.

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LIST OF ACRONYMS

ATR	Automatic Traffic Recorder
AVI	Automatic Vehicle Identification
BI	Buffer Index
CBD	Central Business District
D2D	Door-to-door
DVMT	Daily Vehicle Miles Traveled
FFS	Free-flow Speed
FHWA	Federal Highway Administration
HCM	*Highway Capacity Manual*
HERS-ST	Highway Economic Requirements System—State Version
HOT	High-occupancy Toll Lane
HOV	High-occupancy Vehicle
IDAS	ITS Deployment Analysis System
ITS	Intelligent Transportation System
LOS	Level-of-service
LRT	Light Rail Transit
MAG	Maricopa Association of Governments
MMP	Mobility Monitoring Program
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
PMT	Passenger Miles Traveled
PSL	Posted Speed Limit
PTI	Planning Time Index
TMC	Traffic Management Center
TRI	Travel Rate Index
TTI	Travel Time Index or Texas Transportation Institute
V/C	Volume-to-Capacity Ratio
VMT	Vehicle Miles Traveled
vphpl	Vehicles per hour per lane
WIM	Weigh-in-motion

QUICK REFERENCE GUIDE

Note that while all chapters build upon one another, each chapter also can "stand alone" on the topic and is written as such. To this end, references are included at the end of each chapter.

INTRODUCTION—Chapter 1
Overview of decision process for travelers and goods movement; transportation agency concerns and mobility measure needs.

OBJECTIVES FOR MEASURING MOBILITY—Chapter 2
The needs, uses, and audiences for mobility; definitions of congestion and mobility.

THE PROCESS OF MEASURING MOBILITY—Chapter 3
Description of a complete process from vision and goal definition, through measure selection, data collection, and improvement analysis.

SELECTING MOBILITY MEASURES—Chapter 4
Several key criteria that can be used to identify the correct set of mobility measures; the role of data collection concerns in the selection process; aspects of congestion and mobility that should be measured.

RECOMMENDED MOBILITY MEASURES AND DATA ELEMENTS—Chapter 5
Description of mobility measures and situations for their use.

DATA COLLECTION AND DATABASES—Chapter 6
Description of typical database contents and data collection procedures.

ILLUSTRATION OF MOBILITY MEASUREMENT—Chapter 7
Describes state-of-the-art examples of communicating mobility results.

APPLICATION AND INTERPRETATION OF CONGESTION MEASURES—Chapter 8
Demonstration of practical applications and interpretation of congestion measures described in the report. Spreadsheet is available for download and use for subsequent analyses.

CHAPTER 1—INTRODUCTION

The persons and freight that move on the nation's transportation system have several factors that determine the basic parameters of the trip—departure time, route, travel mode, and cost. Improvements in the transportation system show up in:

- **Faster travel—**due to more travel options or better travel conditions on the same facilities or modes.

- **More reliable transportation—**crashes and vehicle breakdowns are quickly moved so that they do not affect the system for long periods.

- **More travel options—**in terms of mode, route, time, and cost.

- **Cheaper travel options—**including the value of time, environmental impacts, and other factors in addition to out-of-pocket expenditures.

The travelers and freight carriers that move on the network are concerned with a package of these attributes that most closely optimizes their desires. Arriving at a destination on time and at a minimum cost can be thought of as a fairly typical goal; the choices made from that goal statement, however, are widely disparate. They are related to personal tastes, cost of the trip, trip purpose, mode availability, and trip time.

Decisions that transportation agencies make about which projects and programs to select are also concerned with environmental impacts, quality of life in affected neighborhoods, safety, equity, and a variety of other factors. The agencies must analyze the range of options and decisions and attempt to optimize the expenditure of limited transport funds to improve the system.

Developing a measure that relates all the traveler factors to the range of impacts and concerns that will govern urban decision making, then, is not a narrow issue. This paper is a step toward identifying the key concerns and charting a path that allows travelers, citizens, and businesses to provide comments to the professionals in ways that all groups can understand. The agencies, in turn, will get the benefit of guidance to improve the urban area transportation system or identify the key factors that make improvement an undesirable option for a particular portion of the system or specific policy or strategy.

Each chapter of this report identifies research and practices that meet the needs of modal and multimodal analyses with travel time and speed-based measures. Measures that can be presented and used by both technical and public audiences are emphasized in the paper. Where compromises have been made for simplicity or data collection concerns, the ultimate measures or procedures are identified so that users can understand the path to the future as new models, procedures, or technologies are developed.

CHAPTER 2—OBJECTIVES FOR MEASURING MOBILITY

Chapter Summary

The needs and audiences for mobility information are more varied and complicated in an era of flexible funding decisions and diverse transportation improvement programs. Many communities are linking transportation and land use decisions together in ways that change the techniques that are useful for measuring performance.

Implementation decisions and performance measures should be based on an assessment of these community goals. Communicating these ideas requires concepts and definitions that the public and technical experts understand. Toward this end, a definition of mobility is proposed that mirrors the public's perception and is consistent with the targets for most transportation improvement programs.

Mobility is the ability to reach a destination in a time and cost that are satisfactory.

An analysis of transportation system performance measurement needs conducted in the National Cooperative Highway Research Program (NCHRP) project *Quantifying Congestion* (*1*) recommended that travel time-based measures be used to estimate and present mobility and congestion information. The needs identified by a discussion of the uses and the audiences for congestion can best be satisfied by measures such as travel time, travel speed, travel rate, and travel delay. In most situations, the use and presentation of mobility information should also be in travel time-related quantities. This chapter begins from this point and re-examines some of the conclusions and definitions developed in *Quantifying Congestion* (*1*) in relation to the needs of the *Urban Mobility Report*.

2.1 Needs for Mobility Measures

While the needs for mobility information are clearly best satisfied by travel time measures, there is always the question of "where is the data?" *Quantifying Congestion* (*1*) separated the issue of which measures should be used from the data concerns. Travel time measures do not preclude the use of other data, procedures, surrogates, or models when appropriate. The key point was that the set of mobility measures that are used should satisfy the needs for the information and the presentation of that information to the range of audiences.

The decision process used by travelers to select trip modes and routes, and by the transportation or land use professional analyzing alternatives, is influenced by travel time, convenience, user cost, dependability, and access to alternative travel choices. Travel time is also used to justify capital and operating improvements.

A system of performance measurement techniques that use travel time-based measures to estimate the effect of improvements on person travel and freight movement offers a better chance of satisfying the full range of potential needs than conventional level-of-service (LOS) measures (*2*). Technical procedures and data used to create the LOS measures can be adapted to produce time-based measures. The procedures were developed in a time when construction was typically the selected option, and operational improvements were done on a small scale and cost level. The more complicated situation that transportation professionals face in the 21st century means that new techniques and data are available, but the analysis needs are also broader and often cross traditional modal and funding category boundaries.

Exhibit 2-1 lists seven situations identified in *Quantifying Congestion* (*1*) that significantly influence the needs for mobility measurement: scope, location, mode, roadway type, time, planning context, and level of detail.

Exhibit 2-1. Variation in Mobility Measurement Needs.

GEOGRAPHIC SCOPE	Intersection/Interchange Facility Segment Route/Corridor Sector/Subregion Region State/Nation	LOCATION	CBD Core CBD Fringe Central City Suburbs Suburban Fringe Seasonal/Resort Stadium, Arena or Sports Complex
TRANSPORTATION MODE	Roadways HOV or Bus-Only Lanes HOT Lanes Managed Lanes Car Pools Buses Rail in Roadway or Median Exclusive Guideway Transit	ROADWAY TYPE	Freeways and Toll Roads Expressways and Super Arterials Principal Arterials Minor Arterials Collectors Local Streets
TIME OF DAY / DAY OF WEEK	Morning Peak Afternoon Peak Noon Peak Midday Evening Daily Average Weekday Average Special Events Holiday or Weekend	PLANNING CONTEXT	Existing Conditions Existing Demand/Modified Supply Future Demand/Existing Supply Future Year Conditions
		LEVEL OF DETAIL	Policy Planning Design Operations (Also see Uses, Users and Audiences)

HOV = High-occupancy Vehicle
HOT = High-occupancy Toll Lane
Source: Reference (*1*)

2.2 Uses and Audiences

The range of uses and potential audiences for mobility information is significant for their broad nature and their expansion in the last decade. The specifications of any particular application are dictated by the analytical needs and the presentation of information to the audiences.

The expansion of decision alternatives and public involvement in those decisions that has occurred over the last decade has placed greater and more complicated demands on mobility measurement. The conflict between more detailed analyses and ways to present information to non-technical audiences is one example of these demands. The expansion of computing power has made alternative analysis and future scenarios easier to test, but the direct travel time and speed information that should be the focus of informing the public is not always available.

Travel time and speed estimating procedures that produce information for technical uses and non-technical audiences are needed for situations like this, and are an important part of the mobility measurement process. The procedures include relatively simple calculations that use easily obtained data, procedures that can be used by agencies responsible for system operations, techniques that can use operations data to improve a wide range of other transportation analyses, and methods that work well with travel demand models.

Exhibit 2-2 shows how the three basic categories of analysis relate to the four most common types of analysis. It serves as a general guide for practitioners generating mobility information and for identifying the appropriate data collection and analysis strategies.

Exhibit 2-2. Applications of Mobility Analysis Methods.

	Type of Analysis Method			
Analysis Category	**Point-Based Travel Time Analysis**	**Direct Travel Time Measurement**	**Sampling Travel Time on Segments**	**Empirical Travel Time Estimation**
Function				
Policy Analysis				☆
Project Prioritization	T			☆
Planning or Alternative Analysis	T	T	☆	☆
Design	☆	☆	☆	
Operation		☆		
Analysis Period				
Existing Conditions	☆	☆	☆	T[1]
Future Conditions				
Short Range	☆	☆	☆	T[1]
Long Range	T			☆
Analysis Scope and Scale				
Intersections	☆	T		
Single Roadway	T	☆	T	
Corridor		☆	☆	T
Sub-area			☆	☆
Areawide			☆	☆

☆Application in most analyses.
T Limited application.
[1] Particularly when needed as base condition for analysis of future conditions.
Source: NCHRP (*1*)

As a specific example, Exhibit 2-3 presents an overview of potential uses of performance measures. As shown, a variety of transportation applications can make use of performance measures, and significant overlap exists in the requirements of each application.

Exhibit 2-3. Potential Uses of Congestion Performance Measures.

Potential Uses of Performance Measures	Specific Applications	Requirements of Performance Measures
Roadway Operations—Real-time Applications	Incident Management	Current and expected traffic states due to traffic flow breakdowns (travel time based); throughput; diversion volumes
	Traveler Information/Diversion	
	Coordinated Freeway-Arterial Control	
	Weather Management	
	Special Event Management	
Roadway Operations—Operational Planning	Incident Management	Detail on detection, verification, on-scene, and response times
	Traveler Information/Diversion	Trip- and corridor-based performance Effects of information content and timeliness
	Coordinated Freeway-Arterial Control	Effects of improved ramp and signal timing plans
	Evaluations of Operational Improvements	Consistent before/after measurements (travel time performance)
	Safety Countermeasures	Consistent before/after measurements (crash histories and profiles)
Transportation Planning	Travel Demand Forecasting	Ability to identify and rank deficiencies; inputs to assignment process; volumes and speeds for calibration
	Demand Management	Trip- and corridor-based performance
	Air Quality Analysis	Inputs to emission models
	National Performance	Corridor-based and areawide performance
	Congestion Management	Trip- and corridor-based performance
	Truck Travel Estimation; Parking Utilization and Facility Planning; High-occupancy Vehicles, Paratransit, and Multimodal Demand Estimation; Congestion Pricing Policy	Trip- and corridor-based and areawide performance
	Freight and Intermodal Planning	Trip- and corridor-based performance
Transportation Programming	Investment Analysis; Programmatic Funding Levels	Corridor-based and areawide performance
Homeland Security	Evacuation Planning	Trip- and corridor-based performance
Transportation Research	Traffic Flow Model Development	Highly detailed (time/space) performance measures
Emergency Response	Route Planning	Trip- and corridor-based performance
Freight Carriers	Resource requirements	

Source: NCHRP (*3*)

The analysis categories in Exhibit 2-2 are described as:

- **Function—**For most types of general policy, programming, or planning purposes, estimating procedures provide useful results with a minimum of data collection. More specific design and operation concerns require more precision, and direct measures of travel time or travel speed are usually very desirable.

- **Analysis period**—Most techniques can produce useful information for existing conditions, but future conditions require some travel speed estimating procedures (e.g., empirical models or *Highway Capacity Manual* (*HCM*). Estimating procedures are also required for existing conditions where future scenarios will be analyzed. This approach provides uniformity of results, avoiding inconsistencies caused by different data collection/estimation procedures.

- **Analysis scope and scale—***HCM* analysis procedures may continue to be used for most intersection analyses and possibly for short roadway segments. Direct travel time measures are more useful for analysis areas greater than short roadway segments. Some sampling process is useful to limit data collection requirements for large corridors, sub-areas, and regional analyses.

The broader range of uses and audiences for mobility information identified here does not mean every analytical procedure is worthless. Those procedures can be adapted to quantify the mobility of people and goods by incorporating vehicle occupancies, freight movement, and other factors. While there may be a wider range of improvement alternatives, the analyses are consistent with the goals of a transportation system—to get people and goods safely, quickly, and reliably to their destination.

Mobility can be estimated by analyses and measurement of speed and travel rates. Within this context, various transportation groups should re-examine current practices of developing mobility information and analyzing potential improvement projects or programs. The broader perspective suggests that traditional roadway operating analysis procedures be complemented by direct travel time measurements and assessments, especially in the future.

These needs indicate an evolutionary approach is required (*1*). Limited travel time studies in severely congested locations or corridors with significant multimodal characteristics may improve mobility estimates initially. With more extensive use of direct measurement to follow as funds are available, advanced technology systems are installed or mobility levels fall toward unacceptable levels. It is important to retain some historical database whenever possible to allow trend analyses to be developed. The limited initial travel time studies may provide the very useful function of calibrating national procedures with local travel time and speed information.

Direct collection of travel time and speed data is encouraged whenever possible to provide information for local studies, to provide a basis for trend monitoring, and to calibrate national averages to local freeway and street operation. Travel time and speed estimation techniques may, however, be necessary where resource constraints exist or where future conditions are analyzed.

Exhibit 2-4 presents several principles that would help guide the development of mobility monitoring programs. The principles are applicable to both passenger and freight mobility monitoring. By applying the appropriate cost factors for passenger and freight travel, mobility impacts can be monetized.

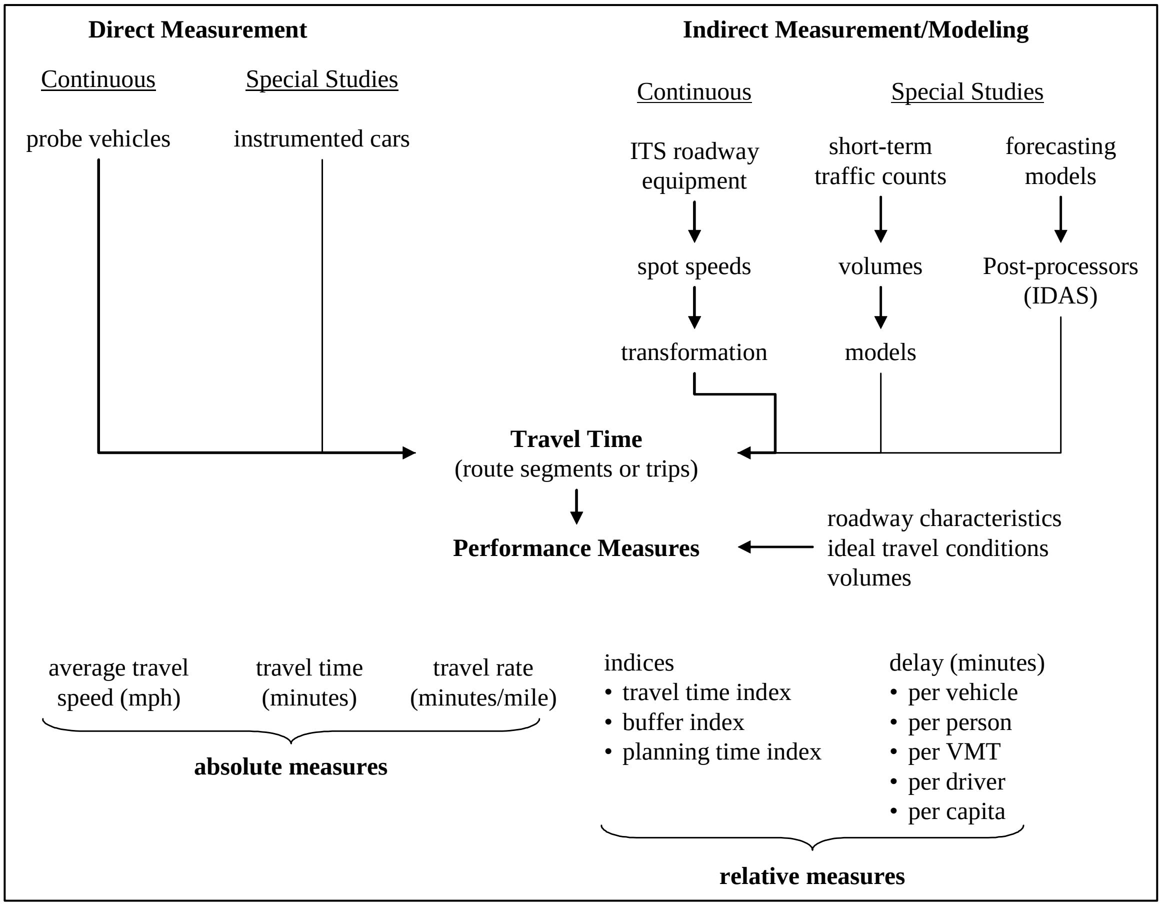
Exhibit 2-4. Basic Principles for Roadway Mobility Monitoring.

Principle 1	Mobility performance measures must be based on the measurement of travel time.
Principle 2	Multiple metrics should be used to report congestion performance.
Principle 3	Traditional HCM-based performance measures (Volume-to-Capacity Ratio [V/C] ratio and level of service) should not be ignored but should serve as supplementary, not primary, measures of performance in most cases.
Principle 4	Both vehicle-based and person-based performance measures are useful and should be developed, depending on the application. Person-based measures provide a "mode-neutral" way of comparing alternatives.
Principle 5	Both mobility (outcome) and efficiency (output) performance measures are required for congestion performance monitoring. Efficiency measures should be chosen so that improvements in their values can be linked to positive changes in mobility measures.
Principle 6	Customer satisfaction measures should be included with quantitative mobility measures for monitoring congestion "outcomes."
Principle 7	Three dimensions of congestion should be tracked with congestion-related performance measures: source of congestion, temporal aspects, and spatial detail.
Principle 8	The measurement of reliability is a key aspect of roadway performance measurement, and reliability metrics should be developed and applied. Use of continuous data is the best method for developing reliability metrics, but abbreviated methods should also be explored.
Principle 9	Communication of freeway performance measurement should be done with graphics that resonate with a variety of technical and nontechnical audiences.

Note: These principles relate to both passenger and freight mobility monitoring.
Source: NCHRP (*4*)

Foremost among these is the notion that ***congestion performance measures must be based on the measurement of travel time.*** Travel times are easily understood by practitioners and the public, and are applicable to both the user and facility perspectives of performance. Exhibit 2-5 shows how travel times can be developed from data, analytic methods, or a combination. Clearly, the best methods are based on direct measurement of travel times, either through probe vehicles or the more traditional "floating car" method. However, both of these have drawbacks: probe vehicles (e.g., toll tags and cellular telephones) currently are not widely deployed and the floating car method suffers from extremely small samples. Further, since many performance measures require traffic volumes as well, additional collection effort is required to develop the full suite of performance measures. Use of Intelligent Transportation System (ITS) roadway equipment addresses these issues, but this equipment does not measure travel time directly; ITS spot speeds must be converted to travel times first. Other indirect methods of travel time estimation use traffic volumes as a basis, either those that are directly measured or developed with travel demand forecasting models.

Exhibit 2-5. Travel Time is the Basis for Defining Mobility-based Performance Measures.



IDAS = ITS Deployment Analysis System
Source: Turner et al. (*5*)

Exhibit 2-5 also shows how basic travel times can then be converted into a variety of performance measures using a few fundamental pieces of information about the environment where travel times were measured (roadway characteristics, "ideal" travel speeds, and traffic volumes). This implies that travel time-based performance measures are extremely similar in their basic nature, although some researchers have tended to exaggerate the differences. Travel time-based performance measures can be thought of as two types: 1) absolute measures and 2) relative measures. Relative measures require comparison to some base conditions, usually "free-flow" or posted speed limit conditions.

2.3 Defining Mobility

The challenge for transportation professionals is to develop a connection to the concepts people measure in their trip-making activity and derive measures that produce consistent evaluations. If the definition is flexible, mode neutral, and focused on providing a trip that meets the needs of the traveler, the discussion of whether improvements are needed and which to pursue can proceed on the merits of the project or program. While several precise definitions are useful, perhaps the following definitions meet a variety of needs.

- **Mobility is the ability to reach a destination in a time and cost that are satisfactory.**
- **Congestion is the inability to reach a destination in a satisfactory time due to slow travel speeds.**
- **Reliability is the level of consistency in transportation service (e.g., hour to hour and day to day).**

A definition of quick or cheap—presumably the desirable end of the mobility spectrum—would be relative to the expectations of the traveler for each trip. This has such considerations as:

- The speed of travel for a trip is not as important if the trip is short. Walking across the street to the sandwich shop does not have to be accomplished at 60 mph to satisfactorily achieve the travel objective.
- Paying a toll for a trip is not necessarily bad if the traveler believes the benefits outweigh the costs. If a toll brings travel conditions that are satisfactory and reliable, the desired mobility level can be achieved.
- The definition can be extended to travel by persons or freight using road, rail, air, water, or electronic forms of trip making.
- Mobility will be understood as good no matter which mode is used. Congestion will be defined as a characteristic that represents less than satisfactory service due to travel demand/supply imbalance.
- Measuring "satisfactory" will not be as easy as counting cars but will provide the profession with a better idea about the transportation goals of the public.

This definition of mobility may lack some precision in identifying the modes or travel patterns that are included, but it is simple and can be used with existing technologies and procedures. It can also be modified to describe individual pieces of the transportation system such as road mobility measures, transit system measures, or multimodal transportation mobility measures. And if transportation and planning agencies explore the input they receive from the public, a definition of "satisfactory" that is consistent with the opinions of their customers will become clear enough to be used for initial phases of project and program evaluation and prioritization. More specific determinations of public support will always occur as plans are updated or designs reviewed for specific projects.

2.4 References

1. *NCHRP Report 398*. Quantifying Congestion—Final Report and User's Guide. National Cooperative Highway Research Program Project 7-13, National Research Council, 1997.

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3. "Guide to Effective Freeway Performance Measurement." National Cooperative Highway Research Program Project 3-68, Amplified Work Plan, National Research Council, December 2003.

4. "Guide to Effective Freeway Performance Measurement (Version 1)," National Cooperative Highway Research Program Project 3-68, Interim Report, National Research Council, November 2004.

5. Turner, S.M., Margiotta, R., and Lomax, T. "Lessons Learned: Monitoring Highway Congestion and Reliability Using Archived Traffic Detector Data." U.S. Department of Transportation, Federal Highway Administration, September 2004.

CHAPTER 3—THE PROCESS OF MEASURING MOBILITY

Chapter Summary

Mobility measures and techniques for developing mobility information are parts of several processes and activities. The key steps in identifying the best mobility measure for any particular situation include the following:

- Identify the vision and goals.
- Identify the uses and audiences.
- Consider possible solutions.
- Develop a set of mobility measures and accompanying analysis procedures.
- Collect or estimate data elements.
- Identify problem areas.
- Test solutions.

Each of these steps is summarized in this chapter.

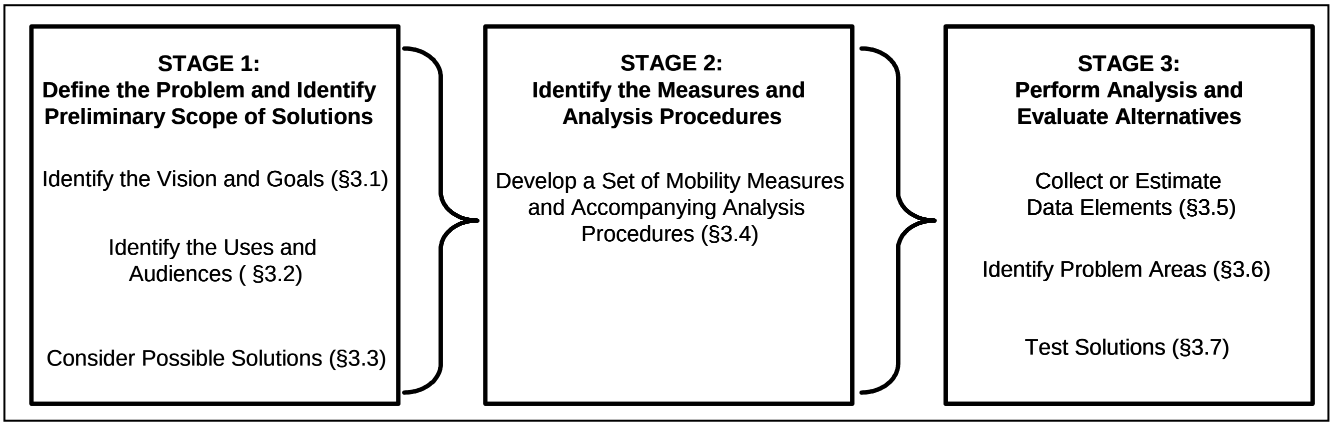
Measuring mobility is a task performed in a variety of ways in several different types of analysis for many purposes. While the measures are often dictated by legislative or regulatory mandates, it is useful to view the selection of the measure or measures as an important task before the data are collected and the estimation or calculation procedures begin. This chapter identifies key elements necessary for a complete mobility analysis. As with any process, the continuous evaluation of the process will lead to improvement—it is important to compare the measures with the uses throughout the process and adjust the measures as necessary. It is also important to recognize that there are many processes that relate to mobility measurement. The steps outlined in this chapter are part of many of those processes. Exhibit 3-1 provides an overview of the three-stage mobility analysis process. Each stage contains one to three considerations that are described in more detail in the sections identified in this chapter. For additional information on each of the sections described in this chapter, the reader is encouraged to review *Quantifying Congestion* (*1*).

3.1 Identify the Vision and Goals

The long-range plan for an area ideally contains a description of the situation that the public wishes to create. As an important element of that plan, transportation facilities must be analyzed and improvements (if any) identified. In order for the selected programs and projects to move the area toward the vision, the measures must identify the proper type and scale of transportation improvements.

A similar line of thinking applies at the individual level (e.g., street, bus route, or demand management program). While the improvement options may not be as broad, and the financial investment may not be as great, it is always instructive to think about possible outcomes before beginning the analysis. Not only will this ensure proper consideration of all options, it will also lead to selection of measures that can fairly evaluate the range of alternatives.

Exhibit 3-1. Illustration of Mobility Analysis Process.



It is this step where the expectations of the public and policy makers can be formulated into a set of statistics that can be used at the project or program evaluation level. The "agreed upon norms" (*1*) referred to in Chapter 2 can be used to make the link between broad outcome goals and the engineer, planner, economist, etc. who must evaluate the need for an improvement.

It is essential, therefore, that performance measures be consistent with the goals and objectives of the process in which they are being employed. Performance measures are key to controlling process outcome, whether the process is alternative selection, congestion management, growth management, or system optimization. For example, within congestion management, performance measures are used for problem identification and assessment, evaluation and comparison of alternative strategies, demonstration of effectiveness, and ongoing system monitoring.

3.2 Identify the Uses and Audiences

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

3.3 Consider Possible Solutions

Before measure selection and data collection begins, it is useful to reflect on the problem areas and consider possible solutions. Possible solutions include potential projects, operational programs, and policies. Understanding the possible solutions will help ensure that key considerations are vetted and understood as the measures and procedures are established in the next step. Can all the improvement types be included in the typical measures? Will the measures be able to illustrate the effect of the improvements? Are there aspects of the projects, programs, or policies that will not be covered by the measures? Are the measures understandable to all the audiences? Are the uses of the measures appropriate, and will the procedures yield reliable information? These questions should start to be considered at this stage and should be fully evaluated with prototype results of the analysis.

3.4 Develop a Set of Mobility Measures and Accompanying Analysis Procedures

Many analyses, especially multimodal alternatives or regional summaries, require more than one measure to describe the problem. Analyses of corridor improvements might require travel time and speed measures to be expressed in person and freight movement terms. Some analyses are relatively simple, and it may be appropriate to use only one measure. Analyses of traffic signal timing where carpool and bus treatments are not part of the improvement options might not require person movement statistics—vehicle volume and delay information may be sufficient.

Poor selection of measures has a high probability of leading to poor outcomes (*1*). In contrast, goals and objectives that are measured appropriately can guide transportation professionals to the best project, program, or strategy and can then check (using evaluation results) that the goals and objectives are best served by the solutions offered (*2*).

3.5 Collect or Estimate Data Elements

Data collection can proceed after an analysis of potential sources of information. The level of precision and statistical reliability must be consistent with the uses of the information and with the data collection sources. Estimates or modeling processes may be appropriate additions to traffic count, travel time, and speed data collection efforts. Statistical sampling procedures may be useful for wide area analyses, as well as for validating models and adapting them to local conditions. Direct data collection may be used from a variety of sources including specific corridor studies, real-time data collection, and annual surveys of travel time routes.

An areawide travel monitoring program will consist of both travel speed data collection and estimated speed information obtained from equations or models. The directly collected data may be more expensive to obtain; statistical sampling techniques will decrease the cost and improve the reliability of the information. It may be possible to focus the data collection on a relatively small percentage of the roadway system that is responsible for a large percentage of the travel delay. Such a program would be supplemented with travel time studies on a few other sections of road and estimation procedures on the remainder of the system.

3.6 Identify Problem Areas

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

3.7 Test Solutions

Testing the potential solutions against the mobility measures during the data collection process may improve the data collection effort and the ultimate results. After data collection and estimation are complete, testing the solutions for effect will be another chance to determine the need to modify mobility measures. Even after the analysis is complete, the measures should be evaluated before similar projects are performed. Inconsistencies or irregularities in results are sometimes a signal that different procedures or data are required to produce the needed products.

3.8 Summary of Implementing Mobility Measures

The use of a set of mobility measures may mean more computer-based analyses, which might be perceived as a move away from direct measurement for some levels of analysis. This does not mean that travel time data will be less useful or less cost-effective to collect. On the contrary, direct measurement of travel time can be used to not only quantify existing conditions, but also to calibrate wide-scale models of traffic and transportation system operation and to perform corridor and facility analyses. Incorporating the important process elements into a sequence of events leading up to a public discussion of alternative improvement plans might result in a series of steps like the following:

- Existing traffic and route condition data are collected directly.
- Measures are calculated.
- Results are compared to target conditions that are determined from public comments during long-range plan discussion.
- Trip patterns, areas, and modes that need improvement are identified.
- Solutions are proposed. Areawide strategies should guide the selection of the type and magnitude of specific solutions.
- A range of the amount and type of improvements is tested.
- Mobility measures are estimated for each strategy or alternative.
- Measures are compared to corridor, sub-area, and regional goals.
- Individual mode or facility improvements that fit with the areawide strategy are identified for possible inclusion in the plan, subject to financial analyses.

3.9 References

1. *NCHRP Report 398*. Quantifying Congestion—Final Report and User's Guide. National Cooperative Highway Research Program Project 7-13, National Research Council, 1997.

2. Deen, T.B., and Pratt, R. "Evaluating Rapid Transit." In *Public Transportation* by editors George E. Gray and Lester A. Hoel, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey, 1991.

CHAPTER 4—SELECTING MOBILITY MEASURES

Chapter Summary

The appropriate set of mobility measures will include several identifiable elements. This chapter identifies the important features as:

- Relate to goals and objectives,
- clearly communicate results to audiences,
- include urban travel modes,
- have consistency and accuracy,
- illustrate the effect of improvements,
- be applicable to existing and future conditions,
- be applicable at several geographic levels,
- use person- and goods-movement terms, and
- use cost-effective methods to collect and/or estimate data.

This chapter also identifies the four aspects of congestion to identify mobility levels. Information about the time, location, level, and reliability are needed to assess mobility for the range of analyses.

Given the wide range and diversity of available measures, it is important to have a clear basis for assessing and comparing mobility measures. Such an evaluation makes it possible to identify and separate measures that are useful for an analytical task from measures that are either less useful or inappropriate for certain analyses. It is important that every use of mobility measures be assessed in such a process. This chapter provides several considerations that can be used to identify the most appropriate mobility measure for a situation.

4.1 Choosing the Right Mobility Measure

The ideal mobility measurement technique for any combination of uses and audiences will include the features listed below (*1*). These issues should be examined before data are collected and the analysis begins, but after the analyst has considered all reasonable responses to the problem or issue being studied. Having an idea of what the possible solutions are will produce a more appropriate set of measures.

- **Relate to goals and objectives**—The measures must indicate progress toward transportation and land use goals that the project or program attempts to satisfy. Measuring transportation and land use characteristics that are part of the desired future condition will provide a continual check on whether the area is moving toward the desired condition.

- **Clearly communicate results to audiences—**While the technical calculation of mobility information may require complicated computer models or estimation techniques, the resulting information should be in terms the audience can understand and find relevant.

- **Include urban travel modes—**Mobility is often a function of more than one travel mode or system. At least some of the measures should contain information that can be calculated for each element of the transportation system. The ability to analyze the system, as well as individual elements, is useful in the selection of alternatives.

- **Have consistency and accuracy—**Similar levels of mobility, as perceived by travelers, should have similar mobility measures. This is important for analytical precision and also to maintain the perception of relevancy with the audiences. There should also be consistency between levels of analysis detail; results from relatively simple procedures should be similar to those obtained from complex models. One method for ensuring this is to use default factors for unknown data items. Another method is to frequently check expected results with field conditions after an improvement to ensure that simple procedures—those that use one to three input factors—produce reasonable values.

- **Illustrate the effect of improvements—**The improvements that may be analyzed should be consistent with the measures that are used. In relatively small areas of analysis, smaller urbanized areas, or portions of urban areas without modal options, this may mean that vehicle-based performance measures are useful. Using a broader set of measures will, however, ensure that the analysis is transferable to other uses.

- **Be applicable to existing and future conditions—**Examining the need for improvements to current operations is a typical use of mobility measures that can be satisfied with data collection and analysis techniques. The ability to relate future conditions (e.g., design elements, demand level, and operating systems) to mobility levels is also required in most analyses.

- **Be applicable at several geographic levels—**A set of mobility measures should include statistics that can illustrate conditions for a range of situations, from individual travelers or locations to subregional and regional levels. Using quantities that can be aggregated and averaged is an important element of these criteria.

- **Use person- and goods-movement terms—**A set of measures should include factors with units relating to the movement of people and freight. In the simplest terms, this means using units such as persons and tons. More complex assessments of benefits will examine the different travel patterns of personal travel, freight shipping, and the intermodal connections for each.

- **Use cost-effective methods to collect and/or estimate data—**Using readily available data or data collected for other purposes is a method of maximizing the usefulness of any data collection activities. Focusing direct data collection on significant problem areas may also be a tactic to make efficient use of data collection funding. Models and data sampling procedures can also be used very effectively.

4.2 The Ideal Mobility Measurement Process?

The best method to gather mobility information and user satisfaction data may be a survey conducted at the end of each trip. The survey would allow the traveler to rate the quality of the trip, both overall and for each facility or modal portion of the trip. Cost, time, and travel options could all be part of the survey. This would provide the transportation and land use professionals with a database they could match to system monitoring databases to identify potential causes of good and bad responses during the trip.

Freight shippers and manufacturers could be similarly surveyed about their use of the transportation system and its effect on their operations. These impacts may be more varied and require different surveying mechanisms. Processes such as just-in-time manufacturing and package delivery services have much different needs from the transportation system than some traditional activities. Just-in-time manufacturing is a method of delivering components to an assembly point at the moment they are required rather than having a large inventory of parts on hand at the factory. This has benefits in reduced warehouse space, reduced financial burden of inventory, and other efficiency impacts. This process, as it is with package delivery services, places great reliance on the transportation system to provide a reliable travel time. Longer travel times are an important issue, but the assembly process can be adjusted to accommodate them; it is more difficult or less efficient to accommodate variable travel times.

While surveys are certainly technologically possible now, and some are conducted, the amount of time needed to complete the survey could be longer than hurried travelers wish to take. If the method of obtaining the input and the time it would take could both be problems, does that make opinion gathering a bad idea? Not at all; the public—private citizens and businesses—pay for the transportation system and are the ultimate decision makers about the worth of a project.

One significant problem, however, is that transport facilities exist in segments or corridors (even telecommunications move in corridors of cable or airwaves) and person trips (and electronic trips to some extent) are made from an origin to a destination. This requires measuring the performance of specific facilities or groups of facilities, in addition to the trip characteristics.

Focusing on individual facilities or modes, however, is not consistent with the manner in which most travelers make their choices. Door-to-door travel time is closer to the primary measure used by travelers and is best described with accessibility measures. Unfortunately, it is difficult to translate an accessibility measure like “population within 30 minutes travel time of a major activity center” into a procedure to evaluate signal improvements on an arterial street or alternative transit service options in a corridor. Accessibility measures do a very good job of explaining the differences in opportunities available to residents and travelers in areas of a city. The transportation and land use planning model required to calculate accessibility measures may not be sensitive enough to identify the improvement in travel conditions from relatively modest improvements. The planner and designer, likewise, need to communicate with the public and businesses who, while they are interested in the jobs and customers that may be within easy traveling distance, also wish to know how the travel time to their destinations will change.

4.3 The Data Collection Issue

Concerns about the cost and feasibility of collecting travel time data are frequently the first issue mentioned in discussions of mobility measures. There are many ways to collect or estimate the travel time and speed quantities; data collection should not be the determining factor about which measures are used. While it is not always possible to separate data collection issues from measure selection, this should be the goal. Chapters 5 and 7 discuss data collection in more detail.

4.4 Aspects of Mobility

The proper set of mobility measures includes an assessment of what traveler concerns are characterized. This assessment can be drawn from experiences with measuring congestion in roadway systems. A set of four aspects of congestion was discussed at the Workshop on Urban Congestion Monitoring (*2*) in May 1990 as a way to begin formulating an overall congestion index. These four components provide a useful framework for mobility estimation procedures as well.

Summarizing Congestion Effects Using Four General Components

While it is difficult to conceive of a single value that will describe all of the travelers' concerns about congestion, there are four components that interact in a congested roadway or system (*2*). These components are duration, extent, intensity, and variation. They vary among and within urban areas. Smaller urban areas, for example, usually have shorter duration, than larger areas, but many have locations with relatively intense congestion.

The four components and measurement concepts that can be used to quantify them are discussed below. They use the definitions of congestion and mobility used in this paper. The data elements and measures associated with each concept are discussed in Chapter 5.

- **Duration—**This is defined as the length of time during which congestion affects the travel system. The peak hour has expanded to a peak period in many corridors, and mobility studies have expanded accordingly. The measurement concept that illustrates duration is the amount of time during the day that the travel speed indicates congested travel on a system element or the entire system. The travel speed might be obtained in several ways depending on data sources or travel mode being studied.

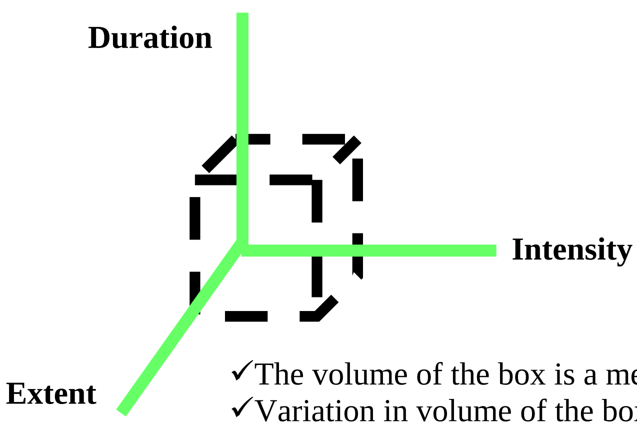
- **Extent—**This is described by estimating the number of people or vehicles affected by congestion and by the geographic distribution of congestion. The person congestion extent may be measured by person-miles of travel or person-trips that occur during congested periods. The percent, route-miles, or lane-miles of the transportation system affected by congestion may be used to measure the geographic extent of mobility problems.

- **Intensity**—The severity of congestion that affects travel is a measure from an individual traveler's perspective. In concept, it is measured as the difference between the desired condition and the conditions being analyzed.

- **Variation**—This key mobility component describes the change in the other three elements. Recurring delay (the regular, daily delay that occurs due to high traffic volumes) is relatively stable. Delay that occurs due to congestion and vehicle breakdowns, however, is less easy to predict. The variation in travel time is a factor that conceptually can be measured as a standard deviation from the average travel time.

The relationship among the four components may be thought of as a three-dimensional box describing the magnitude of congestion. Exhibit 4-1 illustrates three dimensions—duration, extent and intensity—of congestion. These present information about three separate issues: 1) how long the system is congested, 2) how much of the system is affected, and 3) how bad the congestion problem is. The variation in the size of the box from day to day is a measure of variability or reliability.

Exhibit 4-1. The Components of Congestion.



✓The volume of the box is a measure of the magnitude of congestion.
✓Variation in volume of the box is a separate measure of congestion.
Note: Smaller volume is better.

4.5 Summarizing the Aspects of Mobility

Developing a summary of mobility using concepts similar to those used for congestion will ensure that the appropriate measures are used. A similar typology uses different terms; there is a "positive" tone in the phrasing of the definitions and a slightly different orientation from congestion, but the aspects are basically the same. The image of a box is also appropriate to the description of the amount of mobility provided by a transportation and land use system. The axes are time, location, and level. Reliability is now the change in box volume.

- **Time—**The time that mobility is provided or available is an expression of the variation of mobility through the day, week, or year. It can be a function of the existence of congestion or the presence of transit service, operational improvements, or priority treatments. It can be measured as the times when travelers can get to their destinations in satisfactory travel times.

- **Location—**The places or trips for which mobility is available is an important aspect of measurement for transportation and land use analyses, as well as for other issues such as economic development and social equity. It can be described by accessibility maps and statistics and travel time contours that illustrate the areas that can be traveled to in a certain period of time. Descriptions of transit routes or special transportation services can also be used to identify locations where mobility is possible by more than private auto modes.

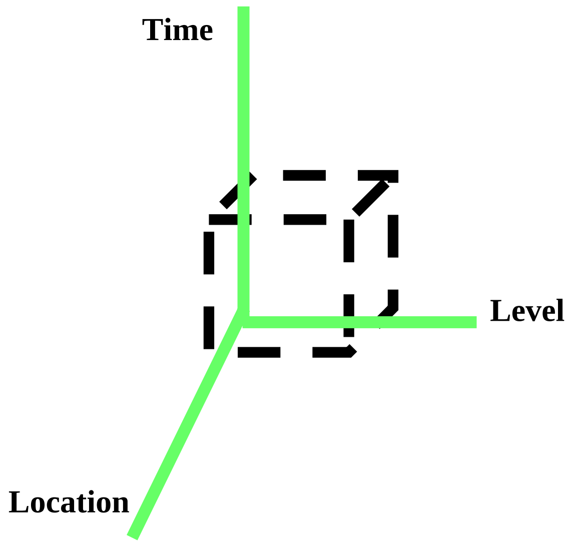
- **Level—**The amount of mobility provided is analogous to the intensity of congestion. The amount of time it takes to travel to a destination and whether this is satisfactory are the key elements of the level of mobility. It can be measured with travel rates or accessibility statistics.

- **Reliability—**The changing times, locations, and levels of mobility are important characteristics for mobility measurement. This is particularly important to freight movement operations that rely on the transportation system as an element of their productivity and to measuring the frustration level of travelers faced with an unexpected loss of mobility.

The total amount of mobility provided to travelers in an area is the volume of a box with axes of time, location, and level. The reliability of the mobility provided to travelers and residents is the change in the volume of the box from time period to time period or from day to day. Exhibit 4-2 illustrates the description of mobility with the four aspects. These answer the key questions of travelers and residents: 1) When can I travel in a satisfactory amount of time? 2) Where can I travel in a satisfactory amount of time? 3) How much time will it take? 4) How much will my travel time vary from trip to trip?

Answering the key questions with measures of the four components of mobility will encompass the needs of residents and travelers as well as transportation and land use professionals.

Exhibit 4-2. The Components of Mobility.



✓The volume of the box is the amount of mobility provided.
✓A change in volume of the box indicates the reliability of the mobility system.
Note: Larger volume is better.

4.6 References

1. *NCHRP Report 398*. Quantifying Congestion—Final Report and User's Guide. National Cooperative Highway Research Program Project 7-13, National Research Council, 1997.

2. *Summary and Recommendations of the Workshop on National Urban Congestion Monitoring*. U.S. Department of Transportation, Federal Highway Administration, Office of Highway Information Management, Report No. FHWA-PL-90-029, September 1990.

CHAPTER 5—RECOMMENDED MOBILITY MEASURES AND DATA ELEMENTS

Chapter Summary

Travel time and speed are key elements in assessing the performance of the transportation system and for evaluating land use pattern changes. A wide range of mobility solutions are typically pursued for a variety of reasons. This chapter describes the measures and quantities that illustrate the effect of the spectrum of solutions on travelers using travel time-based measures. It also identifies the data elements needed to estimate or calculate the measures.

A system of mobility measures should be developed only after an examination of the uses and audiences to be served, the full consideration of program goals and objectives, and the nature of likely solutions. This chapter illustrates a system of travel time-based measures to estimate mobility levels. These procedures are useful for roadway systems, person and freight movement modes, and transportation improvement policies and programs. Although a number of analyses may not benefit from a broad focus, the user should consider the way that measures might be used before selecting the appropriate set of mobility measures.

The following sections describe techniques for measuring mobility on various portions of a transportation network (*1*). Many of the definitions used in this chapter were included in *Quantifying Congestion* (*1*) and the first version of *The Keys to Estimating Mobility in Urban Areas* (*2*).

5.1 Individual Measures

Travel time, speed, and rate quantities are somewhat more difficult to collect and may require more effort than the traffic volume counts that currently provide the basis for most roadway analysis procedures. Travel speed-related measures can, however, be estimated as part of many analysis processes currently used. The ultimate implementation of a set of time-related mobility measures in most urban areas will probably rely on some estimating procedures along with archived data. These measures may include current *Highway Capacity Manual*-based analysis techniques, vehicle density measures estimated from detectors in the pavement or from aerial surveys or relationships that estimate travel rate, or speed from generally available volume and roadway characteristics. The use of estimating procedures will be particularly important in setting policy and the prioritization of transportation improvement projects, pavement designing, responding to developer requests for improvement, and performing many other analyses.

This section describes the measurements that form the basis for the mobility analyses illustrated in subsequent sections of this paper. The focus of this section is those measures most applicable to the individual traveler. The mobility aspects and geographic areas that can be analyzed with the measure are summarized after the measures are presented. Summarizing the mobility aspects and geographic areas illustrates the flexibility of mobility measures based on time and person or freight movement. The application of the mobility measures will often satisfy two of the three "axis aspects" (level, location, and time) shown in Exhibit 4-2.

The total delay (in person- or vehicle-hours) for a transit or roadway segment is the sum of time lost due to congestion. Delay can be expressed as a value relative to free-flow travel or relative to the posted speed limit. Total delay in a corridor or an urban area is calculated as the sum of individual segment delays. This quantity is used as an estimate of the impact of improvements on transportation systems. The values can be used to illustrate the effect of major improvements to one portion of a corridor that affects several other elements of the corridor. The quantity is particularly useful in economic or benefit/cost analyses that use information about the magnitude of the mobility improvement for cost-effectiveness decisions. Equation 5-1 shows the computation of delay in person-hours. In addition, using a delay measure of hours per mile of road, hours per 1,000 miles traveled, or hours per 1,000 travelers might be more meaningful to agencies at the corridor level, but the public may not understand these measures since it is difficult to relate to key decisions or travel experience.

$$\begin{matrix}\textit{Total Delay}\\(\textit{person–hours})\end{matrix}=\left[\begin{matrix}\textit{Actual}\\\textit{Travel Time}\\(\textit{minutes})\end{matrix}-\begin{matrix}\textit{FFS or PSL}\\\textit{Travel Time}\\(\textit{minutes})\end{matrix}\right]\times\begin{matrix}\textit{Vehicle Volume}\\(\textit{vehicles})\end{matrix}\times\begin{matrix}\textit{Vehicle Occupancy}\\(\textit{persons/vehicle})\end{matrix}\times\frac{\textit{1 hour}}{\textit{60 minutes}}\quad\text{(Eq. 5-1)}$$

The delay per person or delay per peak period traveler (in daily minutes or annual hours) can be used to reduce the travel delay value to a figure that is more useful in communicating to non-technical audiences. It can normalize the impact of mobility projects that handle much higher person demand than other alternatives. Delay for the primary route or road, in these alternatives, may be higher due to this higher volume, but this also indicates the need to examine the other facilities or operations within the corridor included in the "before" case. To the extent possible, the initial analysis should include as much of the demand that might move to the improved facility, route, or road.

The travel Time Index (TTI) is a dimensionless quantity that compares travel conditions in the peak period to travel conditions during free-flow or posted speed limit conditions. For example, a TTI of 1.20 indicates that a trip that takes 20 minutes in the off-peak period will take 24 minutes in the peak period or 20 percent longer. TTI reflects travelers' perceptions of travel time on the roadway, transit facility, or other transportation network element. This comparison can be based on the travel time increases relative to free-flow conditions (or the posted speed limit) and compared to the target conditions. Thus, the same index formula can be applied to various system elements with different free-flow or posted speeds. Travel rate (in minutes per mile) is a direct indicator of the amount of travel time, which makes it relevant to travelers.

The measure can be averaged for freeways and arterial streets using the amount of travel on each portion of the network. An average corridor value can be developed using the number of persons using each facility type (or modes) to calculate the weighted average of the conditions on adjacent facilities. The corridor values can be computed for hourly conditions and weighted by the number of travelers or person-miles traveled to estimate peak period or daily index values.

The Travel Time Index in Equation 5-2 compares measured travel rates to free-flow or posted speed limit conditions for any combination of freeway and arterial streets. Index values can be related to the general public as an indicator of the length of extra time spent in the transportation system during a trip. Equation 5-2 illustrates a relatively simple version of the calculation using VMT, but PMT could also be used, as could a value of time calculation that incorporates person and freight travel.

$$\text{Travel Time Index} = \frac{\left[\dfrac{\text{Freeway Travel Rate}}{\text{Freeway Free-flow or Posted Speed Limit Rate}} \times \text{Freeway Peak Period VMT}\right] + \left[\dfrac{\text{Principal Arterial Street Travel Rate}}{\text{Principal Arterial Street Free-flow or Posted Speed Limit Rate}} \times \text{Principal Arterial Street Peak Period VMT}\right]}{\text{Freeway Peak Period VMT} + \text{Principal Arterial Street Peak Period VMT}} \quad \text{(Eq. 5-2)}$$

The travel Rate Index (TRI) is similar to the TTI in that it is also a dimensionless quantity that compares travel conditions in the peak period to travel conditions during free-flow or posted speed limit conditions. However, the TTI includes incident conditions while the TRI does not. Continuous data streams allow for the direct measurement of a TTI that includes incidents. For some applications, incident conditions would not be included. For example, when travel time runs are performed for a corridor study, those runs that are affected by incident conditions are normally removed. This provides an estimate of the non-incident travel time along the corridor. In these conditions, the computed measure would not be a TTI, but rather a TRI. The TRI measure is computed in the same way as the TTI but does not include incident conditions. A typical application of the TRI would be calculating congestion levels from the travel demand planning model because incident conditions are not considered.

The Buffer Index (BI) is a measure of trip reliability that expresses the amount of extra "buffer" time needed to be on time for 95 percent of the trips (e.g., late for work on one day per month). Indexing the measure provides a time- and distance-neutral measure, but the actual minute values could be used by an individual traveler for a particular trip length or specific origin-destination pair. With continuous data, the index is calculated for each road or transit route segment, and a weighted average is calculated using vehicle-miles or, more desirably, person-miles of travel as the weighting factor. Travel rates for approximately 5-mile sections of roadway provide a good base data element for the performance measure. The Buffer Index can be calculated for each road segment or particular system element using Equation 5-3. Note that a weighted average for more than one roadway section could be computed using VMT or PMT on each roadway section. The measure would be explained as "a traveler should allow an extra BI percent travel time due to variations in the amount of congestion delay on that trip."

$$\text{Buffer Index}(\%) = \left[\frac{\underset{(minutes)}{\text{95th Percentile Travel Time}} - \underset{(minutes)}{\text{Average Travel Time}}}{\underset{(minutes)}{\text{Average Travel Time}}} \right] \times 100\% \qquad \text{(Eq. 5-3)}$$

The buffer time concept appears to relate particularly well to the way travelers make decisions. Conceptually, travel decisions proceed through questions such as: "How far is it?" "When do I need to arrive?" "How bad is the traffic?" "How much time do I need to allow?" "When should I leave?" In the "time allowance" stage, there is an assessment of how much extra time has to be allowed for uncertainty in the travel conditions. This includes weather, incidents, construction zones, holiday or special event traffic, or other disruptions or traffic irregularities.

5.2 Area Mobility Measures

The mobility measures described in the previous section mainly relate to the individual traveler. The measures described in this section are area measures where the area may be a corridor or region.

Congested travel is a measure that captures the extent of congestion. It estimates the extent of the system that is affected by the congestion. Equation 5-4 illustrates the computation of congested travel in vehicle-miles as the product of the congested segment length and the vehicle volume summed across all congested segments.

$$\underset{(vehicle\text{ - }miles)}{\text{Congested Travel}} = \sum \left(\begin{matrix}\text{Congested}\\ \text{Segment Length}\\ (miles)\end{matrix} \times \underset{(vehicles)}{\text{Vehicle Volume}} \right) \qquad \text{(Eq. 5-4)}$$

The percent of congested travel is an extension of the congested travel measure. It also measures the extent of congestion. When speed and occupancy data are available for each roadway segment, this measure can be computed. It is computed as the ratio of the congested segment person-hours of travel to the total person-hours of travel. Equation 5-5 shows the computation.

$$\begin{matrix}\text{Percent}\\ \text{of}\\ \text{Congested}\\ \text{Travel}\end{matrix} = \left[\frac{\sum_{i=1}^{m} \left(\left(\begin{matrix}\text{Actual}\\ \text{Travel}\\ \text{Time}_i\\ (minutes)\end{matrix} - \begin{matrix}\text{FFS or PSL}\\ \text{Travel}\\ \text{Time}_i\\ (minutes)\end{matrix} \right) \times \left(\begin{matrix}\text{Vehicle}\\ \text{Volume}_i\\ (vehicles)\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Occupancy}_i\\ (persons/vehicle)\end{matrix} \right) \right)_{\text{Each congested segment}}}{\sum_{i=1}^{n} \left(\begin{matrix}\text{Actual Travel Rate}_i\\ (minutes\ per\ mile)\end{matrix} \times \begin{matrix}\text{Length}_i\\ (miles)\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Volume}_i\\ (vehicles)\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Occupancy}_i\\ (persons/vehicle)\end{matrix} \right)_{\text{All segments}}} \right] \times 100 \qquad \text{(Eq. 5-5)}$$

Congested roadway is another measure of the extent of congestion. It is the sum of the mileage of roadways that operate under free-flow or posted speed limit conditions. This is shown in Equation 5-6.

$$\begin{matrix} Congested\ Roadway \\ (miles) \end{matrix} = \sum \begin{matrix} Congested\ Segment \\ Lengths\ (miles) \end{matrix} \quad \text{(Eq. 5-6)}$$

Accessibility is a measure that often accompanies mobility measures. It quantifies the extent that different opportunities can be realized. These might be accessibility to jobs, a transit station, or other land use or trip attractor of interest. Accessibility is satisfied if the travel time to perform the desired activity is less than or equal to the target travel time as indicted in Equation 5-7.

$$\begin{matrix} Accessibility \\ (opportunities) \end{matrix} = \begin{matrix} \sum Objective\ Fulfillment\ Opportunities \\ (e.g., jobs), Where \\ Travel\ Time \leq Target\ Travel\ Time \end{matrix} \quad \text{(Eq. 5-7)}$$

Exhibit 5-1 summarizes key characteristics of the primary mobility measures described in this section.

Exhibit 5-1. Key Characteristics of Mobility Measures.

Performance Measure	Congestion Component Addressed[1]	Geographic Area Addressed
Delay per traveler	Intensity	Region, Sub-area, Section, Corridor
Travel Time Index	Intensity	Region, Sub-area, Section, Corridor
Buffer Index	Intensity	Region, Sub-area, Section, Corridor
Total delay	Intensity	Region, Sub-area, Section, Corridor
Congested travel	Extent, Intensity	Region, Sub-area
Percent of congested travel	Duration, Extent, Intensity	Region, Sub-area
Congested roadway	Extent, Intensity	Region, Sub-area
Accessibility	Extent, Intensity	Region, Sub-area

[1]See Exhibit 4-1.

5.3 Basic Data Items

This section describes the basic data elements used to define mobility measures. The units are noted for typical urban analyses.

The travel time (in minutes) is the time required to traverse a segment or complete a trip. Times may be measured directly using field studies or archived data from traffic management centers, or can be estimated using empirical relationships with traffic volume and roadway characteristics, computerized transportation network models, or the projected effects of improvements.

The segment or trip length (in miles) is the distance associated with the travel time. Length can be measured directly with a vehicle odometer or scaled from accurate maps but is typically an established item in a transit or roadway inventory database.

The average speed (in miles per hour) for a segment can be used to calculate travel rate or travel times if field data are not readily available.

The average travel rate (in minutes per mile) is the rate at which a segment is traversed or a trip is completed (Equation 5-8). Travel rates may be determined directly using travel time field studies, or can be estimated using transit schedules or empirical relationships (e.g., Bureau of Public Roads formula) between traffic volume and roadway characteristics (e.g., capacity).

$$\underset{(\textit{minutes per mile})}{\textit{Travel Rate}} = \frac{\underset{(\textit{minutes})}{\textit{Travel Time}}}{\underset{(\textit{miles})}{\textit{Segment Length}}} = \frac{60}{\underset{(\textit{mph})}{\textit{Average Speed}}} \qquad \text{(Eq. 5-8)}$$

The person volume is the number of people traversing the segment being studied. The person volume can be collected for each travel mode or estimated using average vehicle occupancy rates for types of vehicles.

The freight volume is the amount of goods moved on a transport segment or system. It can be measured in units of ton-miles, or it can be estimated from truck percentages. Freight volume may be particularly important in analyses dealing with travel time reliability due to the sensitive nature of "just-in-time" manufacturing processes and goods delivery services.

The person-miles of travel is the magnitude of travel on a section of the transportation system or on several elements of the system. It is a particularly useful measure in corridor and areawide analyses where total travel demand is used in calculations. Equation 5-9 indicates it is the product of distance and person volume. Person volume can be estimated as the product of vehicle volume and average vehicle occupancy.

$$\underset{\textit{of Travel (PMT)}}{\textit{Person-miles}} = \underset{(\textit{people})}{\textit{Person Volume}} \times \underset{(\textit{miles})}{\textit{Distance}} \qquad \text{(Eq. 5-9)}$$

The target travel time (in minutes) is the time that indicates a system or mode is operating according to locally determined performance goals. It focuses on the "door-to-door" trip time from origin to destination. The target travel time can be differentiated by the purpose of the travel, the expectation for each mode within the transportation system, the type of activity, and the time of day. It should be influenced by community input, particularly on the issue of the balance between transportation quality, economic activity, land use patterns, and environmental issues.

The target travel rate (in minutes per mile) is the maximum rate (slowest speed) at which a segment is traversed or a trip is completed without experiencing an unsatisfactory level of mobility. The target travel rate is based on factors similar to the target travel time. This is similar to the process used by many states and cities where a target level of service (LOS) is used to determine the need for additional transportation improvements.

In practice, there will also be a need for a corridor average travel rate value. This would be used as the target for facility expansions, operating improvements, program enhancements, or policy implementations. The facility/mode target travel rates can be used for evaluation, but improvement strategies and amounts should be based on corridor-level decisions.

5.4 Definition and Discussion of Speed Terms

Several speed terms are used in this paper and in the mobility analysis examples. This section provides definitions of primary speed measures and guidance on their use in mobility analyses.

Free-flow speed is the average speed that can be accommodated under relatively low traffic volumes (i.e., no vehicle interactions) on a uniform roadway segment under prevailing roadway and traffic conditions. It can be calculated or estimated in a number of ways, with a common approach being to use the 85th percentile speed in the off-peak period. The off-peak periods can be defined by time period (e.g., overnight—10 p.m. to 6 a.m., or midday—9 a.m. to 4 p.m.) or vehicle volume. Vehicle headways of 5 seconds or more could be used to define free-flow speed operating conditions (i.e., traffic volumes of approximately 700 vehicles per hour per lane [vphpl]). Ideally, a continuous data source (e.g., ITS, Weigh in Motion [WIM], Automatic Traffic Recorder [ATR], etc.) could be used to identify the free-flow speed using at least one year of valid data.

The posted speed limit is the posted speed of the roadway. For specific facilities, or sections thereof, this value is obtained by field data collection. Posted speed is a typical roadway inventory data element; therefore, posted speeds can be obtained from such roadway inventories, particularly for a system-level analysis that includes numerous facilities.

Target speed is the speed associated with the target Travel Time Index. The target speed can be computed given the target Travel Time Index and the free-flow travel rate or the posted speed limit travel rate.

5.4.1 Threshold Speed Values

Many analyses begin with the question, “What should we compare to?” The issue usually can be framed as a choice between using a desirable condition or using an achievable condition given the funding, approval, and other constraints.

It should be noted that posted speed limits are included in most roadway inventory files and should be readily available for analytical procedures. Computerized analysis procedures should be modified so that a “negative delay” value is not included in the calculations (as done in the examples in this report). If estimated free-flow speeds are used in the calculation of delay, the speed data collected from field studies may include values with very fast speeds (above the free-flow speed). Free-flow speeds that are higher than the posted speed limit may present an “illegal appearance” problem when used in public discussions. In addition, it may be difficult to justify delay being calculated for travel at the posted speed limit.

5.4.2 When Would I Use Free-flow Speed in Mobility Measure Computation?

Delay and congestion index measure computations can be computed relative to free-flow speed. Using free-flow speed for these computations is most appropriate when continuous data sources are available that allow for the computation of the 85th percentile speed in the off-peak period. The use of a free-flow speed provides an automated and consistent method for computing delay and index values across different metropolitan areas. The free-flow speed could also be used when the analyst does not have ready access to posted speeds along the corridors included in a mobility analysis—particularly large areawide analyses.

5.4.2 When Would I Use a Posted Speed Limit in Mobility Measure Computation?

The posted speed limit can also be used to compute delay and index measures. The posted speed limit can be used when continuous data are not available for the mobility analysis. Posted speed limits are an easy to communicate threshold, are more stable than free-flow speeds, and do not require "value" judgments of assessments of goals or targets.

5.4.3 How Does the Target Travel Time Index Relate to the Computed Measures?

The target Travel Time Index values would be developed with input from citizens, businesses, decision makers, and transportation professionals. The target values represent the crucial link between, 1) the vision that the community has for its transportation system, land uses, and its "quality of life" issues and 2) the improvement strategies, programs, and projects that government agencies and private sector interests will implement. The values are desirably the result of a process that is integrated with the development of the long-range plan, but they must be reasonable and realistic since overstatement or understatement could distort congestion assessment.

Urban areas should approach the use of a target Travel Time Index with a corridor and system strategy. The target value may be developed for every mode or facility as a way to identify individual performance levels, but the key application will be as a corridor or system target. Individual facility "deficiencies" can be addressed through improvements to that mode or route or by other travel mode improvements, strategies, or policies. For example, the freeway mainlanes may not satisfy the target value, but if an HOV lane is successful in moving a large number of people at high speeds, the average Travel Time Index, when weighted by person volume, may achieve the target value.

The target Travel Time Index value can be "adjusted" appropriately irrespective of whether a free-flow speed or a posted speed limit is used in the calculation of the TTI. For example, if free-flow speed is used, the target TTI value might be 1.4, whereas the target TTI value might be 1.3 if the posted speed limit is used.

5.4.5 Summary and Guidance

In summary, free-flow speed is better for matching how people drive given the roadway operating conditions (i.e., "I was 5 mph over the posted speed limit, and I was still being passed"). Posted speed limits are sometimes set for public policy reasons, rather than being tied to actual conditions. This fact makes comparisons between regions and comparisons over several years difficult. Posted speed limits could go down, reducing the apparent "delay," and yet if peak period speeds declined, which should show more congestion, there could be less delay.

These considerations should be evaluated when determining the appropriate reference (free-flow speed or posted speed limit) in delay and index computations for the community and stakeholders involved with the analysis.

5.5 Other Data Elements

There are several other factors that are needed to perform mobility analyses including the following:

Hourly volumes, expressed in vehicles or persons, may be very useful for the peak-period or 24-hour periods. Many roadway and transit analyses focus on the peak hour, but in most large cities this is not enough information to assess the mobility situation or to analyze alternatives. A range of improvements, including demand management, advanced traveler information systems, and high-occupancy vehicle lanes, have an effect on other hours in the peak period.

The daily volume variation is the variability in person or vehicle volume from day to day. These data are particularly important in analyses that examine mobility levels on particularly heavy volume days (e.g., Fridays or days before holidays) or days/time periods with different travel patterns (e.g., special events or weekends).

Incident information includes the number and duration of crashes and vehicle breakdowns that occur on roadway segments and transit routes. This information is used in analyses of the variation in mobility level. The reliability of transport systems is a particular concern in analyses of incident management programs, value pricing projects, and freight movement studies.

Weather information can explain a significant amount of the variation in travel conditions. Snow, ice, fog and rain can be noted in a database used for mobility analysis.

Road work information includes construction activities and their location. This includes the location, number of lanes affected, and time period.

Peak direction hourly travel demand and volume are two measures of person or vehicle travel used in system analyses. The two may be the same for uncongested corridors. Demand is higher than volume in congested corridors, however, and the “excess” volume travels on the main route in hours adjacent to the peak hour and on alternate routes. Improvements to primary routes or travel modes may result in higher traffic volumes in the peak hour that can be predicted if demand is estimated.

5.6 Time Periods for Analysis

5.6.1 Peak and Off-peak Period Analysis

The peak period is the time period most often used for urban mobility analysis. Off-peak periods may be of interest to study the extent of peak spreading at one area compared to another area. The TTI is computed relative to the free-flow speed or posted speed limit. If the analyst is investigating the TTI of an off-peak period that is beginning to experience congestion, the TTI could be used to illustrate the increased congestion if the actual travel rate during the off-peak is higher than the target value. The BI and delay measures could also be useful in the off-peak period in locations that may be experiencing some congestion in the off-peak.

5.6.2 Daily Analysis

Analysis using daily averages is often less useful with the TTI and BI. Using 24-hour speeds for computing the TTI is not meaningful because the measure is meant to compare peak and off-peak travel conditions. Likewise, the BI is intended to be a measure of reliability during a peak period. Daily values "wash out" the impact of peak-periods with the longer off-peak periods. Total delay is more meaningful as a daily congestion measure. Though the total delay in person- or vehicle-hours is less meaningful to an individual driver, it is a good measure for analyzing trends from year to year. Daily delay is used in the Federal Highway Administration-sponsored Mobility Monitoring Program (MMP) (*3*) in this manner.

5.6.3 Seasonal Analysis

Investigating the seasons of the year may also be of interest. Many areas have unique peaking characteristics due to seasonal events (e.g., academic calendars, sporting events, and tourism). These activities can alter the length and extent of the peak period. All of the measures discussed in this chapter can be used in a mobility analysis that compares peak or off-peak period measure changes by month of year.

5.6.4 Urban or Rural Analysis

The discussion above has assumed an urban mobility analysis. Rural locations can also be the subject of mobility analyses. For example, there might be an interest in freight movements in rural areas. Special events and tourism activities are also situations that may generate interest in a rural analysis.

As mentioned previously, continuous data sources provide speed (travel time), volume, and classification information in some urban areas. Point-to-point travel time information is also of interest for rural freight operations. As with travel conditions on an urban congestion map, such point-to-point travel time information would allow insight into rural freight operations. Transponders could be used to provide the continuous information. The University of Washington is investigating such applications in rural areas in the state of Washington. Of the primary measures discussed in this document, TTI and delay measures could be used for this rural application. The TTI could be used to compare current travel rates to a target travel rate for goods movement over the corridor of interest. If continuous data sources are available (e.g., toll tags or cellular telephone), the BI could also be computed for freight carriers. Prior to real-time systems, estimation measures could be used to estimate delay for goods movement.

Special events and tourism may also invite mobility analysis in a rural area. If real-time equipment is already installed, it could be used to obtain travel rate information to compare to a target travel rate. Delay could also be computed. For a special event, and possibly for a tourism activity/season, portable readers could also be installed to monitor mobility along rural corridors of interest.

5.7 The Right Measure for the Analysis Area

Exhibit 5-2 summarizes the mobility measures that should be used for several types of analyses and for different size areas or modal combinations (*1*,*4*). Individual traveler measures such as travel rate and the travel rate index are very useful for analysis up to the corridor level. At higher levels of analysis, magnitude statistics such as delay and accessibility are useful, but there is also a role for communication methods such as the travel rate index. Examples of the application of these measures to situations based on the level of analysis are included in following sections.

Exhibit 5-2. Recommended Mobility Measures for Analysis Levels.

	Mobility Measures									
Analysis Area	**Travel Time**	**Travel Rate**	**Delay per Traveler**	**Travel Time Index**	**Buffer Index**	**Total Delay**	**Congested Travel**	**Percent of Congested Travel**	**Congested Roadway**	**Accessibility**
Individual locations	S		P	P	P	P				
Short roadway sections	P	P	P	P	P	P				
Long roadway sections, transit routes or trips		S	P	P	P	P				
Corridors		S	S	P	P	P				S
Sub-areas		S		P	P	P	P	P	P	P
Regional networks		S		P	P	P	P	P	P	P
Multimodal analyses		S	S	P	P	P				P

Note: P = Primary mobility measure
S = Secondary mobility measure
Note: Measures with delay components can be calculated relative to free-flow or posted speed conditions.
Source: Adapted from NCHRP (*1*) and R. Ewing (*4*)

Most mobility studies should be conducted at geographic areas higher than individual locations and short sections of roadway. At relatively small areas the studies will typically be limited to near-term analysis of operational improvements where new modes or facilities are not realistic options and even the operational improvements will be limited. These analyses may proceed using *Highway Capacity Manual*-type procedures. Total delay, delay per person, and travel time difference are most useful for intersections or individual locations due to problems identifying the length needed for the rate-based measures.

Larger scale analyses, where more detailed analytical tools are used and a wider choice of improvement options is considered, are more frequently identified as mobility studies. The analysis and presentation of mobility data can be accomplished by the travel time index, travel rate index, total delay, and accessibility as primary measures. Secondary measures may also be used for cumulative analyses of several improvements and estimation of benefits.

Mobility for larger areas of analysis, such as long roadway sections and corridors can be quantified with some individual statistics if the roadways are of the same type. But if freeways, streets, and/or other travel modes are included, cumulative statistics and the travel rate index are very appropriate. Index statistics become useful at this higher level of analysis when multiple roadways and large numerical values make interpretation of relative conditions difficult.

5.8 The Right Measure for the Type of Analysis

The recommended uses in Exhibit 5-3 are another illustration of how the mobility measures vary by the scope of the analysis, but not by mode or facility included in the analysis (*1*,*4*). Travel time and speed measures, and the data and estimating techniques used to create them are very flexible analysis tools. When combined with person and freight movement quantities, they illustrate a range of mobility situations. Different values will be used for the target travel rate or target travel time depending on the facility type or travel mode, but the calculation and application of the measures are identical.

While it is difficult to cover every type of mobility analysis, Exhibit 5-3 illustrates recommended measures for many common types of studies and information requirements. As with Exhibit 5-2, the analyses where small areas are analyzed or quick answers are needed use simple measures. More complex analyses, those that typically cover larger areas or multiple modes and those targeting non-technical audiences, use index measures and summary statistics.

Exhibit 5-3. Recommended Mobility Measures for Various Types of Analyses.

	Mobility Measures									
Uses of Mobility Measures	**Travel Time**	**Travel Rate**	**Delay per Traveler**	**Travel Time Index**	**Buffer Index**	**Total Delay**	**Congested Travel**	**Percent of Congested Travel**	**Congested Roadway**	**Accessibility**
Basis for government investment or policies			P	P	P	P	P	P	P	P
Basis for national, state, or regional policies and programs			P	P	P	P	P	P	P	P
Information for private sector decisions	P	P	S	P	P	S	P	P	P	
Measures of land development impact	P	P	P	P	P	P	S	S	S	P
Input to zoning decisions	P	P		P	P					P
Inputs for transportation models	P	P			P					
Inputs for air quality and energy models	P	P	P		P					
Identification of problems	P	P	P	P	P	S	S	S	S	
Base case (for comparison with improvement alternatives)			S	P	P	P	S	S	S	P
Measures of effectiveness for alternatives evaluation		P	P	P	P	P	S	S	S	P
Prioritization of improvements			P	P	P	P				S
Assessment of transit routing, scheduling, and stop placement	P	P	P	P	P	S				
Assessment of traffic controls, geometrics, and regulations	P	P			P					
Basis for real-time route choice decisions	P	P	P	P	P					

Note: P = Primary mobility measure
S = Secondary mobility measure

Source: Adapted from NCHRP (*1*)

5.9 Index Measure Considerations

5.9.1 How Much Congestion is OK?

Analyses of system adequacy, the need for improvements, or time-series analyses conducted in a corridor or area can benefit from comparisons using “target” conditions.

Free-flow conditions will not be the goal of most large urban transportation improvement programs, but using them provides one consistent benchmark relevant for year-to-year and city-to-city comparisons. The “attainment of goals” standard might also be used at the national or state level, but more often during a discussion of planning and project prioritization techniques.

The use of a “target” travel rate can improve the guidance provided to system planners and engineers. If the target travel rates are a product of public discussion, they will illustrate the balance that the public wishes to have between road space, social effects, environmental impacts, economic issues, and quality of life concerns. Areas or system elements where the performance is worse than the target can be the focus of more detailed study. A corridor analysis, for instance, might indicate a problem with one mode, but the solution may be to improve another mode or program that is a more cost-effective approach to raising the corridor value to the target. The amount of corridor or areawide person-travel that occurs in conditions worse than the locally determined targets can be used to monitor progress toward transportation goals and identify problem areas.

5.9.2 Relationship to Door-to-Door Travel Time Measures

The measure of system performance that is closest to the concern of travelers is door-to-door travel time. Any performance measure should relate to door-to-door travel time as closely as possible. Calibrating the user view of system performance with measures that can be more readily collected from existing data sources is the key to the efficient and effective presentation of mobility information. Periodic updates of public opinion can be used to adjust corridor and areawide determinations of service quality. Ten pairs of origin-destination trip patterns, for example, could be used to show the change in travel time. The information for these key travel patterns can be updated daily, monthly, or annually with system monitoring equipment. Every five years the key patterns could be re-examined for relevance to the existing and future land use development patterns and transportation system.

Using target conditions as the comparison standard provides the basis for a map or table showing system deficiencies in a way that is readily understood and uniquely relevant to improvement analyses. A map showing the target travel rates on the system links would accompany such a presentation. This approach could also be easily used in a multimodal analysis, with a target Travel Time Index for the corridor. Future travel rates for the corridor can be changed by improving a facility or service, or by shifting travel to other modes/facilities. The “target” comparison standard would be broader than simply a congestion or mobility measure since it would directly incorporate the idea that the goal for a corridor is not always high-speed travel. It could be used in conjunction with an areawide planning effort to relate the link speeds, used in estimating the travel time index, to the outcome measures of door-to-door trip satisfaction.

5.9.3 Impact on Data Collection

One outcome of a move to the travel time index would be the ability to include directly collected travel time data from the various transportation system elements. Many areas do not collect this information, but the initial statistics can be developed from estimates of travel speed. As travel time studies are conducted or archived data systems developed, the actual data can be used to replace the estimates in the index, as well as to improve the estimation processes. The information derived from systems that automatically collect and analyze travel speed over sections of freeways provide a significant resource for the travel time index calculation.

5.10 References

1. *NCHRP Report 398*. Quantifying Congestion—Final Report and User's Guide. National Cooperative Highway Research Program Project 7-13, National Research Council, 1997.

2. *The Keys to Estimating Mobility in Urban Areas*. Texas Transportation Institute, College Station, Texas, 1999.

3. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data*. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-HOP-05-018, December 2004. Available at: http://mobility.tamu.edu/mmp/.

4. Ewing, R. "A Unified Set of Transportation Performance Measures," Florida Atlantic University, n.d.

CHAPTER 6—DATA COLLECTION AND DATABASES

Chapter Summary

This chapter provides insight into database contents and data collection procedures for mobility analysis. The chapter begins with information on basic data sources and the role of estimation procedures. Data collection coverage is graphically illustrated for different data sources. Finally, insights into databases developed from real-time data sources and those developed with statewide estimation procedures are provided.

6.1 Basic Data Sources and Estimation

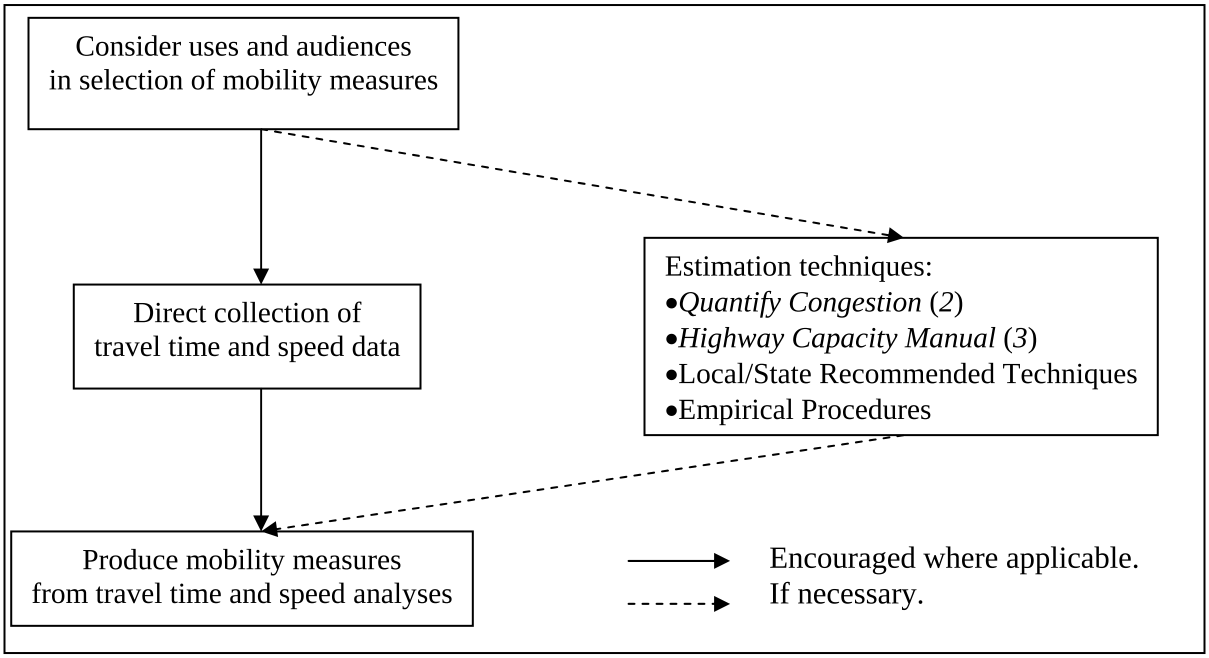
Concerns about the cost and feasibility of collecting travel time data are frequently the first issue mentioned in discussions of mobility measures. **There are many ways to collect or estimate travel time and speed quantities**; data collection should not be the determining factor about which measures are used. Exhibit 6-1 makes the point that while the direct collection of data is the desirable method of obtaining travel speed information, the selection of the proper measures should be the first step. As discussed in this report, while it is not always possible to separate data collection issues from measure selection, this should be the goal.

6.1.1 Sampling and Estimation Techniques

Sampling procedures and estimation techniques can provide useful travel time information with limited data collection budgets. Advanced technologies already provide a significant improvement in travel time data, and the number of transportation analyses that use this real-time information is growing. As these systems are installed in cities, travel time information will be more available in at least some corridors.

Travel time and speed data can be collected on a sample set of roads, routes, or modes in the analysis area. A strategic approach to sampling can be used—focus the travel time collection efforts on the problem or opportunity areas and estimate travel conditions on the rest of the system with a combination of limited data collection and estimating procedures. Techniques such as this allow mobility assessment programs to be more effective and affordable, especially for annual monitoring purposes or for complex study areas. Specific procedures and recommendations for data collection are included in the FHWA publication *Travel Time Data Collection Handbook* (*1*).

Exhibit 6-1. Desirable Role of Data Collection Issues in Measuring Mobility.



Source: NCHRP (*2*)

6.1.2 When and How to Estimate

The results of any estimate should be used with an allowance for the potential error that can be introduced when such estimates are derived. Travel time estimation procedures are most applicable for policy, programming, or planning purposes—situations where the future is not known with precision but it is important to select between alternative actions. This selection process often calls for mixing direct data and estimates. In these cases, a separate estimate of the speed must be made for existing and future conditions. The future rate should be calculated using Equation 6-1, which combines estimated travel rates for existing and future conditions with existing travel rates. This process reduces the error that would be induced by comparing actual rates to estimated rates—the difference may be related to the method used to obtain the estimate.

$$\begin{matrix}\textit{Future}\\ \textit{Travel Rate}\end{matrix} = \begin{matrix}\textit{Existing}\\ \textit{Travel Rate}\end{matrix} \times \frac{\textit{Estimate of Future Conditions}}{\textit{Estimate of Existing Conditions}} \qquad \text{(Eq. 6-1)}$$

Highway Capacity Manual (*3*) procedures are the basis for many national, state and local analytical processes. These count-based procedures are relatively detailed, with default factors provided when data are not available. The procedures and statistics have been developed for planning and operational analyses, and the products have not always been useful for communicating to audiences beyond transportation professionals. The *HCM* procedures have been developed from analysis of physical limitations of road systems at critical points. As such, the interaction between road sections that determines travel time along a congested road, as well as the spread of congested conditions beyond the peak hour, have not been a prominent aspect of *HCM*.

The incorporation of *HCM* procedures into computerized operations models has extended the usefulness of *HCM* to corridor and system analysis needs. Revisions to the basic products that are included in the 2000 edition of the *Highway Capacity Manual* are also developing travel speed and delay estimates for all the key analytical procedures and encouraging computer models for corridor analyses. *HCM*-based procedures will always have a role in producing mobility measures, but the direct collection of travel time data can assist in calibrating computer models and estimation techniques.

Vehicle occupancy data may be important for some analyses where modal, ridesharing, or other actions are being studied. The analysis may be able to use a set of regularly conducted studies in the urban area as a start for the analysis. Focused occupancy studies in locations where the average rate is likely to be different from the remainder of the urban area can be used to identify the effect of actions and assess locations where modal alternatives have been enacted. There may be many studies in an area where the use of general occupancy rates will be sufficient to adjust vehicle quantities to person values for economic analysis and presentation of results. Research performed in the State of New York provided a method for estimating areawide auto occupancy by county, year of occurrence, month of year, day of week, and time of day intervals (*4*).

The key to developing good mobility measures is to recognize the interaction between elements of the transportation system. Changes in one mode, operating system/procedure, or demand patterns can have effects that go beyond the original intent of the analysis. These potential effects should be considered in developing data collection plans.

6.2 Data Collection Coverage

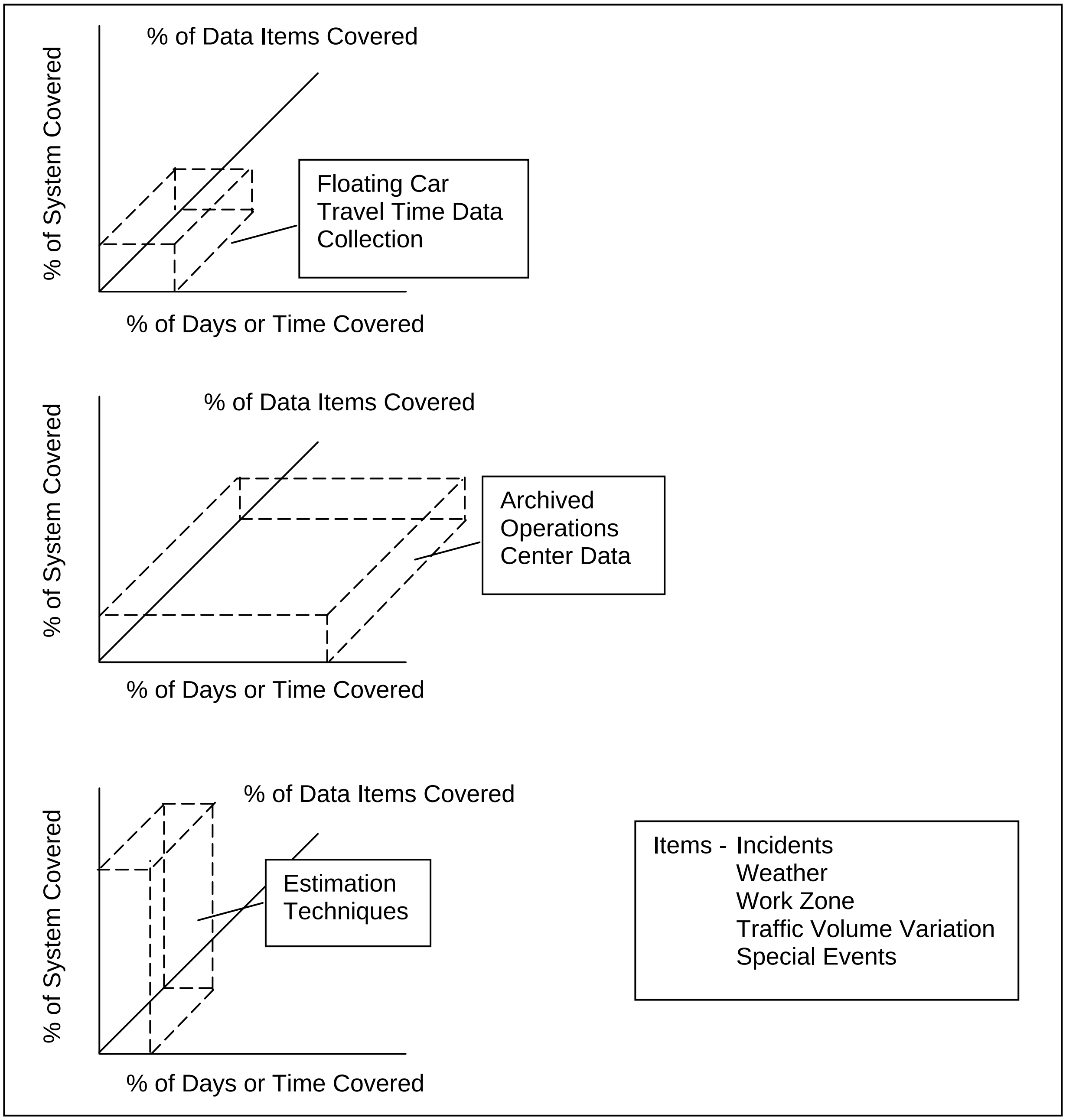
Supporting information for travel time analyses can be generated from three basic approaches—travel time data collection from floating car or other vehicle-based sampling procedures, data from traffic operations center archives, and estimation or modeling techniques. Each of these approaches has strengths and shortcomings. None of the approaches can be used for all analyses, and none of them include all the information required for a comprehensive assessment of congestion and reliability issues. Exhibit 6-2 compares the coverage of three data collection dimensions by the three approaches.

6.2.1 Vehicle-Based Travel Time Data

Floating car or probe vehicle travel time observations typically consist of a few trips on relatively few roads in a corridor or city. The observations are made on a few days and on a sample of roads or on only a few major roads. Data concerning some non-ideal conditions can be collected, but the sample size is typically small.

Some probe vehicle techniques provide more robust datasets. These include travel times obtained from toll tags or cellular telephones.

Exhibit 6-2. Summary of Data Collection Techniques.



Source: Lomax et al. (*5*)

6.2.2 Archived Traffic Operations Center Data

Traffic volume and speed data can be automatically collected and saved for each day of the year. These data will include many days when non-ideal conditions exist, which greatly improves the usefulness of the information. Unfortunately, in almost every city, freeways are the only roadway type where data are archived and usually for only a small portion of the freeway system.

6.2.3 Estimation Techniques

Equations, simulation models, and other estimation techniques are used when areawide or comprehensive network assessments are needed. Of necessity, these are simplifications of the day-to-day variation in conditions and travel patterns. They can be used to estimate the effect of some non-ideal conditions such as construction, maintenance, special events, weather, vehicle breakdowns, and collisions although these models cannot show the complexity of interactions or variations.

6.3 Creating an Archived Database

Archived data can provide much more information about the operation of freeway systems in normal time, during special or irregular events, or after the implementation of programs and techniques designed to improve operations. Until the technologies are more widely deployed, it will be difficult to compare performance characteristics from one area to another. The data collected from continuous monitoring systems result in different performance measure values than those calculated from estimation techniques for a variety of reasons. Any estimation program will have difficulty replicating actual conditions, but the current real-time data collection devices suffer from the lack of coverage of the travel system elements. When events cause travelers to leave the monitored portion of the roadway, the performance measure accuracy suffers.

The data concepts can be divided into four broad categories. Each represents a set of data needs, but fundamentally they are ways of thinking about the desired information and how to get it. Travelers and shippers want information about travel time—both the average and the variation—that indicates how much time should be planned for particular trips or sets of trips. There are a number of ways to obtain this kind of information and several ways to display or communicate it. The data collection concepts are discussed below in descending order of desirability (as ranked by the performance measures that might be developed by each type of collection technique). There are ranges even within each of these levels, but the following four concepts provide a good framework for the discussion of archived data collection and use.

1. **A computer chip on each person or each unit of cargo—**Massive personal privacy concerns are involved, but as a concept this would allow us to understand how people move around the city. It would give us door-to-door (D2D) travel time, allow us to monitor travel on all modes and all facilities, and provide us with information about route, departure time travel time, variation in travel time, and mode choice decisions.

2. **Travel time and volume detection over sections of road, transit systems, bike lanes, and sidewalks—**This would allow us to monitor travel on most facilities or modes and provide a significant portion of the D2D trip time data. Trip information could be estimated from the monitored data and supplemented with targeted surveys.

3. **Detectors of speed and volume at locations along the systems—**Estimating the volume and speed using point detectors is the practice of most archived data systems. The techniques are relatively well defined, but the level of detail does not provide

information at the trip level. Travel time must be estimated using the point speed to indicate the average speed over the adjacent road sections.

4. **Estimates based on volume and roadway inventory—**Equations or computer models that relate volume per lane and speed will always be needed for future condition mobility analyses or for evaluating improvements to existing conditions. The estimating procedures also provide information for portions of the system that are not continuously monitored. These procedures can be improved with information from the continuous monitors.

6.4 Real-time (ITS) Data Collection Practices

Data on operations (e.g., traffic volume, traffic density, speed, or travel time) are archived at some traffic management centers (TMCs). For most cities in the Mobility Monitoring Program (*6*), the data are collected at point locations using a variety of technologies including single and double inductance loops, radar, passive acoustic, and video image processing (some areas use multiple technologies; see Exhibit 6-3). These technologies establish a small, fixed "zone of detection," and the measurements are taken as vehicles pass through this zone. The Houston travel times are collected via their automatic vehicle identification (AVI) system. This system detects vehicles with toll tags and provides a direct measurement of travel time between sensors spaced at 2- to 5-mile intervals.

Data collection and processing procedures have been developed individually, and the details of the archiving vary from site to site. However, there are several procedures that are common to all sites. In general, the process works as follows for each city (with Houston being slightly different):

- Data are collected by field sensors and accumulated in roadside controllers. These field measurements are by individual lane of traffic. At 20-second to 2-minute intervals, the roadside controllers transmit the data to the TMC.

- Some areas perform quality control on original data, but this screening is typically simple and based on minimum and maximum value thresholds. These steps eliminate obviously incorrect data but do not identify all of the problems.

- Areas that use single inductance loops as sensors can only directly measure traffic volume and lane occupancy. In these cases, algorithms are used to estimate speeds for the combinations of volume and occupancy. The algorithms vary from site to site.

- Internal processes at the TMC aggregate the data to specified time intervals for archival purposes. These intervals vary from 20 seconds (no aggregation) to 15 minutes. In some cases, the data are also aggregated across all lanes in one direction at a sensor location.

- The aggregated data are then stored in text files or databases unique to each TMC. CDs are routinely created at the TMCs to reduce some of the storage burden and to satisfy outside requests for the data.

Exhibit 6-3. Summary of Data Collection Technologies and Data Level of Detail in 2003.

Participating City	Traffic Sensor Technology	Data Level of Detail	
		Time	Space
Albany, NY	loop detectors	15 minutes	by lane
Atlanta, GA	video imaging, microwave radar	15 minutes	by lane
Austin, TX	loop detectors	1 minute	by lane
Baltimore, MD	microwave radar, loop detectors	5 minutes	by lane
Charlotte, NC	microwave radar	30 seconds	by lane
Cincinnati, OH-KY	loop detectors, microwave radar, video imaging	15 minutes	by direction
Dallas, TX	video imaging, loop detectors, microwave radar	5 minutes	by lane
Detroit, MI	loop detectors	1 minute	by lane
El Paso, TX	loop detectors, microwave radar	1 minute	by direction
Hampton Roads, VA	loop detectors, microwave radar	5 minutes	by direction
Houston, TX	probe vehicle (toll tags); also loop detectors, video imaging, microwave radar	vehicle-based link travel times	
Los Angeles, CA	loop detectors	5 minutes	by direction
Louisville, KY	microwave radar, video imaging	15 minutes	by direction
Milwaukee, WI	loop detectors, microwave radar, video imaging	5 minutes	by lane
Minneapolis-St. Paul, MN	loop detectors	30 seconds	by lane
Orange County, CA	loop detectors	5 minutes	by direction
Orlando, FL	loop detectors	1 minute	by lane
Philadelphia, PA	microwave radar, passive acoustic detectors	5 minutes	by lane
Phoenix, AZ	loop detectors, passive acoustic detectors	5 minutes	by lane
Pittsburgh, PA	microwave radar, passive acoustic sensors	5 minutes	by lane
Portland, OR	loop detectors	15 minutes	by lane
Riverside-San Bernardino, CA	loop detectors, microwave radar	5 minutes	by direction
Sacramento, CA	loop detectors, microwave radar	5 minutes	by direction
Salt Lake City, UT	loop detectors, acoustic detectors, microloops	15 minutes	by lane
San Antonio, TX	loop detectors, acoustic detectors	20 seconds	by lane
San Diego, CA	loop detectors	5 minutes	by direction
San Francisco, CA	loop detectors, microwave radar	5 minutes	by direction
Seattle, WA	loop detectors	5 minutes	by lane
Washington, DC			
- Maryland	microwave radar, loop detectors	5 minutes	by lane
- Virginia	loop detectors	1 minute	by lane

Source: FHWA (*7*)

The Importance of Maintaining an Accurate Real-time Data Collection System

An area of potential immediate benefit and continuing concern is maintenance of the data collection infrastructure. Funding limitations affect the ability to correct deficiencies even when devices are known to be producing erroneous or no data. The problem is exacerbated where sensors in the pavement are used because most agencies are reluctant to shut down traffic on heavily traveled freeways just to repair monitoring equipment. Maintenance is often postponed to coincide with other roadway activities, which helps spread the cost burden but may delay repairs.

Field checking of sensors is done periodically, but no standardized procedures are used across all areas. If a detector is producing values that are clearly out of range, inspection and maintenance are usually performed. However, calibration to a known standard is rarely, if ever, performed. This means that more subtle errors may go undetected. Bearing in mind that TMCs typically do not require highly accurate data for most of their operations, this approach is reasonable and practical. Work zones exacerbate these problems, and contractors often unknowingly sever communication lines or pave over inductance loops.

Calibration—at least to very tight tolerances—is not seen as a priority, given that operators focus on a broad range of operating conditions rather than precise speed/travel time estimates. This philosophy may be changing as a result of more stringent data requirements for traveler information purposes (e.g., TMC-based posting of expected travel times to destinations using variable message signs). However, the current data resolution used by TMCs is quite coarse; it supports their traditional operations activities, such as incident detection and ramp meter control.

6.5 Statewide Performance Measure Application with Estimation

Recent work was performed by the Texas Transportation Institute (TTI) for the Oregon Department of Transportation (ODOT) to identify and test operations performance measures for statewide application. The results include a methodology and test results that includes the use of real-time data and estimation procedures. The estimation procedures include the use of the Highway Economic Requirements System—State Version (HERS-ST) for obtaining statewide estimates of speed in a consistent manner (*8*,*9*). Observations relevant to statewide mobility measure estimation are described below.

6.5.1 Keeping a Consistent Speed in the Statewide Application

Any statewide performance measure analysis should keep a consistent source of speed data (and subsequently computed performance measures) because this value will change over time, and it is important to understand the extent that this measure is changing due to the measurement versus due to mobility improvements. For example, for the ODOT work (*8*,*9*), if HERS-ST is the source for the measures, then the "HERS-ST speed" should be kept from year to year as a data element. When supplemental speed information is available, it can be kept in the database next to the HERS-ST speed. There may even be speeds from more than one other source if different studies or local knowledge is available. Other speed sources might include real-time ITS data, floating car studies, automatic traffic recorder, etc. This would provide the opportunity to see trends not only in mobility performance from year to year, but to also see how these speed values may differ by data source (i.e., estimated versus direct measurement). This would allow for the calibration of the HERS-ST values with any other data sources that might be used. It should be noted that the geographic extent of data collection will be expanding each year. Consequently, it is important that the analyst only select the observations where prior year and current year data are available to derive the VMT-weighted areawide performance trend.

6.5.2 Possible "Beta" Version before Final Distribution

When implementing new mobility estimation procedures, occasionally there are concerns expressed that potentially unreliable data or errors in the new estimation procedure may indicate mobility problems when such problems do not really exist. To ultimately get a statewide methodology in place, identifying and fixing data issues are an inevitable part of the start-up process. Therefore, it might be prudent that the statewide implementation of the estimation procedures be performed over one to three years, and the results are identified as "beta" or "prototype" to allow a review of the process over the initial years. This could allow for calibration of the results across the initial years, and at different geographic locations, based on local knowledge or studies before the final "rollout."

6.6 References

1. Turner, S.M., Eisele, W.L., Benz, R.J., and Holdener, D.J. *Travel Time Data Collection Handbook*. Report No. FHWA-PL-98-035. , U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., March 1998.

2. *NCHRP Report 398*. Quantifying Congestion—Final Report and User's Guide. National Cooperative Highway Research Program Project 7-13, National Research Council, 1997.

3. *Highway Capacity Manual*. Transportation Research Board, National Research Council, 2000.

4. Asante, S.A., Adams, L.H., Shufon, J.J., and McClean, J.P. "Estimating Average Automobile Occupancy from Accident Data in New York State." *Transportation Research Record 1553*. Transportation Research Board, Washington, D.C., 1996.

5. Lomax, T.J., Schrank, D.L., and Turner, S.M. "Selecting Travel Reliability Measures." May 2003. Available at: http://mobility.tamu.edu/resources.

6. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data*. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-HOP-05-018, December 2004. Available at: http://mobility.tamu.edu/mmp/.

7. "FHWA Mobility Monitoring Program: 2003 City Reports." U.S. Department of Transportation, Federal Highway Administration, February 2005. Available at: http://mobility.tamu.edu/mmp.

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9. Eisele, W.L., Lomax, T.J., Gregor, B.J., and Arnold, R.D. "Developing and Implementing Statewide Operations Performance Measures in the State of Oregon: Methodology and Application for Using HERS-ST and Archived Real-time Data." Paper prepared and presented at the Transportation Research Board's 84th Meeting, Washington, DC, January 2005. Available at: http://mobility.tamu.edu/resources.

CHAPTER 7—GRAPHICAL ILLUSTRATION OF MOBILITY MEASUREMENT

Chapter Summary

Communicating mobility analysis results is a vital step in illustrating system performance and demonstrating the need for transportation improvements. Effective graphical presentation of mobility results typically includes spatial and/or temporal aspects. This chapter provides state-of-the-art examples of effective ways of communicating mobility results.

A key step in any mobility analysis is communicating the results. This chapter illustrates some premier examples of communicating temporal and spatial congestion characteristics. Tables can certainly be effective in communicating results; however, providing congestion severity spatially through maps or temporally through trend analyses illustrates a visually effective way of communicating results. Additional methods of illustrating temporal and spatial congestion characteristics are included in this chapter.

The examples in this chapter are primarily from real-time data sources; however, similar graphics can certainly be created for measures computed from other data sources. While some of the graphical displays may initially appear time consuming to create, automated methods can be developed to facilitate report generation.

Exhibit S-1 and the measures presented in Chapter 5 are not the only measures illustrated in the examples shown in this chapter. The mobility measures in Chapter 5 represent the primary measures that often form the foundation of a mobility analysis. The measures shown in Chapter 5 are the focus of the applications shown in Chapter 8 as well.

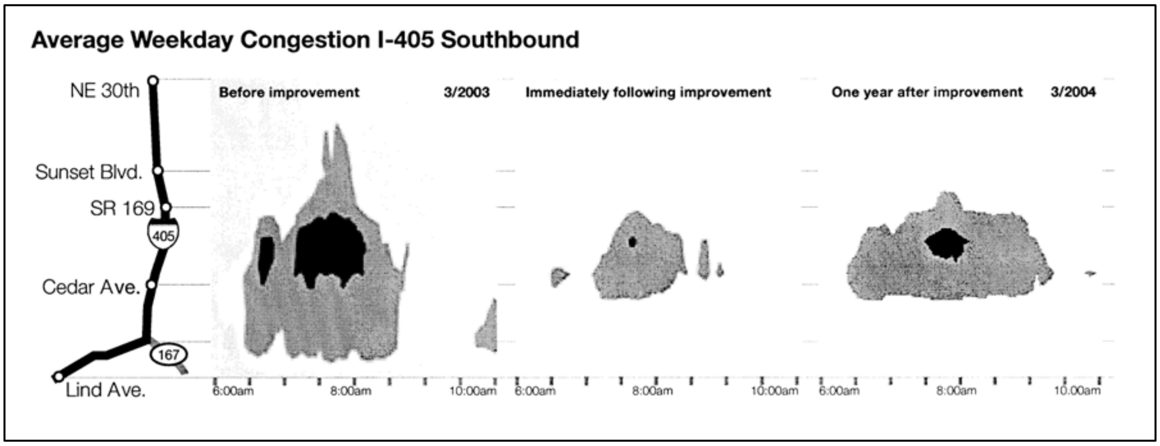
It should also be noted that all aspects of congestion (duration, extent, intensity, and variation) can be illustrated with graphical methods. It is important to consider what questions are to be answered when selecting the appropriate graphic to quantify congestion levels.

7.1 Graphical Examples Illustrating Temporal Congestion Aspects

Numerous graphics that present the temporal aspects of congestion are presented in this section. These graphics typically present information at one particular location over time. Similar graphics could be generated for different locations of interest and compared to provide a spatial perspective on congestion.

Exhibit 7-1 illustrates severity and duration of congestion. These “thermal graphs” combine multiple datasets to display a corridor over time. It illustrates when and where the freeway is congested along with the severity, duration, and location. It provides a quick assessment to the viewer, and “before-and-after” graphics could be created to identify transportation improvements. Exhibit 7-1 shows “before-and-after” decreased congestion due to the construction of a flyover ramp at I-405 and SR 167 in the Puget Sound area.

Exhibit 7-1. Average Weekday and Weekend Congestion at I-405 Southbound.
Source: Washington State Department of Transportation (*1*)



The Mobility Monitoring Program (*2*) includes numerous examples of presenting congestion statistics computed from real-time (ITS) data sources. Several graphics from MMP are included here to illustrate various presentation methods with data from the freeway systems of different cities across the nation in 2003. Exhibit 7-2 illustrates computed measures and trends related to performance measures, explanatory measures, and data quality measures. The exhibit provides a system-level summary to the reader at a glance while also providing color-coded arrows for the changes from past years to the current year.

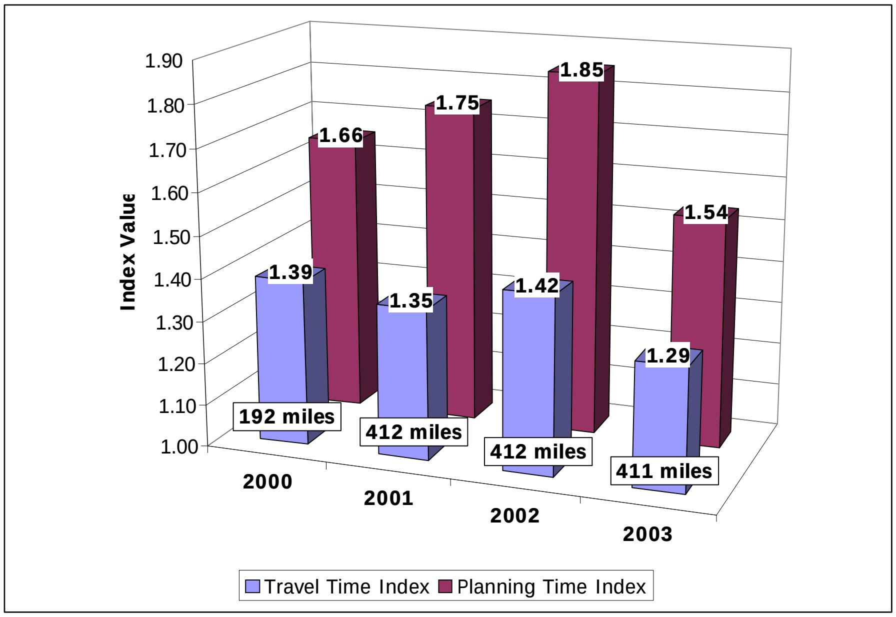
Exhibit 7-2. Illustration of Measures and Trends.

Measures	Current Year	Last Year		Two Years Ago	
	2003	2002	Change	2001	Change
Performance Measures					
Travel Time Index	1.23	1.20	+2% ↑	1.27	-3% ↓
Planning Time Index	1.52	1.49	+2% ↑	1.61	-5% ↓
Buffer Index	20%	21%	-1% ↓	23%	-3% ↓
% Congested Travel	37%	39%	-2% ↓	50%	-13% ↓
Total Delay (vehicle-hours) per 1000 VMT	3.92	3.78	+4% ↑	4.86	-19% ↓
Explanatory Measures					
Peak Period VMT (000)	5,750	4,720	+22% ↑	4,560	+26% ↑
Avg. Annual DVMT (000)	19,610	16,160	+21% ↑	15,520	+26% ↑
Data Quality Measures					
% Complete	79%	85%	-6% ↓	98%	-19% ↓
% Valid	78%	89%	-11% ↓	92%	-14% ↓
% of VMT Covered	72%	59%	+13% ↑	55%	+17% ↑
% of Freeway Miles	69%	60%	+9% ↑	60%	+9% ↑

DVMT = Daily Vehicle Miles Traveled
Source: FHWA (*2*)

Exhibit 7-3 illustrates trends in the system-level travel time index and the planning time index values from 2000 to 2003. The planning time index is statistically defined as the 95th percentile travel time index and also represents the extra time most travelers add to a free-flow travel time when planning trips. Exhibit 7-3 also shows the miles of freeway coverage.

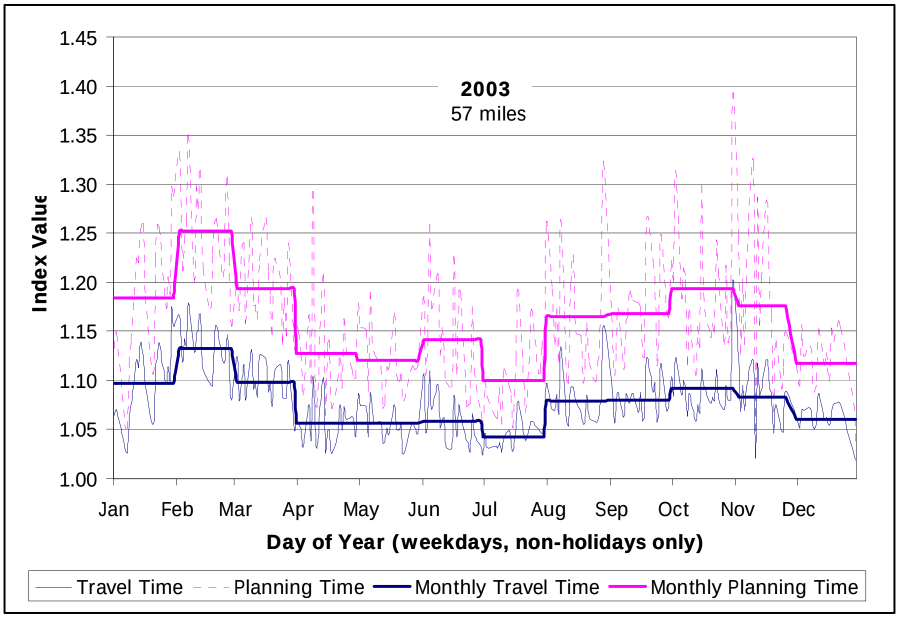
Exhibit 7-3. Illustration of Annual Trends in Travel Time Index and Planning Index.



Source: FHWA (*3*)

Exhibit 7-4 illustrates daily, monthly, seasonal, and yearly trends in the travel time index and the planning time index. Therefore, several temporal levels of detail are provided in one graphic for the system (in this case), or this exhibit could be produced for specific areas of interest.

Exhibit 7-4. Illustration of Daily and Monthly Trends in Travel Time Index and Planning Index.

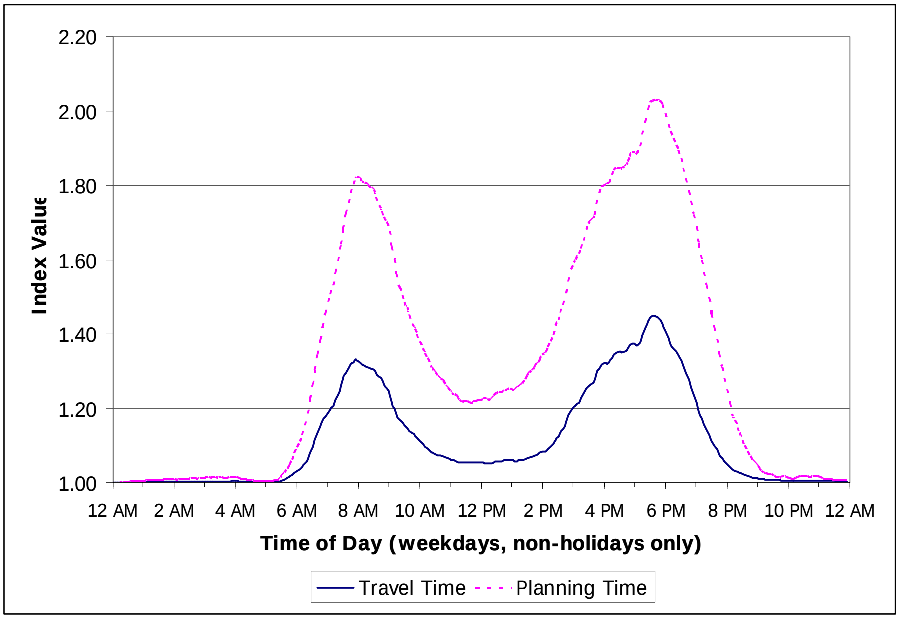


Source: FHWA (*3*)

Exhibit 7-5 and Exhibit 7-6 illustrate travel time index and planning time index values by time of day. Exhibit 7-5 shows areawide congestion and reliability patterns. The difference between the solid line (travel time index) and the dashed line (planning time index) is the additional "buffer" or "time cushion" that travelers must add to average trip times to ensure 95 percent on-time arrival. Exhibit 7-5 also indicates that the evening congestion level is higher and longer than in the morning and that travelers must add 25 to 35 percent additional buffer time during peak periods to account for traffic unreliability. While this graphic is for areawide conditions, a similar graphic could be created for specific locations as well.

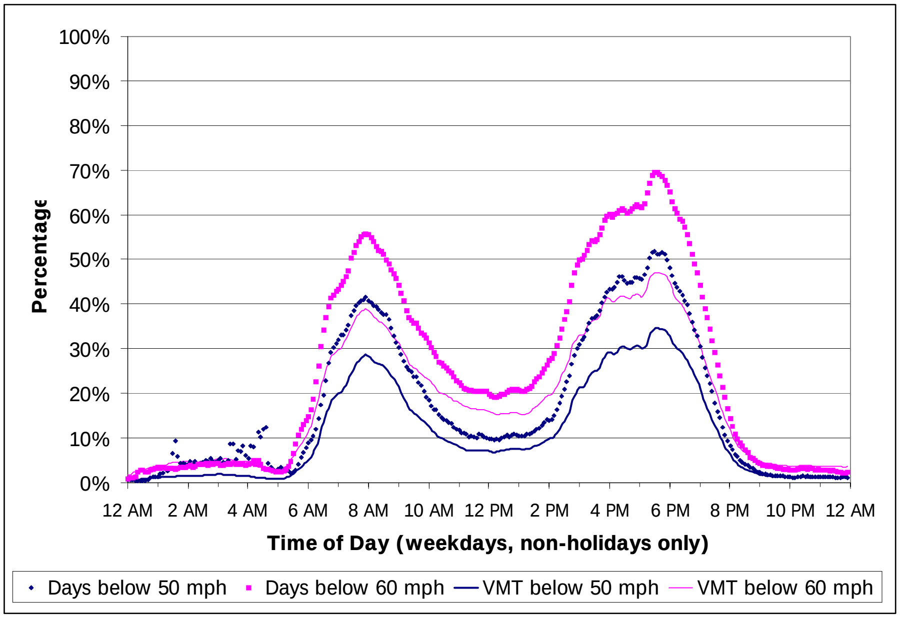
Exhibit 7-6 illustrates the difference in using two different speed thresholds (50 and 60 mph) to compute the percent of congested days as well as the percent of congested travel (as vehicle-miles of travel). There is about a 10 to 15 percent difference in using a 50 mph or 60 mph congestion threshold in this example.

Exhibit 7-5. Illustration of Mobility and Reliability by Time of Average Weekday.



Source: FHWA (*3*)

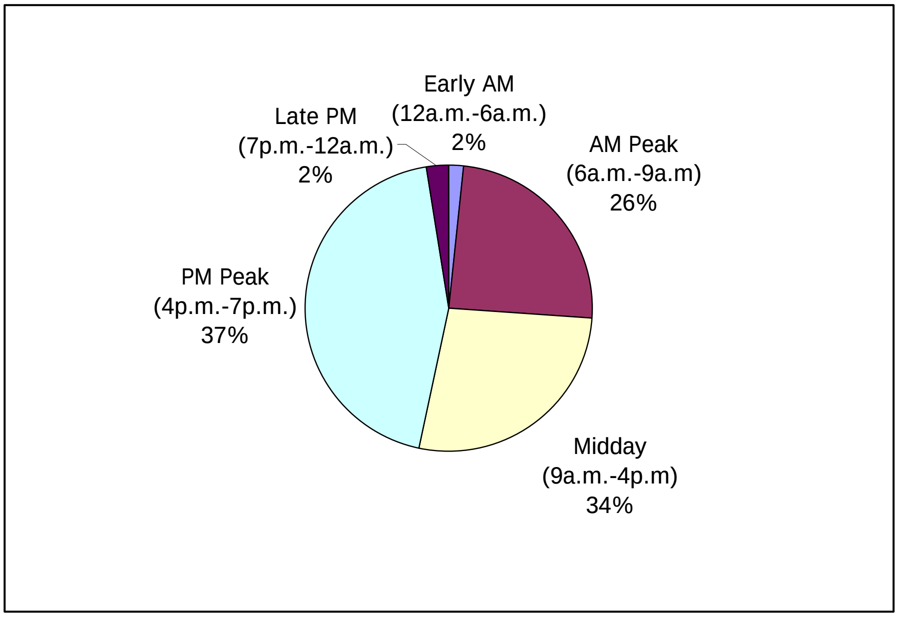
Exhibit 7-6. Illustration of Frequency and Percentage of Congested Travel by Time of Average Weekday.



Source: FHWA (*3*)

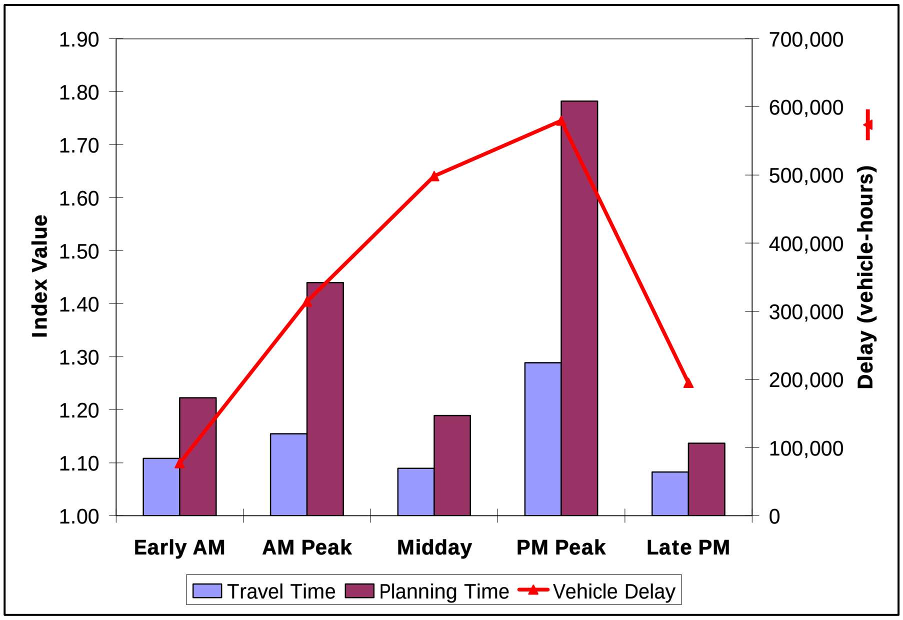
Exhibit 7-7 illustrates a method to present congestion levels by time period of the day with a pie chart. It shows the percent of delay that occurs during different time periods of an average weekday. Note that the morning and afternoon peak periods are the same duration (3 hours each), but other time periods have different lengths. As illustrated in Exhibit 7-5, the delay in the afternoon is greater than the morning peak period. Exhibit 7-8 illustrates congestion and reliability (shown as bars) as well as delay (shown as a line) during different time periods of an average weekday. The trends in this graphic follow closely to those illustrated in Exhibit 7-7. Note that the travel time index for the midday period is low, but the delay is relatively high because of the length of this time period (7 hours).

Exhibit 7-7. Illustration of Percent of Delay by Time Period.



Source: FHWA (*3*)

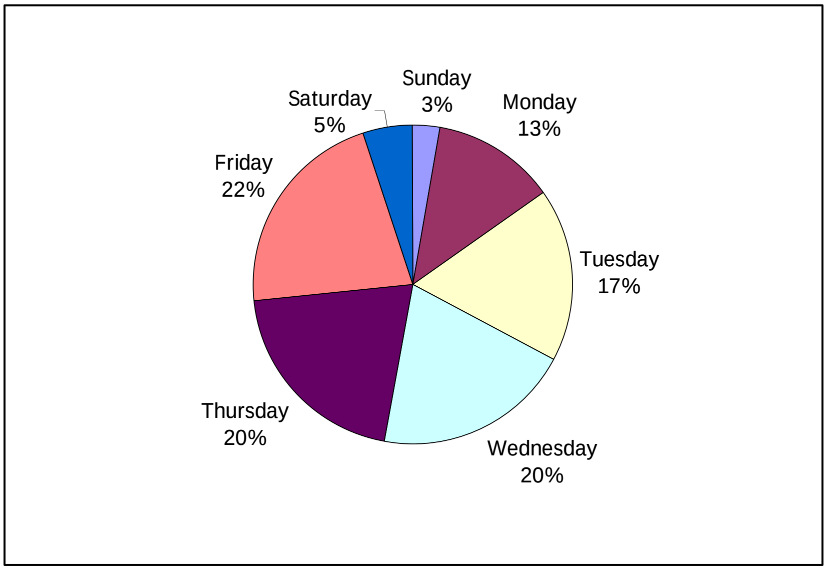
Exhibit 7-8. Illustration of Mobility, Reliability, and Delay by Time Period.



Source: FHWA (*3*)

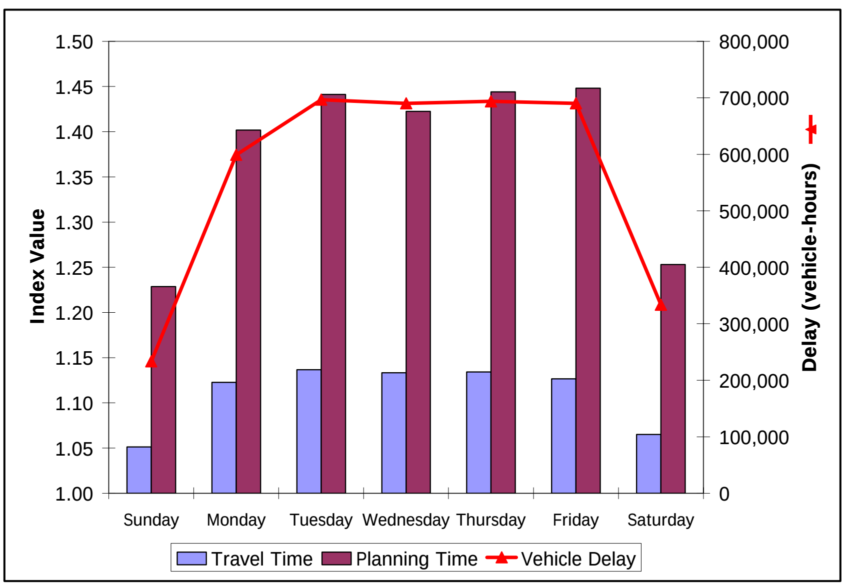
Exhibits 7-9 and 7-10 illustrate day of week variations in congestion. Exhibit 7-9 shows the percent of total daily delay that occurred during each day of the week. The pie chart indicates that delay on Mondays is significantly less than all other weekdays, and delay on all other weekdays is comparable. Both weekend days combined have about half of the normal weekday delay. Exhibit 7-10 is similar to Exhibit 7-8 except it investigates congestion by day of the week. The chart shows the average daily congestion and reliability (shown as bars) as well as total daily delay (show as a line) during each day of the week. The trends shown in Exhibit 7-10 closely follow those shown in Exhibit 7-9. Friday has the most delay, and it is the least reliable day (highest planning time index).

Exhibit 7-9. Illustration of Percent of Delay by Day of Week.



Source: FHWA (*3*)

Exhibit 7-10. Illustration of Mobility, Reliability, and Delay by Day of Week.



Source: FHWA (*3*)

7.2 Graphical Examples Illustrating Spatial Congestion Aspects

Most of the temporal graphics presented thus far can also provide some level of spatial congestion analysis as well. In the simplest form, this includes creating the temporal graphic of interest at two or more locations and then comparing the graphics. Alternatively, spatial illustrations of congestion levels can be well represented through maps. One example was shown previously in Exhibit 7-1. The examples in this section include illustrations of spatial maps that illustrate congestion levels. Finally, additional examples of displaying congestion levels are provided that can be created for numerous locations and compared.

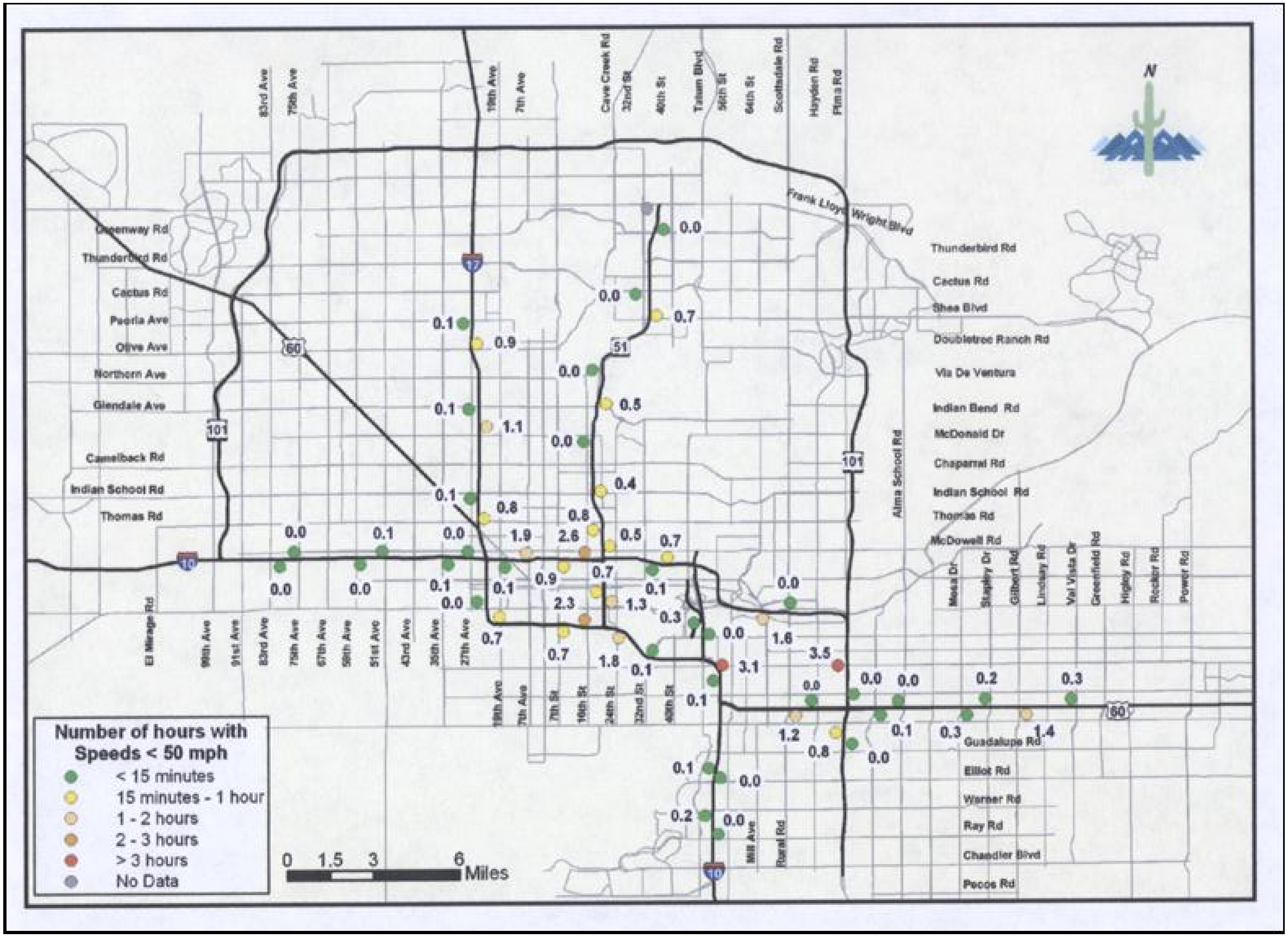
Exhibit 7-11 illustrates a spatial example of the hours of congestion in the afternoon and early evening hours in Phoenix. Color-coded points are indicated on the roadway that correspond to different ranges in the number of congested hours. The color-coded points on the map are located where the directional real-time (ITS) detectors are located in the freeway. Exhibit 7-12 presents the average speeds for the weekday evening peak period in the Phoenix area. Speed data are again provided at color-coded point locations. This provides the reader spatial congestion impacts throughout the region. Exhibit 7-13 provides another representation of the severity of congestion. In this example, delay is illustrated spatially throughout the Puget Sound region. The vertical length of the bars indicates the extent of the delay at the location indicated.

Exhibit 7-14 displays the concept of “lost capacity.” The November 13 data represent relatively free-flow travel at this location throughout the day. November 12 represents a day with a reduction in speed beginning at approximately 3:30 p.m. Note that prior to 3:30 p.m., the volume traces for both days were relatively similar. Using November 13 as a “baseline,” the “lost capacity” is shown on the graphic as the difference between the traffic volumes for these two days. The “lost capacity” can be illustrated graphically in this manner and/or displayed for different locations to provide a spatial comparison. It should be noted that each day of data could be investigated to determine capacity. November 13 is just used for illustrative purposes in Exhibit 7-14. Alternatively, the efficiency at a point can be presented in the form of a map such as Exhibit 7-15 that displays the efficiency as a color-coded point on the map.

Exhibit 7-16 provides another way to perform side-by-side comparisons of different locations while also providing a comparison over consecutive years. The exhibit illustrates “stamp graphs” (named for their size) that visually describe the percent of days when speeds are less than 35 mph. The graphics compare data for two years over the daily time periods of interest.

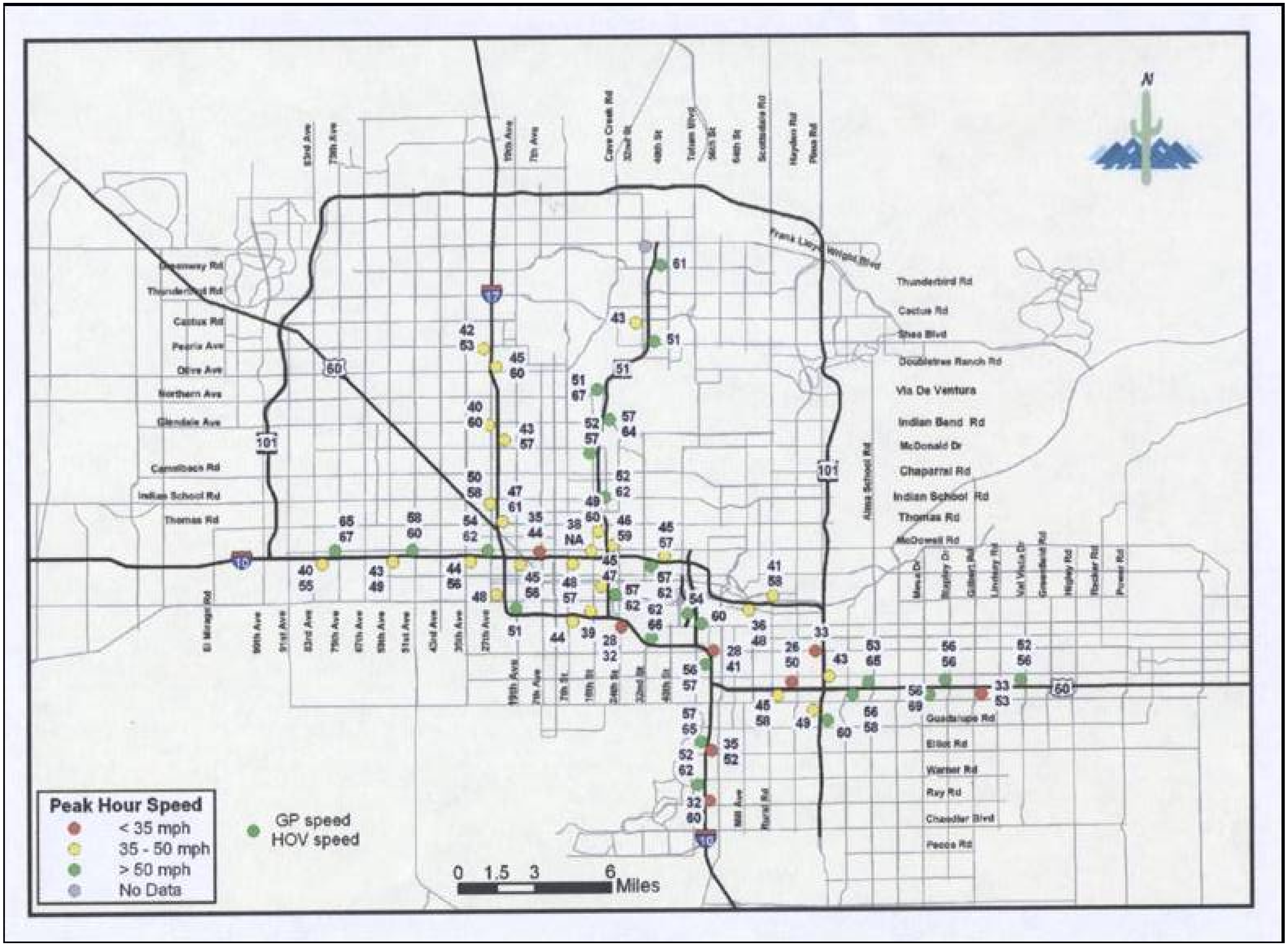
Exhibit 7-17 illustrates the percent of vehicle-miles of travel, time, and delay in different speed ranges. This chart is useful to determine how much VMT and delay are occurring at different congestion levels. About 75 percent of the VMT occurred at speeds greater than 60 mph. More than 85 percent of the delay is at speeds less than 40 mph. Though this graphic is for a regional system for the entire year, the graphic could also be created for specific locations and then compared—thus providing a spatial illustration of the congestion levels.

Exhibit 7-11. Hours of Congestion in the Afternoon and Early Evening (2 p.m. to 7 p.m.), 2004.



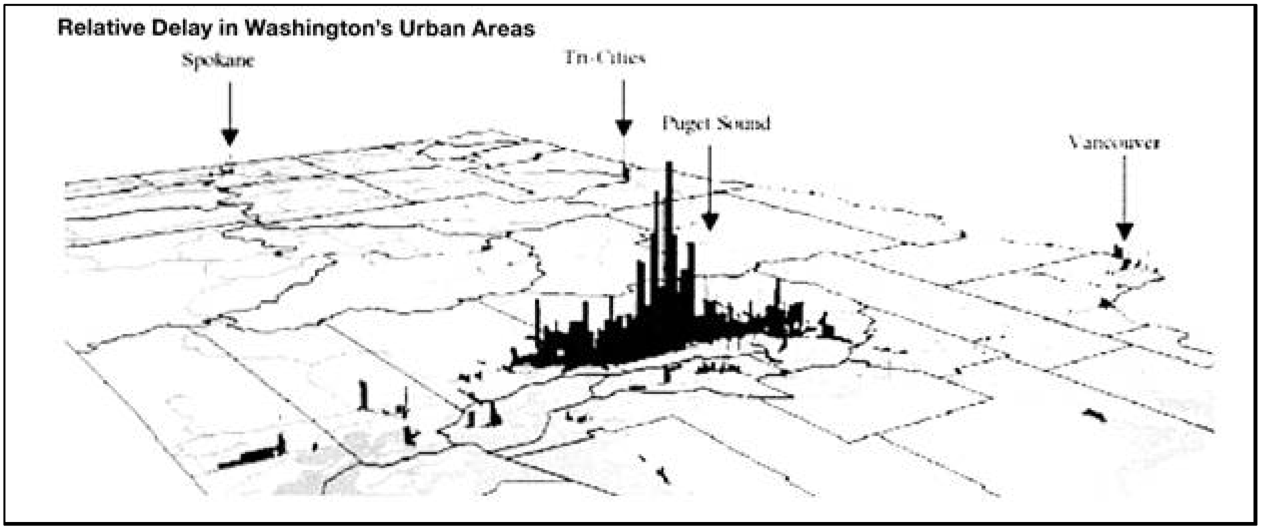
Source: FHWA (*4*)

Exhibit 7-12. Average Weekday Evening Peak Period Speeds, 2004.



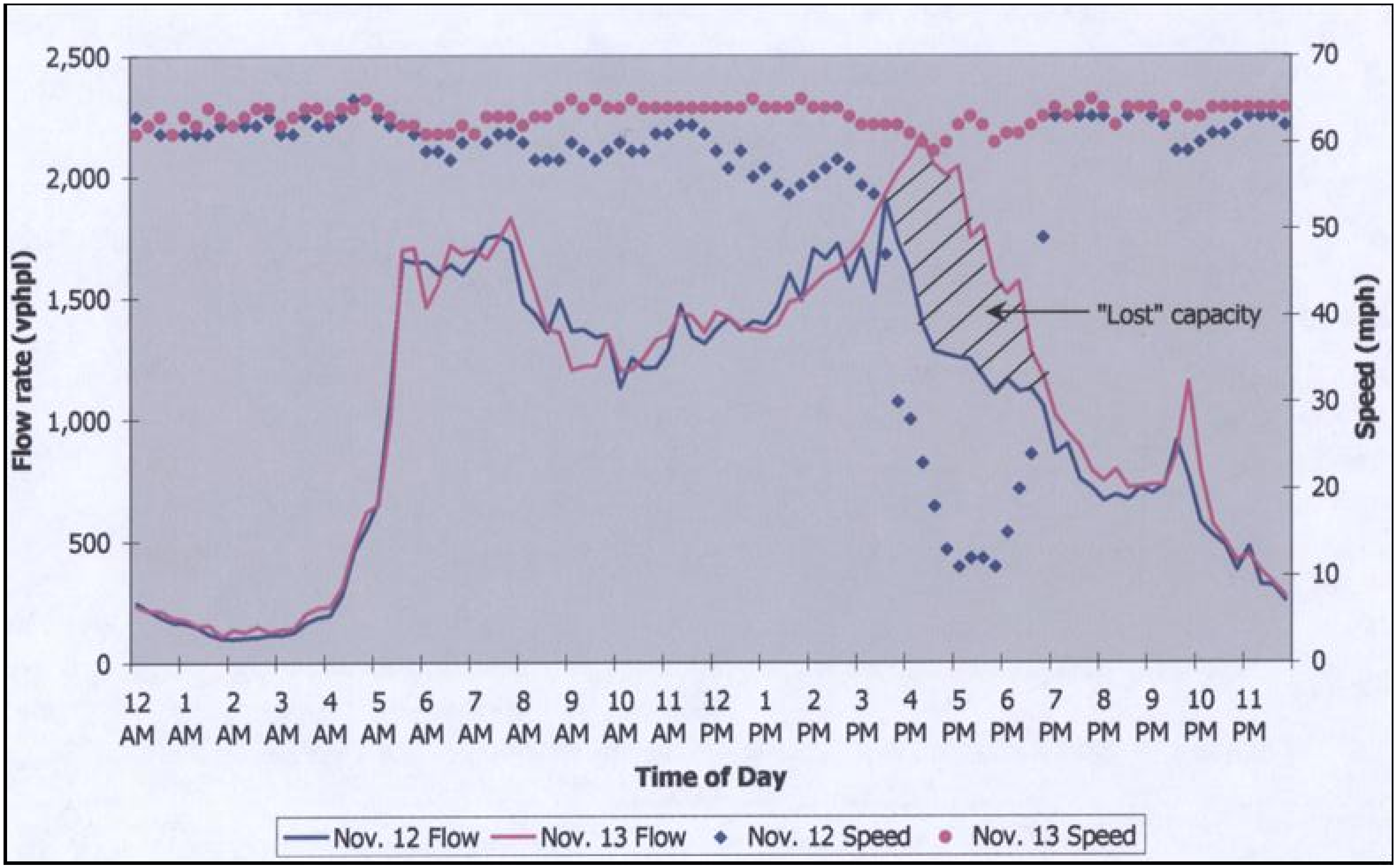
Source: FHWA (*4*)

Exhibit 7-13. Puget Sound Freeway Delay.



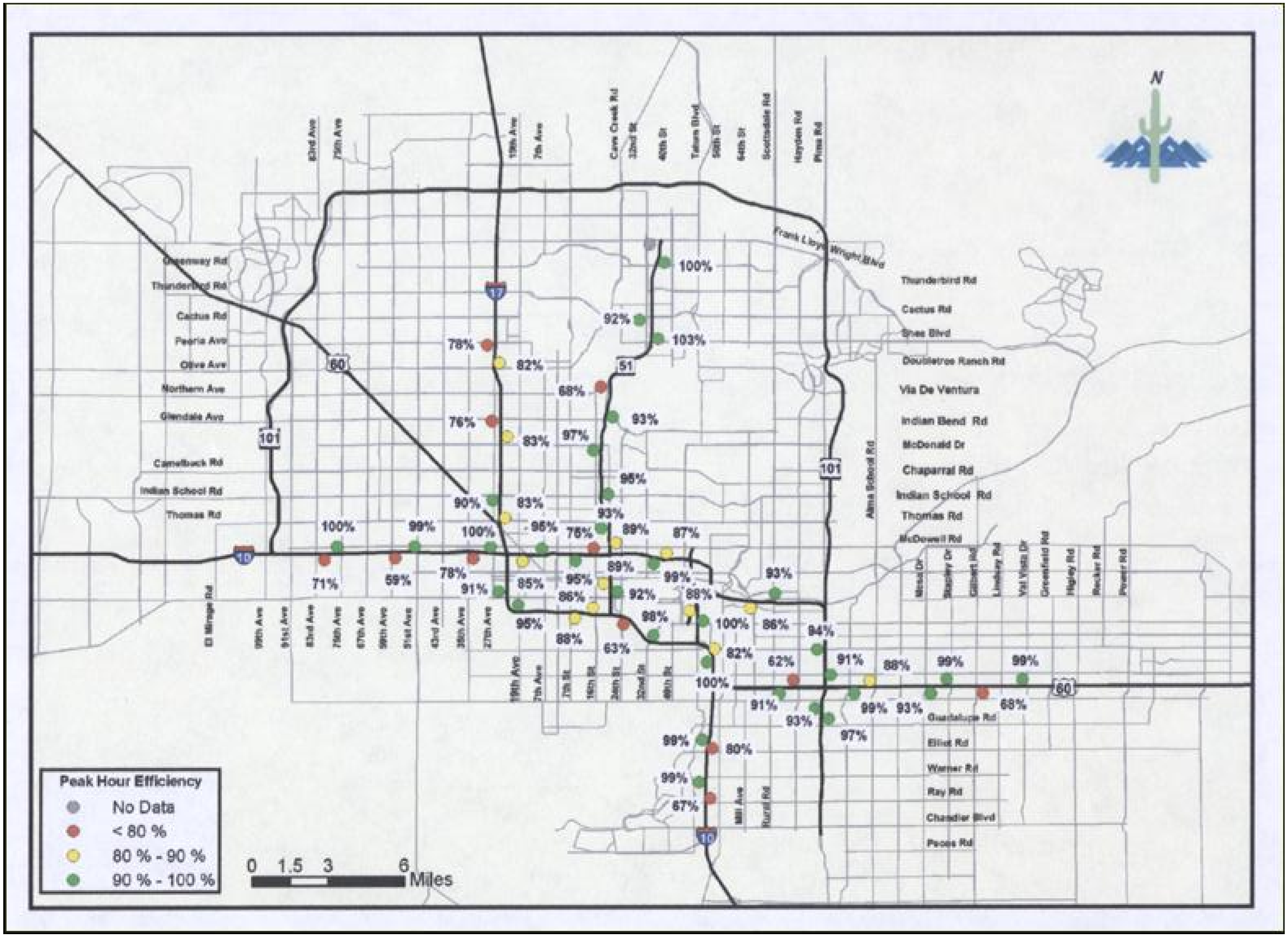
Source: Washington State Department of Transportation (*1*)

Exhibit 7-14. Illustration of "Lost Capacity."



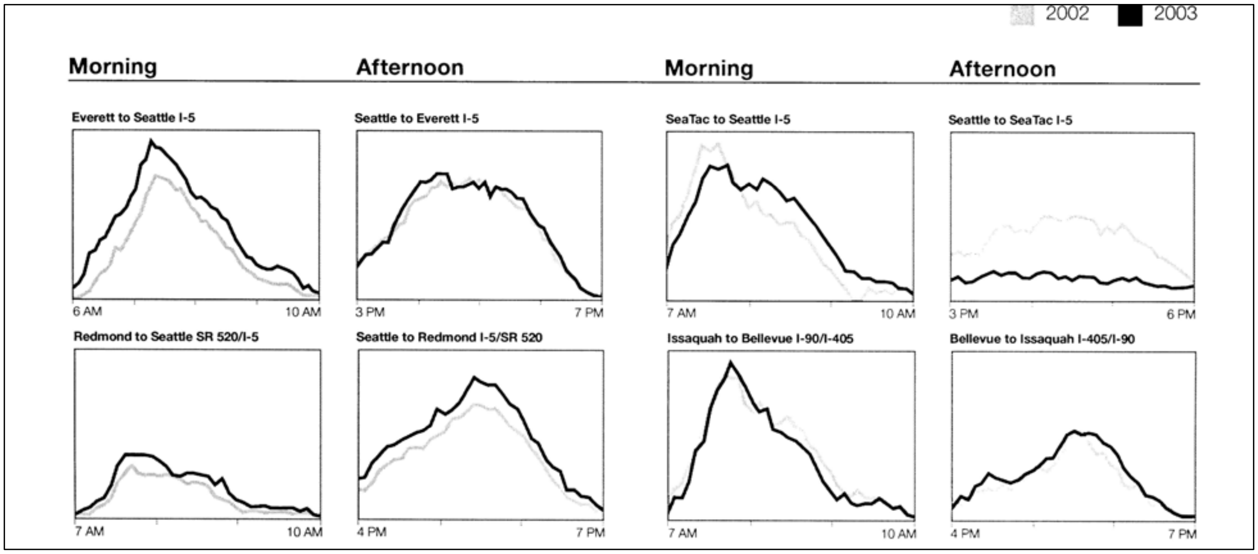
Source: FHWA (*4*).

Exhibit 7-15. Peak Hour Efficiency Values Based on "Lost Capacity" Concepts.



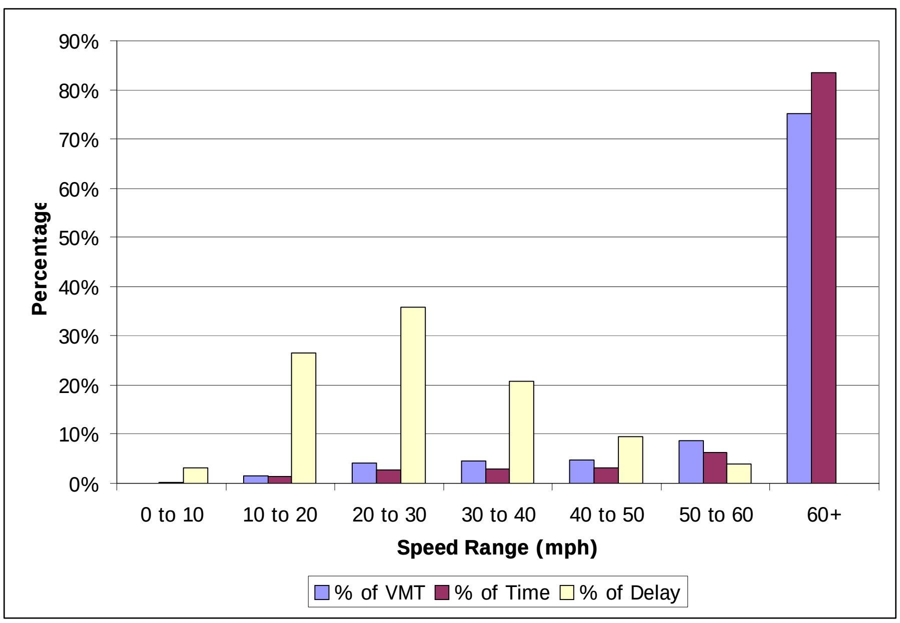
Source: FHWA (*4*).

Exhibit 7-16. Percent of Days with Speeds Less Than 35 mph.



Source: Washington State Department of Transportation (*1*)

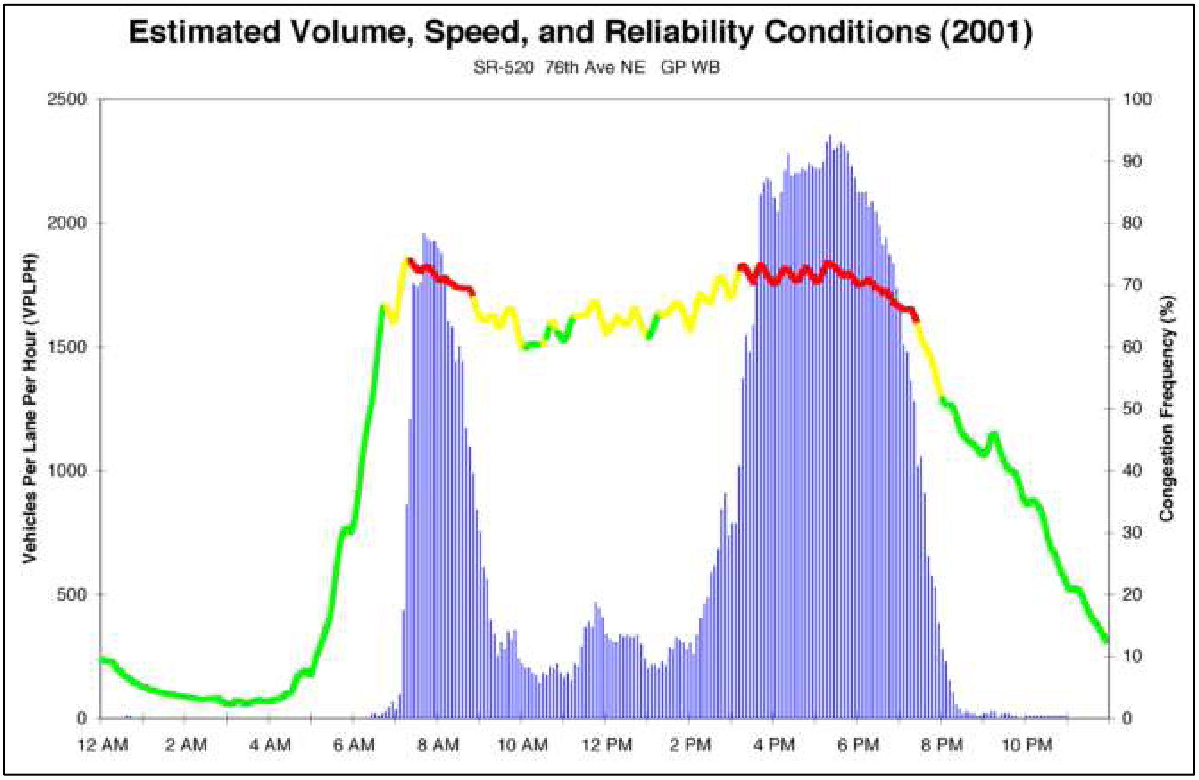
Exhibit 7-17. Percent of VMT, Delay, and Time Periods in Different Speed Ranges.



Source: FHWA (*3*)

Exhibit 7-18 illustrates a method for displaying volume, speed, and reliability conditions for SR 520 in the Puget Sound region. The information is provided by time of day. Vertical bars provide the congestion frequency (percent chance trips are below 45 mph). The volume line is color-coded to represent speeds of >55 mph (green), 45-55 mph (yellow), and <45 mph (red) for each 5-minute period.

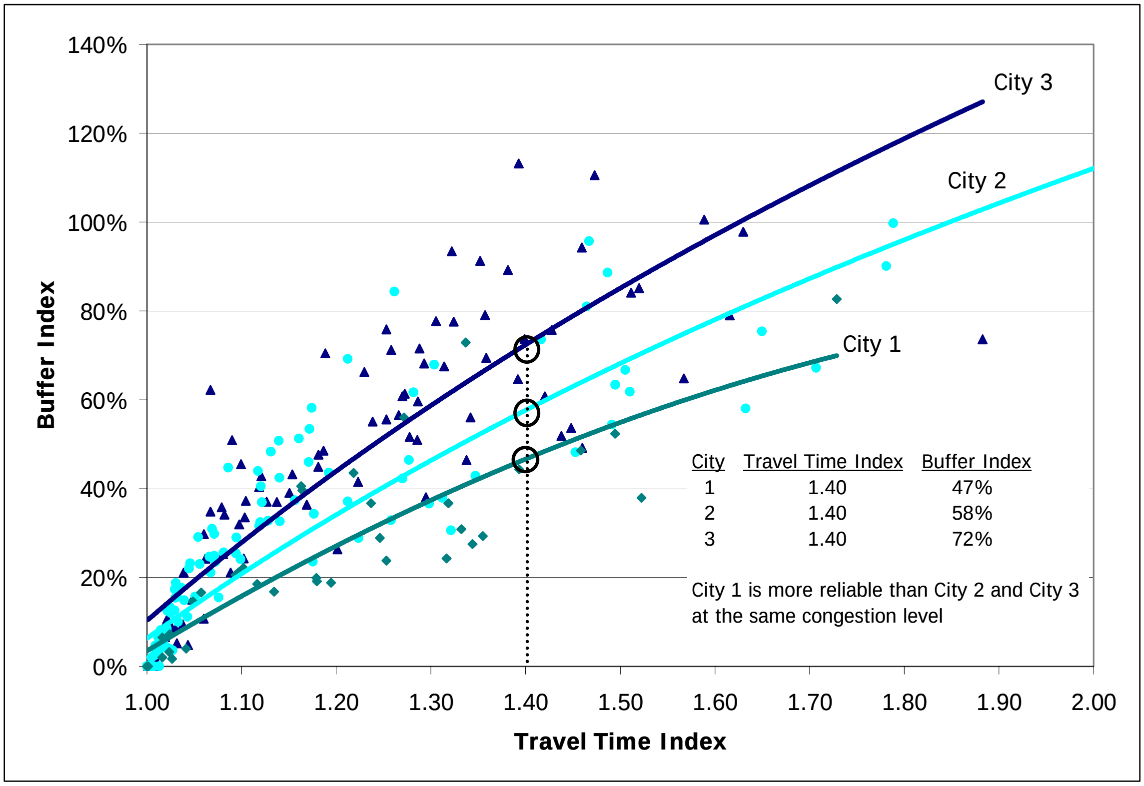
Exhibit 7-18. Change in HOV Speed and Reliability: I-5 Southbound, South of the Seattle CBD, S Spokane Street to S 184th Street.



Source: TTI (*4*)

Exhibit 7-19 illustrates an alterative way of estimating reliability. Travel time reliability is estimated as a function of the buffer index. Research continues at the Texas Transportation Institute to further identify the relationships between the travel time index and the buffer index using archived ITS data.

Exhibit 7-19. Exploring the Relationship between Congestion Level and Travel Reliability.



Source: FHWA (*2*)

7.3 References

1. "Measures, Markers and Mileposts: The Gray Notebook for the Quarter Ending September 30, 2004." Washington State Department of Transportation, November 2004. Available at: http://www.wsdot.wa.gov/accountability.

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CHAPTER 8—APPLICATION AND INTERPRETATION OF CONGESTION MEASURES

Chapter Summary

The focus of this chapter is to provide the reader with practical applications and interpretation of the congestion measures described in this report. This chapter discusses the application of techniques at different levels of analysis, including multimodal as well as long and short roadway sections. The sample applications include both an arterial and freeway roadway along the same corridor. The spreadsheet that includes the computations performed in this chapter is available at http://mobility.tamu.edu/resources. The spreadsheet can be downloaded and altered for specific analyses of interest.

While the spreadsheet applications primarily provide examples of congestion analyses that might be obtained from travel demand models or travel time runs, there is an example provided at the end of this chapter that illustrates typical mobility analysis using real-time (ITS) data. The final workbook of the spreadsheet includes the computation of mobility measures from an ITS data source.

This chapter will provide numerous applications of the performance measures defined and discussed in this paper. The examples include multimodal, corridor, and traffic operations improvement analyses. Many of the examples are updated from their initial presentation in *Quantifying Congestion* (*1*).

8.1 Application of Techniques at Different Levels of Analysis

Developing a system of congestion measures should be initiated only after an examination of the uses, users, and audiences to be served, and after full considerations of program goals and objectives and the nature of likely solutions. This chapter illustrates a system of travel time-based measures to estimate congestion levels. Chapter 5 introduced most of these mobility measurements. The procedures in this chapter are useful for roadway systems, other person and freight movement modes, and transportation improvement strategies and programs. Although a number of analyses may not benefit from such a broad focus, consideration of the context in which the measures are to be used will allow the user to identify the appropriate set of congestion measures.

Congestion measures are applied in different geographic settings, in different time frames, at differing levels of detail, at different scales, and under existing, changed, and future conditions. They must accurately describe present conditions and be capable of being forecast. There is a need for measures that can be applied across all passenger modes of urban travel individually and simultaneously. The majority of congestion measure applications remain highway oriented, but with increased emphasis on the movement of people.

The following sections describe techniques for measuring congestion on various sections of a transportation network. Examples are used to illustrate the application of the basic measures to typical situations of system evaluation or analysis of alternative improvements. Single mode and multimodal systems are integrated in the examples.

8.1.1 Applying Analysis Methods

The research clearly indicates the need to separate the issues of data collection from the measures that are used in technical analyses and presentations. The measures that are needed to evaluate the transportation system or the effect of improvements are the most important consideration. Data collection or measurement estimates can be developed in a variety of ways; these are important elements of a congestion monitoring program, but they should not be the key consideration in deciding which measures are used.

While direct measurement of travel time and speed is desirable for evaluation of existing congestion, it is not always practical. Moreover, when future conditions are analyzed, the travel time data that would be helpful in assessing potential effects of operational improvements or judging the cost-effectiveness of additional roadway lanes are obviously not available to be collected. Travel time and speed estimating procedures are needed for situations like this and are thus an important part of the congestion measurement process. Overall, there are several ways to accomplish measurement and estimation of congestion information.

The travel time and speed estimating procedures that are needed include relatively simple procedures that use easily obtained data, procedures that can be used by agencies responsible for system operations, and procedures that work well with travel demand models.

Exhibit 8-1 shows how the three basic categories of analysis relate to the four most common types of analysis. It serves as a general guide for practitioners to generate congestion information and to identify the appropriate data collection and analysis strategies.

- **Purpose—**For most types of general policy, programming, or planning purposes, the surrogate estimation procedures will provide useful results with a minimum of data collection. More specific design and operation concerns will require more precision, and direct measures of travel time or travel speed will usually be required.

- **Analysis period—**Most techniques can produce useful information for existing conditions, but future conditions will require some surrogate procedures (e.g., travel time or *HCM*). Surrogates will also be required for existing conditions where future scenarios will be analyzed. This approach will provide uniformity of estimation, avoiding inconsistencies associated with differences in roadway system operations.

- **Analysis scope and scale—***HCM* analysis procedures will be used for most intersection analyses and possibly for short roadway segments; direct travel time measures will be more useful for analysis areas greater than short roadway segments. If large corridors, sub-areas, or regions are to be analyzed, some sampling process will be useful to limit data collection requirements.

Exhibit 8-1. Applications of Congestion Analysis Methods.

Analysis Category	Type of Analysis Method			
	Highway Capacity Manual	**Direct Travel Time Measurement**	**Sampling Travel Time on Segments**	**Surrogate Travel Time Procedures**
Purpose				
Policy Analysis				T
Project Prioritization				T
Planning or Alternative Analysis		•	T	T
Design	•	T	T	
Operation	T	•		
Analysis Period				
Existing Conditions	T	T	T	•[1]
Future Conditions				
Short range	T	T	T	•[1]
Long range	•			T
Analysis Scope and Scale				
Intersections	T	•		
Single Roadway	•	T	•	
Corridor		T	T	•
Sub-area			T	T
Areawide			T	T

Source: NCHRP (*1*)

• Application in most analyses

T Limited application

[1] Particularly when needed as base condition for analysis of future conditions

8.1.2 Free-flow Travel Conditions

If estimated free-flow travel rates or speeds are used in the calculation of delay, the speed data collected from field studies may include values with faster speeds or lower rates. Computerized analysis procedures should be modified so that a "negative delay" value is not included in the calculations (as done in the examples in this chapter).

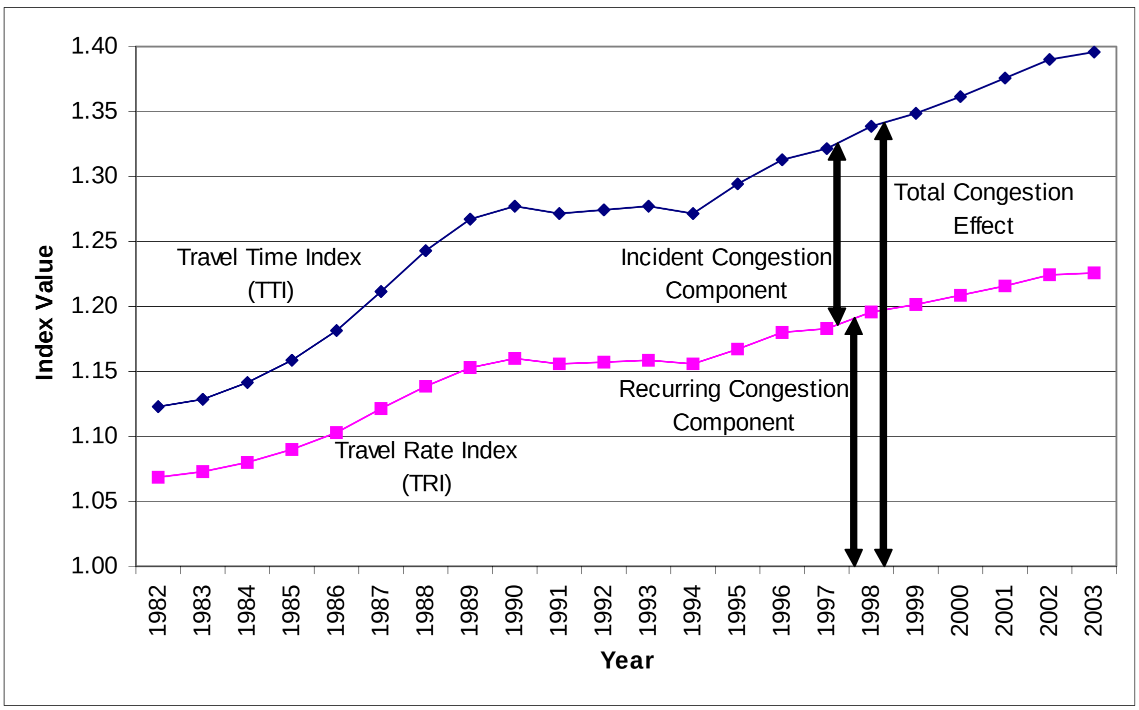
8.1.3 Travel Rate Index and Travel Time Index

It is important to recognize the fundamental differences between the Travel Rate Index and the Travel Time Index. Chapter 5 described the TTI in detail and provided an equation for computation. It should be noted that the TTI includes the impacts of incident conditions on congestion for the analysis period. Incident effects can be difficult to account for unless they are inherently included in the data source. Archived ITS (real-time) data include the effects of incidents because they monitor continuously. Therefore, the data captures the effects of recurring and incident conditions in the speed, volume, and occupancy information that they collect. Post-processing of travel demand model data can also be performed to estimate the effects of incidents to obtain TTI values. This can be done by estimating incident factors. Incident delay factors (the ratio of incident to recurring delay) are used in the *Urban Mobility Report* to include the effects of incidents.

Typically, incident conditions are not included for corridor studies along which travel time runs are performed. Incident-free conditions are often desired with travel time runs that have a limited number of travel time runs. To ensure the limited sample of travel time data collection are not "skewed" by falsely including a run or two that might include an incident condition, incident runs are usually removed from the travel time data set. Assuming an adequate sample, and by removing runs that include incidents, the resulting travel time data set provides an estimate of the recurring congestion along the corridor. In these conditions, the computed measure would be a TRI because it is computed with travel rates that do not include incident conditions (i.e., recurring congestion only). TRI is computed mathematically the same way as the TTI, but it does not include incident conditions.

Exhibit 8-2 graphically illustrates the difference between the TRI (includes recurring congestion only) and the TTI (includes both recurring and incident congestion). The spreadsheet applications in this chapter include a user-input percent of incident delay from which the performance measures are computed that include incidents.

Exhibit 8-2. Relationship between TTI and TRI over Time.



8.1.4 Common Data for All Examples

The basic formulas for congestion measurement are listed in Exhibit 8-3. More information on the measures can be found in Chapter 5. This summary is provided for easy reference in the examples. More specifically, Exhibit 8-4 describes the calculations and format used in the examples. The lines of data are labeled, and the calculations refer to the labels so that the information is easy to understand and code into spreadsheet or database formats. The first column of Exhibit 8-4 shows a discontinuity in the alphabetical data labels because the delay values and congested travel summary are shown in comparison to the "free-flow travel rate" conditions for illustration. The spreadsheet used for the calculations of the examples in this chapter is available at http://mobility.tamu.edu/ums, and it contains calculations relative to target, free-flow, and posted speed limit travel rates.

Exhibit 8-3. Quick Reference Guide to Measures of Congestion.

INDIVIDUAL MEASURES[1]	
Delay per Traveler	$\underset{(\text{annual hours})}{\text{Delay per Traveler}} = \frac{\left(\underset{(\text{minutes})}{\text{Actual Travel Time}} - \underset{(\text{minutes})}{\text{FFS or PSL Travel Time}}\right) \times \underset{(\text{vehicles})}{\text{Vehicle Volume}} \times \underset{(\text{persons/vehicle})}{\text{Vehicle Occupancy}} \times \frac{250 \text{ weekdays}}{\text{year}} \times \frac{\text{hour}}{60 \text{ minutes}}}{\underset{(\text{vehicles})}{\text{Vehicle Volume}} \times \underset{(\text{persons/vehicle})}{\text{Vehicle Occupancy}}}$
Travel Time	$\underset{(\text{person} - \text{minutes})}{\text{Travel Time}} = \underset{(\text{minutes per mile})}{\text{Actual Travel Rate}} \times \underset{(\text{miles})}{\text{Length}} \times \underset{(\text{vehicles})}{\text{Vehicle Volume}} \times \underset{(\text{persons/vehicles})}{\text{Vehicle Occupancy}}$
Travel Time Index[2]	$\text{Travel Time Index} = \frac{\underset{(\text{minutes per mile})}{\text{Actual Travel Rate}}}{\underset{(\text{minutes per mile})}{\text{FFS or PSL Travel Rate}}}$
Buffer Index[2]	$\text{Buffer Index } (\%) = \left[\frac{\underset{(\text{minutes})}{\text{95th Percentile Travel Time}} - \underset{(\text{minutes})}{\text{Average Travel Time}}}{\underset{(\text{minutes})}{\text{Average Travel Time}}}\right] \times 100\%$
AREA MOBILITY MEASURES[1]	
Total Delay	$\underset{(\text{person-minutes})}{\text{Total Segment Delay}} = \left[\underset{(\text{minutes})}{\text{Actual Travel Time}} - \underset{(\text{minutes})}{\text{FFS or PSL Travel Time}}\right] \times \underset{(\text{vehicles})}{\text{Vehicle Volume}} \times \underset{(\text{persons/vehicle})}{\text{Vehicle Occupancy}}$
Congested Travel	$\underset{(\text{vehicle-miles})}{\text{Congested Travel}} = \sum \left(\underset{(\text{miles})}{\text{Congested Segment Length}} \times \underset{(\text{vehicles})}{\text{Vehicle Volume}}\right)$
Percent of Congested Travel	$\text{Percent of Congested Travel} = \left[\frac{\sum_{i=1}^{m}\left(\left(\underset{(\text{minutes})}{\text{Actual Travel Time}_i} - \underset{(\text{minutes})}{\text{FFS or PSL Travel Time}_i}\right) \times \left(\underset{(\text{vehicles})}{\text{Vehicle Volume}_i} \times \underset{(\text{persons/vehicle})}{\text{Vehicle Occupancy}_i}\right)\right)_{\text{Each congested segment}}}{\sum_{i=1}^{n}\left(\underset{(\text{minutes per mile})}{\text{Actual Travel Rate}_i} \times \underset{(\text{miles})}{\text{Length}_i} \times \underset{(\text{vehicles})}{\text{Vehicle Volume}_i} \times \underset{(\text{persons/vehicle})}{\text{Vehicle Occupancy}_i}\right)_{\text{All segments}}}\right] \times 100$
Congested Roadway	$\underset{(\text{miles})}{\text{Congested Roadway}} = \sum \text{Congested Segment Lengths (miles)}$
Accessibility	$\underset{(\text{opportunities})}{\text{Accessibility}} = \sum \text{Objective Fulfillment Opportunities (e.g., jobs), Where Travel Time} \leq \text{Target Travel Time}$

[1]"Individual" measures are those measures that relate best to the individual traveler, whereas the "area" mobility measures are more applicable beyond the individual (e.g., corridor, area, or region). Some individual measures are useful at the area level when weighted by PMT or VMT.

[2]Can be computed as a weighted average of all sections using VMT or PMT).

Note: FFS = Free-flow speed, PSL = Posted speed limit.

Exhibit 8-4. Formula Descriptions for Congestion Measurement Examples.

Label	Measure	Units	Description
a	Length	Miles	input value
b	Vehicle Volume	Vehicles	collected value
c	Average Vehicle Occupancy	Persons/Vehicle	collected value
d	Percent Incident Delay	Percent	collected value
	Speeds		
e	Free-flow Speed	Miles/Hour	collected value
f	Speed limit	Miles/Hour	collected value
g	Target Speed	Miles/Hour	collected value
h	Non-incident Speed	Miles/Hour	collected value
i	Estimated Actual Speed	Miles/Hour	(g x a x b x c) / ([g x bp]) + [a x b x c])
Initial Computations			
j	Person Volume	Persons	b x c
k	Vehicle-miles	Vehicle-miles	a x b
l	Person-miles	Person-miles	j x a
	Travel Rates		
m	Free-flow Travel Rate	Minutes/Mile	60 / e
n	Speed Limit Travel Rate	Minutes/Mile	60 / f
o	Target Travel Rate	Minutes/Mile	60 / g
p	Non-incident Travel Rate	Minutes/Mile	60 / h
q	Estimated Actual Travel Rate	Minutes/Mile	60 / i
	Travel Times		
r	Free-flow Travel Time	Person-Hours	(l x m) / 60
s	Speed Limit Travel Time	Person-Hours	(l x n) / 60
t	Target Travel Time	Person-Hours	(l x o) / 60
u	Non-incident Travel Time	Person-Hours	(l x p) / 60
v	Estimated Actual Travel Time	Person-Hours	(l x q) / 60
	Total Delay Rate		
w	vs. free-flow	Minutes/Mile	q - m
x	vs. speed limit	Minutes/Mile	q - n
y	vs. target	Minutes/Mile	q - o
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	collected value
Recurring Delay Computations (Supports Mobility Measures)			
	Recurring Delay Rate		
aa	vs. free-flow	Minutes/Mile	p - m
	Recurring Delay (vs. free-flow)		
ad	Vehicle Travel	Vehicle-Hours	(k x aa) / 60
ae	Person Travel	Person-Hours	(l x aa) / 60
Mobility Performance Measures Computations			
	Congested Travel Summary		
ay	Person-Miles (vs. free-flow)	Person-Hours	Sum of congested person-miles (line l if line w is greater than zero)
bb	Person-Hours (vs. free-flow)	Person-Hours	Sum of congested person hours (line v if line w is greater than zero)
be	Miles of Congested Roadway (vs. free-flow)	Miles	Sum of congested miles (line a if line w is greater than zero)
	Percent of Congested Travel		
bh	vs. free-flow	Percent	(bb / v) x 100
	Total Delay (vs. free-flow)		
bk	Vehicle Travel	Vehicle-Hours	ad / (1 - d/100)
bl	Person Travel	Person-Hours	ae / (1 - d/100)
	Total Delay (vs. free-flow) per:		
bw	Person-Mile	Person-Minutes	(bl x 60) / l
bx	Mile of Road	Person-Hours	bl / a
	Travel Time Index		
cc	vs. free-flow	Travel Rate Ratio	q / m

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-5 presents the free-flow speeds used in the examples. Exhibit 8-6 shows the target TTI values used in the examples. In a typical application, the target TTI values would be developed with input from citizens, businesses, decision makers, and transportation professionals. They represent the crucial link between 1) the vision that the community has for its transportation system, land uses, and its "quality of life" issues and 2) the improvement strategies, programs, and projects that government agencies and private sector interests will implement. The values are desirably the result of a process that is integrated with the development of the long-range plan, but they must be reasonable and realistic, since overstatement or understatement could distort congestion assessment. The level of information needed to carry out this type of process at an optimum level is not currently distributed in most urban areas. The values can, however, be interpreted from existing input processes. **The values in Exhibit 8-5, Exhibit 8-6, and Exhibit 8-7 are for illustration purposes only.**

Exhibit 8-5. Free-flow Speed (mph) Used in the Examples.

Freeway Mainlane	Freeway HOV	Major Street	Bus on Street	Rail in Street	Bike
60	60	35	15	20	15

Exhibit 8-6. Target TTI Used in the Examples.

Area Type	Peak	Off-peak
Central Business District	1.7	1.2
Central City/Major Activity Center	1.5	1.1
Suburban	1.3	1.0
Fringe	1.0	1.0

Exhibit 8-7. Target Peak and Off-peak Speeds (mph).

	Freeway Mainlane		Freeway HOV		Major Street		Bus on Street		Rail in Street		Bike	
Area Type	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
Central Business District	35	50	35	50	21	29	9	13	12	17	9	13
Central City /Major Activity Center	40	55	40	55	23	32	10	14	13	18	10	14
Suburban	46	60	46	60	27	35	12	15	15	20	12	15
Fringe	60	60	60	60	35	35	15	15	20	20	15	15

The examples in this section are for several levels of analysis from isolated locations to regional analyses, but they are based on individual facility evaluations. These include segments of freeways and streets, with general-purpose traffic, as well as buses, rail transit, and carpools. The examples also show several alternative improvements that might be proposed to address congestion and mobility problems including better operational efficiency, increases in transit and rideshare use, and improvements in operations through improved traffic signals and incident response.

Urban areas should approach the use of target travel rates with a systemwide strategy. They should recognize that the targets may not be achievable for every roadway situation. Other travel mode improvements, strategies, or policies may be needed. For example, the target speeds shown in Exhibit 8-7 do not equate to slow enough speeds to justify an HOV lane under normal circumstances. It is likely, however, that the freeway speeds will be lower than those in Exhibit 8-7 in most large urban areas. An HOV lane can contribute to bringing the Travel Time Index for the corridor, when weighted by person volume, closer to the target value.

The examples are focused on the appropriate level of detail necessary to identify the effect of a proposed treatment. For most alternatives, this is at the corridor level or more detailed; this is the area where the effect of the improvement can be identified and the reasonableness of the measurement techniques can be checked. The magnitude of the numbers for a wider area may mask the impact of a single improvement, especially for relatively small changes. The corridor level of analysis is also where most projects are evaluated, prioritized, and funded.

Focusing on individual facilities or modes, however, is not consistent with the manner in which most travelers make their choices. Door-to-door travel time is closer to the primary measure used by travelers and is best expressed in accessibility measures (see Exhibit 8-3 for more information on the accessibility measure). Unfortunately, it is difficult to translate an accessibility measure like "population within 30 minutes' travel time of a major activity center" into a procedure to evaluate signal improvements on an arterial street. The transportation and land use planning model required to calculate the accessibility may not be sensitive enough to identify the improvement in travel conditions.

The method to connect accessibility measures with the many smaller scale analyses is the target travel condition values. The target Travel Time Index and associated speeds identify when citizens believe improvements should be made. The conditions that citizens find unacceptable will be a mix of economic development, transportation, and quality of life considerations. The discussion about what constitutes unacceptable conditions could be conducted in conjunction with the long-range planning process and the future visions of the area.

The examples depict peak-hour conditions, but the same procedures could be used for peak-period, off-peak periods, or daily analyses. The weighting process used in the examples to calculate averages and totals for different modes and sections of roadway—using person-volume—is the same one used to calculate peak period and daily measures. The peak hour focus used here allows the users to see the calculation procedures and usage of the statistics. Post-project evaluations may show no improvement in peak hour performance, but there may be reductions in the length of the peak period that are affected by congestion.

8.1.5 Individual Locations

Analyses of intersections should be performed according to the 2000 *Highway Capacity Manual* procedures or other commonly accepted intersection or site analysis procedures. Stopped delay intersection studies can be used to directly collect delay information. Observations of traffic backups—their extent and duration—are very useful.

It is difficult to apply travel time and speed study types to the analysis of intersections. Floating car runs or license plate matching studies are not very meaningful for short distances in which one signal controls the variability of travel speeds. As traffic signals are connected into systems, however, it will become more difficult to analyze any intersection in isolation, and longer sections of roadway will become the basic unit for more analyses.

Traditional measures of service quality at signalized intersections include stopped delay per vehicle and the number of stops. It is suggested that the measures of **delay** and **delay per vehicle** or **per person** be considered for intersection congestion studies. These measures are consistent with current intersection analysis measures and provide the ability to calculate quantities that reflect the importance of person movement. These quantities can be developed from direct data collection efforts or from the *Highway Capacity Manual* procedures. **Accessibility** can be used to estimate the effect of transportation conditions on travel associated with localized site development but has little applicability to evaluating traffic operations at individual locations.

Short Roadway Sections

The analysis of short roadway sections, on the magnitude of 1 to 4 miles, differs somewhat from the analysis of longer roadway sections. Short roadway sections may match existing divisions of roadway inventory data or could include several relatively homogenous roadway links between intersections and interchanges. These individual roadway links within a short section should have similar cross sections, traffic volumes, and operating conditions. Individual links that have different cross sections or operating conditions should not be combined together to form a short roadway section. Instead, roadway links with different characteristics should be considered separately or with other adjacent links that have similar characteristics.

The use of travel time and travel rate data is well suited to the analysis of roadway sections. Travel times between intersections or interchanges can be added to match the appropriate section length. Because the cross section and traffic volumes are similar for each link, a single average or representative data value can be used to represent all links within a section. Congestion on short sections can be identified by comparing the actual Travel Time Index to the target Travel Time Index.

Suggested Measures. Appropriate measures for short roadway sections include the **average travel rate**, **delay rate**, **total segment delay,** and the **Travel Time Index**. These measures will provide useful information at this level of analysis. The average travel rate, delay rate, and Travel Time Index can be used in absolute terms or can be used to compare similar classes of facilities. The total delay and Travel Time Index can be used to compare different classes of facilities.

Highway Capacity Manual procedures may be used to develop estimates for these quantities. However, in severely congested corridors or for before/after studies of coordinated or adaptive signal systems (systems that can change timing plans several times during the peak in response to demand), direct data collection studies will be more appropriate and useful in estimating congestion levels.

Example. Exhibits 8-8 and 8-9 illustrate several key congestion statistics for a freeway and a major street. These statistics are similar to those that would be used if a congestion evaluation were performed on an individual facility or as one part of an areawide analysis. License plate matching, floating car travel time runs, or automated vehicle monitoring could be used to develop the travel time and speed information. Roadway inventory files could be used to identify logical section limits as well as other useful information, such as the number of lanes.

Main Street. Two sections of four-lane Main Street are displayed in Exhibit 8-8. The auto and bus modes are separated because the travel speed and vehicle occupancy rates are significantly different. Improvements to the sections may also change the travel characteristics of the modes differently, so the data were collected separately. The total or average column presents information on both sections together.

The length, volume, and person-miles of travel are used in calculating cumulative statistics and in weighting for average statistics. The target speeds are less than the free-flow speeds, indicating that some level of congestion is considered acceptable for this portion of the system. The actual travel rates are higher than the target rates, indicating a need for improvements to attain the target travel rates.

The most useful statistics for evaluations are found in lines v through bs. Note that additional calculations are included in the attached spreadsheet. This is why the alphabetical label names are discontinuous. The delay rate is calculated relative to the free-flow speed, target speed, and speed limit. The target travel rate is the value that would be used to compare alternative improvement projects, while the free-flow comparison is useful in quantifying areawide congestion levels. The delay values are the cumulative statistics that would be used in estimating the benefit/cost relationship for new projects or improvement strategies.

The TTI for this suburban corridor is 1.55 when comparing to the target speed. In comparison with Exhibit 8-6, this indicates that improvements are necessary to meet the target TTI value of 1.3.

Southside Freeway. The statistics for this section of six-lane Southside Freeway are the same type as those presented for Main Street. This section of Southside Freeway is also congested relative to both free-flow and target values. The bus volume on the freeway is double that on Main Street, but the autos in the freeway mainlanes carry many more persons than the buses such that the cumulative statistics are governed by the auto travel conditions. Since the buses are not stopping on the freeway, as they do on the street, their performance statistics are very similar to the autos with respect to speed and speed reliability.

Exhibit 8-8. Existing Operation on Main Street Example.

Roadway Name: Main Street
Location: 71st to 89th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: Existing Operation

Label	Measure	Units	System Element: 71st Street to 80th Street – Auto	71st Street to 80th Street – Bus	80th Street to 89th Street – Auto	80th Street to 89th Street – Bus	Total or Average
a	Length	Miles	2.8	2.8	3.5	3.5	6.3
b	Vehicle Volume	Vehicles	1000	8	1200	10	
c	Average Vehicle Occupancy	Persons/Vehicle	1.20	31.25	1.21	30.00	1.44
d	Percent Incident Delay	Percent	40	40	50	50	
	Speeds						
e	Free-flow Speed	Miles/Hour	35	15	35	15	28
f	Speed limit	Miles/Hour	30	30	30	30	30
g	Target Speed	Miles/Hour	25	15	25	15	22
h	Non-incident Speed	Miles/Hour	20	12	15	10	15
i	Estimated Actual Speed	Miles/Hour	18	11	11	8	12
Initial Computations							
j	Person Volume	Persons	1,200	250	1,452	300	
k	Vehicle-miles	Vehicle-miles	2,800	22	4,200	35	7,057
l	Person-miles	Person-miles	3,360	700	5,082	1,050	10,192
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	1.71	4.00	1.71	4.00	2.11
n	Speed Limit Travel Rate	Minutes/Mile	2.00	2.00	2.00	2.00	2.00
o	Target Travel Rate	Minutes/Mile	2.40	4.00	2.40	4.00	2.67
p	Non-incident Travel Rate	Minutes/Mile	3.00	5.00	4.00	6.00	3.95
q	Estimated Actual Travel Rate	Minutes/Mile	3.40	5.67	5.60	8.00	5.13
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	190	66	474	140	871
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	1.69	1.67	3.89	4.00	3.02
x	vs. speed limit	Minutes/Mile	1.40	3.67	3.60	6.00	3.13
y	vs. target	Minutes/Mile	1.00	1.67	3.20	4.00	2.45
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.7	0.5	0.7	0.5
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	1.29	1.00	2.29	2.00	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	60.0	0.4	160.0	1.2	
ae	Person Travel	Person-Hours	72.0	11.7	193.6	35.0	
Mobility Performance Measures Computations							
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	100	1	320	2	423
bl	Person Travel	Person-Hours	120	19	387	70	597
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	2	2	5	4	4
bx	Mile of Road	Person-Hours	43	7	111	20	72
	Travel Time Index						
cc	vs. free-flow	Travel Rate Ratio	1.98	1.42	2.33	1.50	2.07

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-9. Existing Operation of Southside Freeway.

Roadway Name: Southside Freeway

Location: 71st to 130th Street (Suburban)

Travel Period: Morning Peak Hour

Travel Direction: Northbound (Peak Direction)

Alternative: Existing Operation

Label	Measure	Units	System Element: 71st Street to 101st Street – Auto	System Element: 71st Street to 101st Street – Bus	System Element: 101st Street to 130th Street – Auto	System Element: 101st Street to 130th Street – Bus	Total or Average
a	Length	Miles	4.4	4.4	4.0	4.0	8.4
b	Vehicle Volume	Vehicles	5,800	20	5,500	20	
c	Average Vehicle Occupancy	Persons/Vehicle	1.20	32.50	1.20	32.50	1.31
d	Percent Incident Delay	Percent	50	50	50	50	50
	Speeds						
e	Free-flow Speed	Miles/Hour	65	65	65	65	65
f	Speed limit	Miles/Hour	60	60	60	60	60
g	Target Speed	Miles/Hour	45	45	45	45	45
h	Non-incident Speed	Miles/Hour	30	30	25	25	27
i	Estimated Actual Speed	Miles/Hour	23	23	17	17	20
Initial Computations							
j	Person Volume	Persons	6,960	650	6,600	650	
k	Vehicle-miles	Vehicle-miles	25,520	88	22,000	80	47,688
l	Person-miles	Person-miles	30,624	2,860	26,400	2,600	62,484
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	0.92	0.92	0.92	0.92	0.92
n	Speed Limit Travel Rate	Minutes/Mile	1.00	1.00	1.00	1.00	1.00
o	Target Travel Rate	Minutes/Mile	1.33	1.33	1.33	1.33	1.33
p	Non-incident Travel Rate	Minutes/Mile	2.00	2.00	2.40	2.40	2.19
q	Estimated Actual Travel Rate	Minutes/Mile	2.67	2.67	3.47	3.47	3.04
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	1361	127	1525	150	3,164
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	1.08	1.08	1.48	1.48	1.26
x	vs. speed limit	Minutes/Mile	1.00	1.00	1.40	1.40	1.19
y	vs. target	Minutes/Mile	0.67	0.67	1.07	1.07	0.85
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5	0.5	0.5
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	1.08	1.08	1.48	1.48	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	458	2	542	2	
ae	Person Travel	Person-Hours	550	51	650	64	
Mobility Performance Measures Computations							
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	916	3	1,083	4	2,006
bl	Person Travel	Person-Hours	1,099	103	1,300	128	2,630
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	2	2	3	3	3
bx	Mile of Road	Person-Hours	250	23	325	32	262
	Travel Time Index`						
cc	vs. free-flow	Travel Rate Ratio	2.89	2.89	2.60	2.60	2.75

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Long Roadway Sections or Routes

The analysis of long roadway sections or routes, generally greater than 4 to 5 miles, must take into consideration the different operating characteristics of the roadway along the entire length. Routes will contain two or more short roadway sections with different cross sections and operating characteristics. Consequently, congestion studies must recognize and account for the different operating conditions along the route. Average or representative travel time values should be developed for each short roadway section within a route, and various cumulative statistics can be calculated for the entire route.

Suggested Measures. Average statistics, like the **average travel rate** and the **average delay rate**, are weighted by the length of each segment and may be less meaningful for long routes or routes with widely varying conditions. The **Travel Time Index** is also a good measure. Cumulative statistics, like **total delay**, **congested travel**, and **congested roadway** may provide more useful information for these longer routes. Again, vehicle occupancies should be used to obtain person delay.

Main Street Example. Longer route section summaries can either identify each mode individually (as in Exhibit 8-8) or present the statistics as a combination of all modes on the route. Exhibit 8-10 shows the simpler nature of the combined mode format for sections with several road segments. The 71st to 89th Street segment statistics are drawn from Exhibit 8-8 and combined with the new 89th to 95th Street segment. The estimated actual travel rate is equal to the target travel rate for 89th to 95th. This is presented as no delay in line af and line am. The standard deviation is also slightly less in the less-congested section, possibly due to the lower volume, which allows for minor incidents to be handled without much impact on traffic flow.

Travel conditions in longer sections are more easily described by the cumulative statistics in lines ay through bh. Using person-miles of travel to weight the individual section values results in a measure of the average condition seen by the travelers in the 71st to 95th section of Main Street. An average of 3 minutes of delay is incurred by the travelers on Main Street, and an average of 92 person-hours of delay is incurred daily on each mile of this section of Main Street. The Travel Time Index for the entire arterial section is 2.25 (relative to the free-flow travel rate). These averages obviously hide some of the problems between 71st and 89th, but these are identified in the person-miles, person-hours, and miles of congested roadway statistics. These are developed by summing the statistics (for lines a, l, and v) in every section of road that is congested (71st to 95th).

Exhibit 8-10. Long Section Analysis along Main Street.

Roadway Name: Main Street
Location: 71st to 95th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: Existing Operation

Label	Measure	Units	System Element 71st to 80th (Exhibit 8-8)	System Element 80th to 89th (Exhibit 8-8)	System Element 89th to 95th (New Section)	Total or Average
a	Length	Miles	2.8	3.5	2.1	8.4
b	Vehicle Volume	Vehicles	1,008	1,210	700	
c	Average Vehicle Occupancy	Persons/Vehicle	1.44	1.44	1.44	1.44
d	Percent Incident Delay	Percent	45	45	50	
	Speeds					
e	Free-flow Speed	Miles/Hour	25	25	25	25
f	Speed limit	Miles/Hour	30	30	30	30
g	Target Speed	Miles/Hour	20	20	20	20
h	Non-incident Speed	Miles/Hour	15	12	25	14
i	Estimated Actual Speed	Miles/Hour	12	9	20	11
Initial Computations						
j	Person Volume	Persons	1,452	1,742	1,008	
k	Vehicle-miles	Vehicle-miles	2,822	4,235	1,470	8,527
l	Person-miles	Person-miles	4,064	6,098	2,117	12,279
	Travel Rates					
m	Free-flow Travel Rate	Minutes/Mile	2.40	2.40	2.40	2.40
n	Speed Limit Travel Rate	Minutes/Mile	2.00	2.00	2.00	2.00
o	Target Travel Rate	Minutes/Mile	3.00	3.00	3.00	3.00
p	Non-incident Travel Rate	Minutes/Mile	4.00	5.00	2.40	4.22
q	Estimated Actual Travel Rate	Minutes/Mile	4.82	6.64	3.00	5.41
	Travel Times					
v	Estimated Actual Travel Time	Person-Hours	326	675	106	1,107
	Total Delay Rate					
w	vs. free-flow	Minutes/Mile	1.60	2.60	0.00	1.82
x	vs. speed limit	Minutes/Mile	2.00	3.00	0.40	2.22
y	vs. target	Minutes/Mile	1.00	2.00	0.00	1.32
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5	0.5
Recurring Delay Computations (Supports Mobility Measures)						
	Recurring Delay Rate					
aa	vs. free-flow	Minutes/Mile	1.60	2.60	0.00	
	Recurring Delay (vs. free-flow)					
ad	Vehicle Travel	Vehicle-Hours	75	184	0.0	
ae	Person Travel	Person-Hours	108	264	0.0	
Mobility Performance Measures Computations						
	Congested Travel Summary					
ay	Person-Miles (vs. free-flow)	Person-Hours	4,064	6,098	0	10,163
bb	Person-Hours (vs. free-flow)	Person-Hours	326	675	0	1,001
be	Miles of Congested Roadway (vs. free-flow)	Miles	2.8	3.5	0.0	6.3
	Percent of Congested Travel					
bh	vs. free-flow	Percent	100	100	0	83
	Total Delay (vs. free-flow)					
bk	Vehicle Travel	Vehicle-Hours	137	334	0.0	471
bl	Person Travel	Person-Hours	197	481	0.0	678
	Total Delay (vs. free-flow) per:					
bw	Person-Mile	Person-Minutes	3	5	0.0	3
bx	Mile of Road	Person-Hours	70	137	0.0	92
	Travel Time Index					
cc	vs. free-flow	Travel Rate Ratio	2.01	2.77	1.25	2.25

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Corridors

The analysis of congestion along corridors would be similar to a route analysis but could include parallel freeway and arterial street routes that serve dense travel corridors. At this level of analysis, surrogate measurement techniques could be combined with direct data collection to obtain the necessary information. A calibration process would be required to correlate the direct and surrogate statistics so that variations in estimated travel speed are due to traffic conditions and not due to differences in the measurement technique.

The number of data collection sites could be governed by a statistical sample of the routes or could be performed for all major movements in the corridor. The calculation of average travel and delay rates for the corridor as a whole would be based on individual segment data. Statistics for each segment could be summed or averaged in discrete quantities (short sections) to form a corridor analysis. The relative delay rate can serve as a method to examine congestion levels on the combination of freeways and streets.

Suggested Measures. Average statistics for travel rate and delay rate are useful for intermediate calculations, but they may not provide an accurately detailed description of operating conditions and are difficult to interpret or relate to some audiences. Cumulative statistics like **total delay**, **congested travel**, and **travel time** are more meaningful at this level of analysis. The **delay rate** and **Travel Time Index** can be used to compare congestion levels on freeways and arterial streets.

Corridor Example. The Main Street and Southside Freeway summary statistics are presented in Exhibit 8-11 to quantify the corridor congestion level. **Total delay**, **Travel Time Index**, and **congested travel** measures are evaluative statistics that are particularly useful in improvement analyses. They identify the magnitude of the problem and point to some solutions that might be studied. The **delay per person** quantifies a measure of the intensity of congestion, which is more explainable to the public and is close to the way the public perceives congestion levels. The **person delay per mile of road** is also a useful value for comparing congestion levels on sections of road with varying lengths and varying transit ridership and rideshare activity.

More relevant values in comparisons between streets and freeways in a corridor are the **delay rate** and the **Travel Time Index**. Relative comparisons are very important to identifying corridors and facilities within those corridors for improvement studies. The process of combining the modes for a corridor average should not overlook the important modal analyses that must also take place to evaluate individual facilities because that is the level where many improvements are made (e.g., more lanes, parking spaces, buses, improved traffic signal systems, improved rideshare programs, and access management policies).

Exhibit 8-11. Corridor Analysis Including Main Street and Southside Freeway.

Roadway Name: Main Street and Southside Freeway					
Location: Main Street 71st to 95th (Suburban)					
Travel Period: Morning Peak Hour					
Travel Direction: Northbound (Peak Direction)					
Alternative: Corridor Roadways					
			System Element		
Label	**Measure**	**Units**	**Main Street (Exhibit 8-10)**	**Southside Freeway (Exhibit 8-9)**	**Total or Average**
a	Length	Miles	8.4	8.4	16.8
b	Vehicle Volume	Vehicles	1,015	5,677	
c	Average Vehicle Occupancy	Persons/Vehicle	1.44	1.31	1.33
d	Percent Incident Delay	Percent	45	50	
	Speeds				
e	Free-flow Speed	Miles/Hour	25	65	51
f	Speed limit	Miles/Hour	30	60	52
g	Target Speed	Miles/Hour	20	45	37
h	Non-incident Speed	Miles/Hour	14	27	24
i	Estimated Actual Speed	Miles/Hour	11	20	
Initial Computations					
j	Person Volume	Persons			
k	Vehicle-miles	Vehicle-miles	8,527	47,688	56,215
l	Person-miles	Person-miles	12,279	62,484	74,763
	Travel Rates				
m	Free-flow Travel Rate	Minutes/Mile	2.40	0.92	1.17
n	Speed Limit Travel Rate	Minutes/Mile	2.00	1.00	1.16
o	Target Travel Rate	Minutes/Mile	3.00	1.33	1.61
p	Non-incident Travel Rate	Minutes/Mile	4.22	2.19	2.52
q	Estimated Actual Travel Rate	Minutes/Mile	5.41	3.04	3.43
	Travel Times				
v	Estimated Actual Travel Time	Person-Hours	1,107	3,164	2,826
	Total Delay Rate				
w	vs. free-flow	Minutes/Mile	1.82	1.26	1.35
x	vs. speed limit	Minutes/Mile	2.22	1.19	1.36
y	vs. target	Minutes/Mile	1.32	0.85	0.93
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5
Mobility Performance Measures Computations					
	Congested Travel Summary				
ay	Person-Miles (vs. free-flow)	Person-Hours	10,163	62,484	72,647
bb	Person-Hours (vs. free-flow)	Person-Hours	1,001	3,164	4,165
be	Miles of Congested Roadway (vs. free-flow)	Miles	6.3	8.4	14.7
	Percent of Congested Travel				
bh	vs. free-flow	Percent	83	100	97
	Total Delay (vs. free-flow)				
bk	Vehicle Travel	Vehicle-Hours	471	2,006	2,477
bl	Person Travel	Person-Hours	678	2,630	3,307
	Total Delay (vs. free-flow) per:				
bw	Person-Mile	Person-Minutes	3	3	3
bx	Mile of Road	Person-Hours	92	262	234
	Travel Time Index				
cc	vs. free-flow	Travel Rate Ratio	2.25	2.75	2.67

Note: See Section 5.4 for further explanation of speed terms and application guidance.

The Travel Time Index is a particularly useful measure for corridor analysis as shown in Exhibit 8-11. It is a ratio of actual to target travel rate conditions and is quantified as 1.89 for this corridor analysis. In this case, the TTI, for the arterial section and freeway section are similar.

Corridor Improvement Comparisons

New projects, programs, or strategies are frequently selected and implemented at the corridor level. Travel time and speed statistics are very useful for single-mode and multimodal comparisons at this level of analysis. The corridor measures that are most useful will vary according to the types of improvements that are examined. Strategies that do not significantly change average vehicle occupancy can be conducted without person-travel measures. However, it may be desirable to use a general average vehicle occupancy factor to present the information in person terms if the audience is used to seeing values in that way or if the presenter is trying to educate the audience on those types of measurement techniques.

Main Street Examples. Two types of improvements were modeled for the congested section of Main Street. An improvement in signal operations is illustrated in Exhibit 8-12 and the addition of a light rail transit (LRT) line in the median of Main Street is illustrated in Exhibit 8-13. A summary of the statistics in Exhibit 8-8, Exhibit 8-12, and Exhibit 8-13 forms Exhibit 8-14, which can be used to evaluate the improvements. In general, the light rail line example shows increases in person travel, vehicle occupancy, transit ridership, and transit travel speed. The signal operation improvement example was prepared to show increased traffic volume and reductions in delay but not a significant change in vehicle occupancy.

The target delay rate decreases more for the signal improvement alternative, but the light rail example also shows a decrease despite the fact that the light rail line has a lower target travel rate than the bus routes. This is because there is a greater number of people using the transit lane, which operates at a lower speed than cars. The increased person movement of the light rail alternative results in a slightly higher level of total delay relative to the target travel rate than either the existing condition or the signal alternative. The signal improvements result in more reliable operations, as illustrated in the smaller range of person-hours of delay (smaller standard deviation). The relative congestion level indicators also show that the signal alternative performed better, reducing the existing level and resulting in a Travel Time Index of 1.75 compared to 1.91 for the LRT alternative.

This analysis also illustrates the importance of examining the proper combination of corridor facilities. The light rail alternative had substantially greater person travel than the other two alternatives. This could have been due to new (or induced) demand, but some of the travel also would have transferred from other transit routes or streets. If more roads and transit routes had been included in the analysis, the demand may have remained relatively constant. It may also be that the transit alternative was part of a centralized growth plan and denser development was modeled for the area near Main Street. Placing the LRT line in a protected right-of-way would improve corridor mobility, especially if signal improvements are also implemented.

Use of accessibility measures and establishment of an analysis area that includes roads and transit operations that might be significantly affected by the improvement would result in a better comparison of these two alternatives. The Travel Time Index illustrates the main line performance of the facilities but cannot address the added accessibility afforded by transit or intermodal stations.

Exhibit 8-12. Arterial Signal Improvements along Main Street.

Roadway Name: Main Street

Location: 71st to 89th Street (Suburban)

Travel Period: Morning Peak Hour

Travel Direction: Northbound (Peak Direction)

Alternative: Signal Improvement

Label	Measure	Units	System Element: 71st Street to 80th Street Auto	71st Street to 80th Street Bus	80th Street to 89th Street Auto	80th Street to 89th Street Bus	Total or Average
a	Length	Miles	2.8	2.8	3.5	3.5	6.3
b	Vehicle Volume	Vehicles	1,200	8	1,300	10	
c	Average Vehicle Occupancy	Persons/Vehicle	1.21	31.25	1.21	30.00	1.42
d	Percent Incident Delay	Percent	45	45	45	45	
	Speeds						
e	Free-flow Speed	Miles/Hour	35	15	35	15	29
f	Speed limit	Miles/Hour	30	30	30	30	30
g	Target Speed	Miles/Hour	25	15	25	15	23
h	Non-incident Speed	Miles/Hour	22	14	18	13	18
i	Estimated Actual Speed	Miles/Hour	20	13	15	12	16
Initial Computations							
j	Person Volume	Persons	1,452	250	1,573	300	
k	Vehicle-miles	Vehicle-miles	3,360	22	4,550	35	7,967
l	Person-miles	Person-miles	4,065.6	700	5,505.5	1,050	11,321
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	1.71	4.00	1.71	4.00	2.07
n	Speed Limit Travel Rate	Minutes/Mile	2.00	2.00	2.00	2.00	2.00
o	Target Travel Rate	Minutes/Mile	2.40	4.00	2.40	4.00	2.65
p	Non-incident Travel Rate	Minutes/Mile	2.73	4.29	3.33	4.62	3.29
q	Estimated Actual Travel Rate	Minutes/Mile	3.00	4.52	4.10	5.12	3.82
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	203	53	376	90	721
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	1.28	0.52	2.38	1.12	1.75
x	vs. speed limit	Minutes/Mile	1.00	2.52	2.10	3.12	1.82
y	vs. target	Minutes/Mile	0.60	0.52	1.70	1.12	1.17
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.7	0.5	0.7	0.5
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	1.01	0.29	1.62	0.62	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	57	0	123	0	
ae	Person Travel	Person-Hours	69	3	149	11	
Mobility Performance Measures Computations							
	Congested Travel Summary						
ay	Person-Miles (vs. free-flow)	Person-Hours	4,066	700	5,506	1,050	11,321
bb	Person-Hours (vs. free-flow)	Person-Hours	203	53	376	90	721
be	Miles of Congested Roadway (vs. free-flow)	Miles	2.8	2.8	3.5	3.5	6.30
	Percent of Congested Travel						
bh	vs. free-flow	Percent	100	100	100	100	100
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	103	0	225	1	327
bl	Person Travel	Person-Hours	125	6	270	20	421
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	2	1	3	1	2
bxcc	Mile of Road	Person-Hours	45	2	77	6	54
	Travel Time Index						
au	vs. free-flow	Travel Rate Ratio	1.75	1.13	1.94	1.15	1.75

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-13. Light Rail Transit (LRT) Improvement along Main Street.

Roadway Name: Main Street
Location: 71st to 89th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: Light Rail Transit

Label	Measure	Units	System Element: 71st Street to 80th Street – Auto	System Element: 71st Street to 80th Street – Light Rail	System Element: 80th Street to 89th Street – Auto	System Element: 80th Street to 89th Street – Light Rail	Total or Average
a	Length	Miles	2.8	2.8	3.5	3.5	6.3
b	Vehicle Volume	Vehicles	1,000	12	1,200	12	
c	Average Vehicle Occupancy	Persons/Vehicle	1.20	58.33	1.21	62.50	1.84
d	Percent Incident Delay	Percent	45	30	45	30	
	Speeds						
e	Free-flow Speed	Miles/Hour	35	20	35	20	28
f	Speed limit	Miles/Hour	25	25	25	25	25
g	Target Speed	Miles/Hour	25	20	25	20	23
h	Non-incident Speed	Miles/Hour	20	16	15	15	16
i	Estimated Actual Speed	Miles/Hour	17	15	11	14	13
Initial Computations							
j	Person Volume	Persons	1,200	700	1,452	750	
k	Vehicle-miles	Vehicle-miles	2,800	34	4,200	42	7,076
l	Person-miles	Person-miles	3,360	1,960	5,082	2,625	13,027
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	1.71	3.00	1.71	3.00	2.17
n	Speed Limit Travel Rate	Minutes/Mile	2.40	2.40	2.40	2.40	2.40
o	Target Travel Rate	Minutes/Mile	2.40	3.00	2.40	3.00	2.61
p	Non-incident Travel Rate	Minutes/Mile	3.00	3.75	4.00	4.00	3.70
q	Estimated Actual Travel Rate	Minutes/Mile	3.49	4.07	5.31	4.43	4.48
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	195	133	450	194	972
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	1.78	1.07	3.59	1.43	2.31
x	vs. speed limit	Minutes/Mile	1.09	1.67	2.91	2.03	2.08
y	vs. target	Minutes/Mile	1.09	1.07	2.91	1.43	1.87
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.7	0.5	0.7	0.6
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	1.29	0.75	2.29	1.00	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	60	0	160	1	
ae	Person Travel	Person-Hours	72	25	194	44	
Mobility Performance Measures Computations							
	Congested Travel Summary						
ay	Person-Miles (vs. free-flow)	Person-Hours	3,360	1,960	5,082	2,625	13,027
bb	Person-Hours (vs. free-flow)	Person-Hours	195	133	450	194	972
be	Miles of Congested Roadway (vs. free-flow)	Miles	2.8	2.8	3.5	3.5	6.30
	Percent of Congested Travel						
bh	vs. free-flow	Percent	100	100	100	100	100
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	109	1	291	1	402
bl	Person Travel	Person-Hours	131	35	352	63	580
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	2	1	4	1	3
bx	Mile of Road	Person-Hours	47	13	101	18	57
	Travel Time Index						
cc	vs. free-flow	Travel Rate Ratio	2.04	1.36	2.33	1.33	1.91

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-14. Example of Project Selection for Main Street.

Roadway Name: Main Street
Location: 71st to 89th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: Improvement Summary

Label	Measure	Units	Improvement Alternative: Existing (Exhibit 8-8)	Signal Improvement (Exhibit 8-12)	Light Rail Transit (Exhibit 8-13)
a	Length	Miles	6.3	6.3	6.3
b	Vehicle Volume	Vehicles			
c	Average Vehicle Occupancy	Persons/Vehicle	1.44	1.42	1.84
d	Percent Incident Delay	Percent			
	Speeds				
e	Free-flow Speed	Miles/Hour	28	29	28
f	Speed limit	Miles/Hour	30	30	25
g	Target Speed	Miles/Hour	22	23	23
h	Non-incident Speed	Miles/Hour	15	18	16
i	Estimated Actual Speed	Miles/Hour	12	16	13
Initial Computations					
j	Person Volume	Persons			
k	Vehicle-miles	Vehicle-miles	7,057	7,967	7,076
l	Person-miles	Person-miles	10,192	11,321	13,027
	Travel Rates				
m	Free-flow Travel Rate	Minutes/Mile	2.11	2.07	2.17
n	Speed Limit Travel Rate	Minutes/Mile	2.00	2.00	2.40
o	Target Travel Rate	Minutes/Mile	2.67	2.65	2.61
p	Non-incident Travel Rate	Minutes/Mile	3.95	3.29	3.70
q	Estimated Actual Travel Rate	Minutes/Mile	5.13	3.82	4.48
	Travel Times				
v	Estimated Actual Travel Time	Person-Hours	871	721	972
	Total Delay Rate				
w	vs. free-flow	Minutes/Mile	3.02	1.75	2.31
x	vs. speed limit	Minutes/Mile	3.13	1.82	2.08
y	vs. target	Minutes/Mile	2.45	1.17	1.87
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.6
Mobility Performance Measures Computations					
	Congested Travel Summary				
ay	Person-Miles (vs. free-flow)	Person-Hours	10,192	11,321	13,027
bb	Person-Hours (vs. free-flow)	Person-Hours	871	721	972
be	Miles of Congested Roadway (vs. free-flow)	Miles	6.30	6.30	6.30
	Percent of Congested Travel				
bh	vs. free-flow	Percent	100	100	100
	Total Delay (vs. free-flow)				
bk	Vehicle Travel	Vehicle-Hours	423	327	402
bl	Person Travel	Person-Hours	597	421	580
	Total Delay (vs. free-flow) per:				
bw	Person-Mile	Person-Minutes	3.5	2.2	2.7
bx	Mile of Road	Person-Hours	71.8	54.2	56.8
	Travel Time Index				
cc	vs. free-flow	Travel Rate Ratio	2.07	1.75	1.91

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Southside Freeway Examples. The example improvements from Southside Freeway include adding an HOV lane (Exhibit 8-15), adding one lane and an HOV lane (Exhibit 8-16), and adding an HOV lane and an incident management program (Exhibit 8-17). The incident management program alternative was included to show the analysis techniques employed for changes in travel time reliability that come from quickly detecting and removing crashes and vehicle breakdowns, even when there is no significant reduction in usual daily congestion. This is shown by the reduced standard deviation values. The HOV lane improvement was added to show the multimodal analysis techniques and evaluation of person movement and speed changes. They assume a high utilization of the HOV lane—a condition that is consistent with the high congestion level on the Southside Freeway, but one that is not encountered in many communities.

Exhibit 8-18 presents a summary of statistics that are relevant for evaluating the existing operation and the three alternatives. The HOV lane alternative results in lower but still existing congestion (TTI=2.48) due to the greater reliability of the HOV lane when compared to the existing condition (TTI=2.75). The added freeway lane and HOV lane alternative reduces congestion (TTI=1.85). Note that according to the target TTI values shown in Exhibit 8-6, this alternative is closest to the TTI=1.3 target condition. The incident management alternative with the HOV lane has a TTI=2.29. The incident management alternative also includes lower HOV ridership levels (these might result when travel times are more reliable due to the improvement in incident response), accounting for the lower TTI, but the delay rate relative to the target travel rate is approximately similar to the HOV lane alternative.

Sub-areas

Sub-area travel time analyses would be governed by the need to collect a statistically significant number of samples for the roads in the sub-area. The sampling program would include stratification factors like facility type and traffic volume range to minimize variation among roadways and reduce sample sizes. A statistically reliable sample size for estimating the number of segments on which congestion measurement is estimated is a function of travel time variability among segments, the permitted relative error, and the confidence level of the estimate.

The resulting sample indicates the number of roadway segments within a stratus (e.g., freeways, arterials, and CBD streets) within the sub-area that require direct travel time data collection. The segments to be sampled should be randomly chosen from different routes in each state and should be representative of typical roadways within the sub-area. Travel times for the remaining segments that are not sampled can be estimated by applying the results from sections with data collection. Segments with similar traffic volume and roadway characteristics would be grouped, and the congestion statistics (e.g., TTI and delay) for the section with direct data collection would be increased to account for the segments without data collection. In addition, "bottleneck" sections (where traffic volumes are not indicative of operating speeds) should be studied individually.

Suggested Measures. Average statistics for travel rate and delay rate are useful for intermediate calculations but may not provide an accurately detailed description of operating conditions within a sub-area. Cumulative statistics like **total delay**, **congested travel**, and **congested roadway** are more meaningful at this level of analysis. These measures are calculated in the same manner as in the corridor analysis, with sub-totals for measures being calculated for each route within the sub-area.

Exhibit 8-15. Congestion Analysis of Adding an HOV Lane to Southside Freeway.

Roadway Name: Southside Freeway
Location: 71st to 130th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: Add 1 HOV Lane

Label	Measure	Units	System Element: 71st Street to 101st Street Auto	System Element: 71st Street to 101st Street HOV	System Element: 101st Street to 130th Street Auto	System Element: 101st Street to 130th Street HOV	Total or Average
a	Length	Miles	4.4	4.4	4.0	4.0	8.4
b	Vehicle Volume	Vehicles	5,800	1,200	5,500	1,200	
c	Average Vehicle Occupancy	Persons/Vehicle	1.05	2.25	1.05	2.25	1.26
d	Percent Incident Delay	Percent	50	45	50	45	48
	Speeds						
e	Free-flow Speed	Miles/Hour	65	65	65	65	65
f	Speed limit	Miles/Hour	60	60	60	60	60
g	Target Speed	Miles/Hour	45	60	45	60	49
h	Non-incident Speed	Miles/Hour	26	60	25	60	31
i	Estimated Actual Speed	Miles/Hour	18	60	17	60	23
Initial Computations							
j	Person Volume	Persons	6,090	2,700	5,775	2,700	
k	Vehicle-miles	Vehicle-miles	25,520	5,280	22,000	4,800	57,600
l	Person-miles	Person-miles	26,796	11,880	23,100	10,800	72,576
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	0.92	0.92	0.92	0.92	0.92
n	Speed Limit Travel Rate	Minutes/Mile	1.00	1.00	1.00	1.00	1.00
o	Target Travel Rate	Minutes/Mile	1.33	1.00	1.33	1.00	1.23
p	Non-incident Travel Rate	Minutes/Mile	2.31	1.00	2.40	1.00	1.93
q	Estimated Actual Travel Rate	Minutes/Mile	3.28	1.00	3.47	1.00	2.63
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	1,466	198	1,335	180	3,178
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	1.38	0.08	1.48	0.08	1.01
x	vs. speed limit	Minutes/Mile	1.31	0.00	1.40	0.00	0.93
y	vs. target	Minutes/Mile	0.97	0.00	1.07	0.00	0.70
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5	0.5	0.5
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	1.38	0.08	1.48	0.08	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	589	7	542	6	
ae	Person Travel	Person-Hours	619	15	569	14	
Mobility Performance Measures Computations							
	Congested Travel Summary						
ay	Person-Miles (vs. free-flow)	Person-Hours	26,796	11,880	23,100	10,800	72,576
bb	Person-Hours (vs. free-flow)	Person-Hours	14,66	198	13,35	180	3,178
be	Miles of Congested Roadway (vs. free-flow)	Miles	4.4	4.4	4.0	4.0	8.40
	Percent of Congested Travel						
bh	vs. free-flow	Percent	100	100	100	100	100
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	1,178	12	1,083	11	2,284
bl	Person Travel	Person-Hours	1,237	28	1,137	25	2,427
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	3	0	3	0	2
bx	Mile of Road	Person-Hours	281	6	284	6	196
	Travel Time Index						
cc	vs. free-flow	Travel Rate Ratio	3.56	1.08	2.60	1.08	2.48

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-16. Congestion Analysis of Adding an HOV Lane and One General-purpose Lane to Southside Freeway.

Roadway Name: Southside Freeway
Location: 71st to 130th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: Add 1 HOV Lane and 1 General Lane

Label	Measure	Units	System Element: 71st Street to 101st Street Auto	71st Street to 101st Street HOV	101st Street to 130th Street Auto	101st Street to 130th Street HOV	Total or Average
a	Length	Miles	4.4	4.4	4.0	4.0	8.4
b	Vehicle Volume	Vehicles	7,000	1,000	7,000	1,000	
c	Average Vehicle Occupancy	Persons/Vehicle	1.15	2.70	1.15	2.70	1.34
d	Percent Incident Delay	Percent	50	45	50	45	49
	Speeds						
e	Free-flow Speed	Miles/Hour	65	65	65	65	65
f	Speed limit	Miles/Hour	60	60	60	60	60
g	Target Speed	Miles/Hour	45	60	45	60	48
h	Non-incident Speed	Miles/Hour	33	60	39	60	40
i	Estimated Actual Speed	Miles/Hour	26	60	34	60	34
Initial Computations							
j	Person Volume	Persons	8,050	2,700	8,050	2,700	
k	Vehicle-miles	Vehicle-miles	30,800	4,400	28,000	4,000	67,200
l	Person-miles	Person-miles	35,420	11,880	32,200	10,800	90,300
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	0.92	0.92	0.92	0.92	0.92
n	Speed Limit Travel Rate	Minutes/Mile	1.00	1.00	1.00	1.00	1.00
o	Target Travel Rate	Minutes/Mile	1.33	1.00	1.33	1.00	1.25
p	Non-incident Travel Rate	Minutes/Mile	1.82	1.00	1.54	1.00	1.51
q	Estimated Actual Travel Rate	Minutes/Mile	2.31	1.00	1.75	1.00	1.78
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	1,361	198	937	180	2,677
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	0.90	0.08	0.62	0.08	0.59
x	vs. speed limit	Minutes/Mile	0.82	0.00	0.54	0.00	0.51
y	vs. target	Minutes/Mile	0.49	0.00	0.21	0.00	0.27
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5	0.5	0.5
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	0.90	0.08	0.62	0.08	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	460	6	287	5	
ae	Person Travel	Person-Hours	528	15	330	14	
Mobility Performance Measures Computations							
	Congested Travel Summary						
ay	Person-Miles (vs. free-flow)	Person-Hours	35,420	11,880	32,200	10,800	90,300
bb	Person-Hours (vs. free-flow)	Person-Hours	1,361	198	937	180	2,677
be	Miles of Congested Roadway (vs. free-flow)	Miles	4.4	4.4	4.0	4.0	8.40
	Percent of Congested Travel						
bh	vs. free-flow	Percent	100	100	100	100	100
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	919	10	574	9	1,513
bl	Person Travel	Person-Hours	1,057	28	661	25	1,770
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	2	0	1	0	1
bx	Mile of Road	Person-Hours	240	6	165	6	155
	Travel Time Index						
cc	vs. free-flow	Travel Rate Ratio	2.50	1.08	1.67	1.08	1.85

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-17. Congestion Analysis of Adding an HOV Lane and an Incident Management Program along Southside Freeway.

Roadway Name: Southside Freeway
Location: 71st to 130th Street (Suburban)
Travel Period: Morning Peak Hour
Travel Direction: Northbound (Peak Direction)
Alternative: HOV and Incident Management on Freeway

Label	Measure	Units	System Element: 71st Street to 101st Street Auto	System Element: 71st Street to 101st Street HOV	System Element: 101st Street to 130th Street Auto	System Element: 101st Street to 130th Street HOV	Total or Average
a	Length	Miles	4.4	4.4	4.0	4.0	8.4
b	Vehicle Volume	Vehicles	5,800	1,000	5,500	1,000	
c	Average Vehicle Occupancy	Persons/Vehicle	1.05	2.25	1.05	2.25	1.23
d	Percent Incident Delay	Percent	50	45	50	45	49
	Speeds						
e	Free-flow Speed	Miles/Hour	65	65	65	65	65
f	Speed limit	Miles/Hour	60	60	60	60	60
g	Target Speed	Miles/Hour	45	60	45	60	48
h	Non-incident Speed	Miles/Hour	29	60	27	60	33
i	Estimated Actual Speed	Miles/Hour	21	60	19	60	25
Initial Computations							
j	Person Volume	Persons	6,090	2,250	5,775	2,250	
k	Vehicle-miles	Vehicle-miles	25,520	4,400	22,000	4,000	55,920
l	Person-miles	Person-miles	26,796	9,900	23,100	9,000	68,796
	Travel Rates						
m	Free-flow Travel Rate	Minutes/Mile	0.92	0.92	0.92	0.92	0.92
n	Speed Limit Travel Rate	Minutes/Mile	1.00	1.00	1.00	1.00	1.00
o	Target Travel Rate	Minutes/Mile	1.33	1.00	1.33	1.00	1.24
p	Non-incident Travel Rate	Minutes/Mile	2.07	1.00	2.22	1.00	1.83
q	Estimated Actual Travel Rate	Minutes/Mile	2.81	1.00	3.11	1.00	2.41
	Travel Times						
v	Estimated Actual Travel Time	Person-Hours	1,254	165	1,199	150	2,768
	Total Delay Rate						
w	vs. free-flow	Minutes/Mile	1.15	0.08	1.30	0.08	0.90
x	vs. speed limit	Minutes/Mile	1.07	0.00	1.22	0.00	0.83
y	vs. target	Minutes/Mile	0.74	0.00	0.89	0.00	0.59
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5	0.5	0.5
Recurring Delay Computations (Supports Mobility Measures)							
	Recurring Delay Rate						
aa	vs. free-flow	Minutes/Mile	1.15	0.08	1.30	0.08	
	Recurring Delay (vs. free-flow)						
ad	Vehicle Travel	Vehicle-Hours	488	6	476	5	
ae	Person Travel	Person-Hours	512	13	500	12	
Mobility Performance Measures Computations							
	Congested Travel Summary						
ay	Person-Miles (vs. free-flow)	Person-Hours	26,796	9,900	23,100	9,000	68,796
bb	Person-Hours (vs. free-flow)	Person-Hours	1,254	165	1,199	150	2,768
be	Miles of Congested Roadway (vs. free-flow)	Miles	4.4	4.4	4.0	4.0	8.40
	Percent of Congested Travel						
bh	vs. free-flow	Percent	100	100	100	100	100
	Total Delay (vs. free-flow)						
bk	Vehicle Travel	Vehicle-Hours	975	10	953	9	1,947
bl	Person Travel	Person-Hours	1,024	23	1,000	21	2,068
	Total Delay (vs. free-flow) per:						
bw	Person-Mile	Person-Minutes	2	0	3	0	2
bx	Mile of Road	Person-Hours	233	5	250	5	176
	Travel Time Index						
cc	vs. free-flow	Travel Rate Ratio	3.04	1.08	2.41	1.08	2.29

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Exhibit 8-18. Southside Freeway Improvement Summary and Congestion.

Roadway Name: Southside Freeway

Location: 71st to 130th Street (Suburban)

Travel Period: Morning Peak Hour

Travel Direction: Northbound (Peak Direction)

Alternative: Freeway Improvement Project Summary

Label	Measure	Units	System Element: Existing (Exhibit 8-9)	Add HOV Lane (Exhibit 8-15)	Add 1 Lane and HOV Lane (Exhibit 8-16)	Inc. Mgmt. and HOV (Exhibit 8-17)
a	Length	Miles	8.4	8.4	8.4	8.4
b	Vehicle Volume	Vehicles				
c	Average Vehicle Occupancy	Persons/Vehicle	1.31	1.26	1.34	1.23
d	Percent Incident Delay	Percent	50	48	49	49
	Speeds					
e	Free-flow Speed	Miles/Hour	65	65	65	65
f	Speed limit	Miles/Hour	60	60	60	60
g	Target Speed	Miles/Hour	45	49	48	48
h	Non-incident Speed	Miles/Hour	27	31	40	33
i	Estimated Actual Speed	Miles/Hour	20	23	34	25
Initial Computations						
j	Person Volume	Persons				
k	Vehicle-miles	Vehicle-miles	47,688	57,600	67,200	55,920
l	Person-miles	Person-miles	62,484	72,576	90,300	68,796
	Travel Rates					
m	Free-flow Travel Rate	Minutes/Mile	0.92	0.92	0.92	0.92
n	Speed Limit Travel Rate	Minutes/Mile	1.00	1.00	1.00	1.00
o	Target Travel Rate	Minutes/Mile	1.33	1.23	1.25	1.24
p	Non-incident Travel Rate	Minutes/Mile	2.19	1.93	1.51	1.83
q	Estimated Actual Travel Rate	Minutes/Mile	3.04	2.63	1.78	2.41
	Travel Times					
v	Estimated Actual Travel Time	Person-Hours	3,164	3,178	2,677	2,768
	Total Delay Rate					
w	vs. free-flow	Minutes/Mile	1.26	1.01	0.59	0.90
x	vs. speed limit	Minutes/Mile	1.19	0.93	0.51	0.83
y	vs. target	Minutes/Mile	0.85	0.70	0.27	0.59
z	Std. Dev. of Actual Travel Rate	Minutes/Mile	0.5	0.5	0.5	0.5
Mobility Performance Measures Computations						
	Congested Travel Summary					
ay	Person-Miles (vs. free-flow)	Person-Hours	62,484	72,576	90,300	68,796
bb	Person-Hours (vs. free-flow)	Person-Hours	3,164	3,178	2,677	2,768
be	Miles of Congested Roadway (vs. free-flow)	Miles	8.4	8.4	8.4	8.4
	Percent of Congested Travel					
bh	vs. free-flow	Percent	100	100	100	100
	Total Delay (vs. free-flow)					
bk	Vehicle Travel	Vehicle-Hours	2,006	2,284	1,513	1,947
bl	Person Travel	Person-Hours	2,630	2,427	1,770	2,068
	Total Delay (vs. free-flow) per:					
bw	Person-Mile	Person-Minutes	2.5	2.0	1.2	1.8
bx	Mile of Road	Person-Hours	262	196	155	176
	Travel Time Index					
cc	vs. free-flow	Travel Rate Ratio	2.75	2.48	1.85	2.29

Note: See Section 5.4 for further explanation of speed terms and application guidance.

Regional Networks

Regional analyses should be governed by many of the same needs as those on a sub-area basis. Sampling programs would be required to collect statistically valid data on a limited number of roadways, and stratification factors would be used to minimize variation among roadways and reduce sample sizes. Cost-effective data collection techniques should be considered because of the large data collection requirements and limited financial resources typical of most large urban areas. Where bottlenecks and points of recurrent congestion are known, they should be measured in addition to the samples.

Suggested Measures. Some congestion statistics are useful in areawide analyses, but at the regional level the questions asked of the transportation analyses often require a broader set of answers. Displaying these statistics will require the analyst to mix a variety of facility-specific and regional summary values. Exhibit 8-19 presents a summary of the information that might be used for corridor, sub-area, and areawide analyses. The level of information would vary depending on the analysis being performed, but the measures are selected to support the types of evaluations and decisions typically made at each level. As noted in the corridor-level discussion, the use of facility- or mode-specific analyses is more appropriate than regional analyses. Accessibility measures become more important as the analysis area is widened or the modal coverage expands.

Average statistics for travel rate and delay rate are useful for intermediate calculations but most likely will not provide an accurately detailed description of operating conditions within a regional network. Cumulative statistics like **Travel Time Index, total delay**, **congested travel**, and **congested roadway** are more meaningful at this level of analysis. These measures are calculated in the same manner as in the corridor analysis, with sub-totals for measures being calculated for each route (and possibly sub-area) within the regional network.

Exhibit 8-19 shows that individual mode or facility analyses are used to “build up” to the areawide statistics and can be used in conjunction with areawide analyses. Average vehicle occupancy and daily VMT per lane-mile can be used to evaluate the effect of some types of improvements but are not sufficient for all.

Analyzing all facilities in an area (in the second group of values) requires summary statistics, but other statistics can also provide information depending on the type of analysis and improvements being studied. Congested travel and facility miles are useful summaries of conditions and can be presented as either (or both) relative to the target measures for areawide studies, or relative to an absolute value such as free-flow travel for national or state “needs” studies.

Accessibility measures are highlighted in Exhibit 8-19 because they focus on the basic reason for having transportation systems at all: allowing achievement of travel objectives. They measure performance of the transportation system, and its interaction with land use, in how well travel objectives are met.

Exhibit 8-19. Summary of Performance Measures for Corridors, Sub-areas, and Regions.

Measure	Corridor	Sub-area or Sub-region	Region or Urban Area
For Each Functional Class or Mode			
Lane-miles of road	NP		
Daily VMT (1000)[1]	NP		
Daily PMT (1000)[1]	NP		
Average vehicle occupancy	P	P	P
Number of daily person trips	NP		
Daily VMT/Lane-mile	P	P	P
For all Facilities			
Congested PMT (1000)	S	S	S
% of Daily PMT	P	P	P
Congested lane-miles	S	S	S
% of total system	P	P	P
Delay rate (minutes/mile)	P	S	S
Total delay (person-hours)	P	P	P
Relative congestion level			
Relative delay rate	P	S	S
Delay ratio	P	S	S
Travel Time Index	P	P	P
Accessibility Measures			
Travel objectives within target travel time			
Jobs within target travel time (of persons)	P*	P*	P*
% of jobs within target time (of persons)	P*	P*	P*
Area within target travel time of shopping	P*	P*	P*
Area within target travel time of school	P*	P*	P*
Weighted average % of jobs within target time	P	P	P
% of persons within target time of shopping	P	P	P
% of children within target time of school	P	P	P
% of persons within 30 minutes (during peak period) of:			
Central business district		S	P
Airport		S	P
Major activity center		P	P

Source: NCHRP (*1*)
[1]VMT and PMT provide good measures of the amount of service provided.
Note: All congestion levels compared to target travel values. See Exhibit 8-4 for calculation procedures and Exhibit 8-5 to Exhibit 8-7 for target speeds and TTI values.
NP = Not a performance measure.
P = Primary performance measure.
S = Secondary performance measure.
* = Calculated and displayed for each small analysis area within the corridor, sub-area, or region on the basis of all opportunities within the region for travel objective fulfillment.

Accessibility measures allow the travel time focus of travelers and shoppers, and the need that agencies have to identify facilities that need improvements, to be combined into the number and percentage of potential travel objectives reachable within target time limits. The results of this analysis can identify areas and sub-areas in which some type of improvement is needed. The effect of a broad range of construction, operation, policy, or land use pattern changes can be identified with accessibility measures. Pricing actions that affect demand and travel patterns also change travel time and accessibility.

A few typical measures and geographic scopes are illustrated in Exhibit 8-19, but others also could be used. The measure of "percent of children within target time of school" was included for a simple illustration of travel market stratification, but the example equally well could have been "percent of commerce (quantified on the basis of employment) within target time of freight distribution centers."

These analyses can be conducted for either individual improvements or areawide strategies although they are more effective at the corridor, sub-area, or areawide strategy level. As noted in Exhibit 8-19, accessibility measures are normally calculated for each small area (traffic analysis zone) within the corridor, sub-area, or region being examined, taking into account all of the opportunities for meeting travel objectives within the region as a whole. Maps of the zone by zone results are very instructive in identifying who is most in need and who is most helped by a particular improvement. Zonal level results can be accumulated for the corridor, sub-area, or region as a summary measure, using weighted averages where appropriate.

A limitation is that the magnitude of existing land development and transportation facilities tends to overwhelm the effect of any new improvements. This causes accessibility measures to represent current features more than the changes accruing from new developments, especially where the new development is focused on achieving a different set of goals. This problem can be addressed by calculating the change in "no-build" alternative. This change will be attributable to the new developments and/or transportation facilities under analysis. This approach will help identify those developments and improvements that contribute to achieving areawide goals for target travel times and accessibility.

Concerns about the effect of "urban sprawl" can be addressed using accessibility measures. Several different areawide development scenarios can be tested and presented to citizens in a format that can be readily understood. Current and future travel conditions as described by measures such as those in Exhibit 8-18 can be noted, along with such characteristics as percent of trips by mode, the cost of new facilities or operating strategies, and land use patterns. This type of information is much better than the statistics that are currently presented for review in public discussions of long-range planning options. Accessibility measures and associated maps and graphics give transportation land use professionals a method to provide citizens with an idea of the impact of their choices.

The use of accessibility measures will require more computer-based analyses, which might be perceived as a move away from direct measurement of congestion for some levels of analysis. This does not mean that travel time data will be less useful or less cost-effective to collect. On the contrary, direct measurement of travel time can be used not only to quantify existing conditions but also to calibrate wide-scale models of traffic and transportation system operation and to perform corridor and facility analyses. Geographic information systems are being used to calculate accessibility measures based on planning model travel time and speed output statistics. The typical sequence of events leading up to a public discussion of the alternative improvement plans might be:

1. Collecting existing traffic condition data directly.
2. Calculating performance measure(s).
3. Comparing results to target conditions that are determined from public comments during long-range plan discussion.
4. Identifying areas or modes that need improvement.
5. Proposing solutions—areawide strategies will guide which specific improvements are tested.
6. Testing areawide improvements.
7. Estimating accessibility, mobility, and congestion measures for each strategy or alternative.
8. Comparing measures to goals.
9. Evaluating and selecting for inclusion in the plan individual mode or facility improvements that fit with the areawide strategy.

8.2 Discussion of Real-time Data Applications

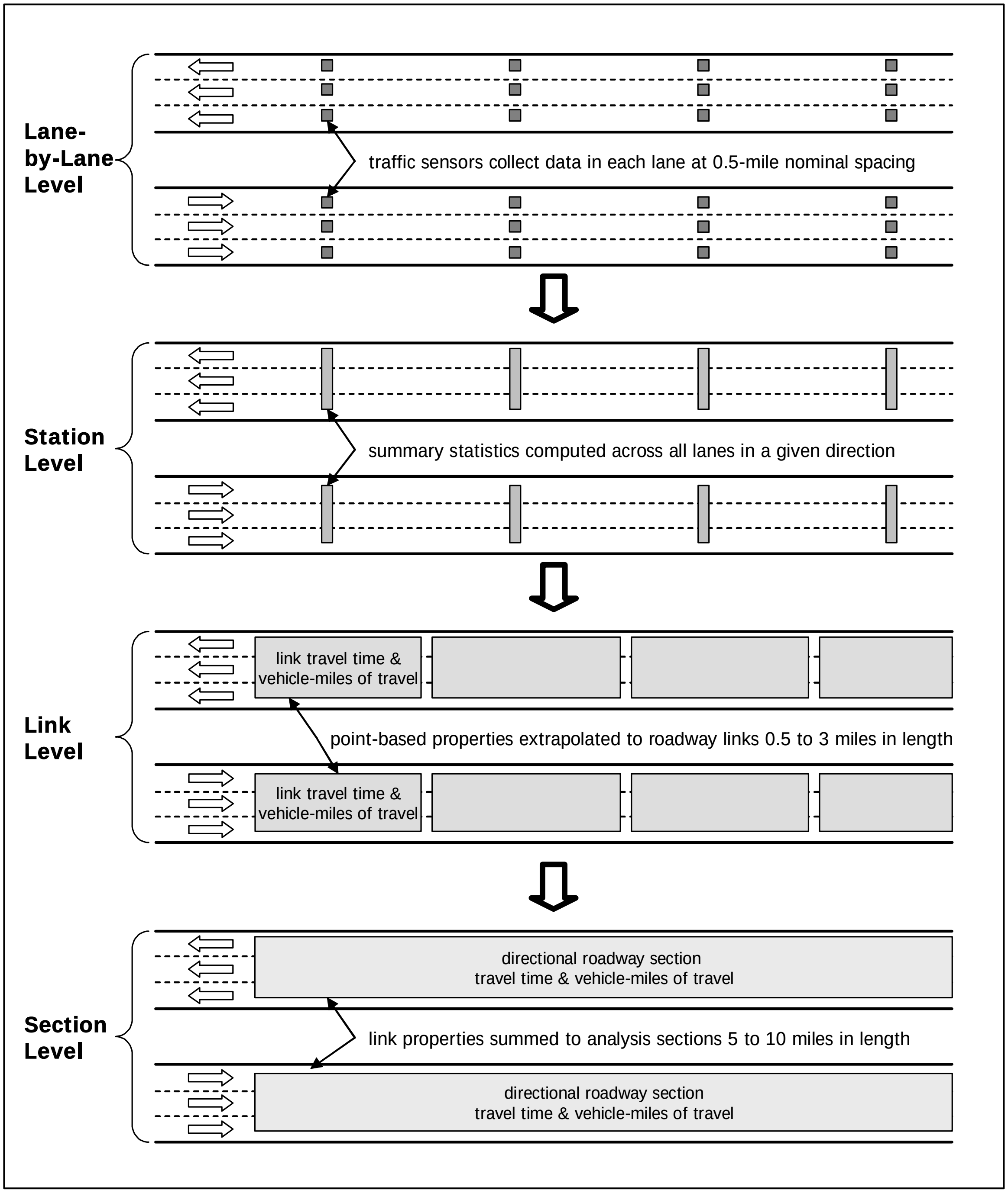
The examples provided in this chapter thus far have illustrated mobility analysis at different levels for both arterials and freeways. The data source is assumed to not include incident conditions, and that is why the spreadsheet provides an area for the user to input the percent of incident delay. Therefore, typical data sources for the applications shown thus far might be travel time runs or estimation from demand models.

Direct measurement might also include the use of real-time data sources. This would include sensors (typically inductance loops) that provide speed, volume, and occupancy data at a given time increment. The Mobility Monitoring Program (*2*) uses such data to compute congestion performance measures along instrumented freeways of several metropolitan areas in the United States. Certainly data quality and quality control are key issues to consider when processing the real-time data. Computer analysis is required due to the large amount of data that are processed. The MMP annual report discusses these data quality factors in more detail, and it can be reviewed at http://mobility.tamu.edu/mmp. This section of the paper provides insights into how congestion measures can be computed with the real-time data based upon the MMP research.

8.2.1 Congestion and Reliability Measure Calculations

As indicated previously, archived data from the cities participating in MMP consist of traffic speeds and volumes collected at various points along the freeway routes. Because mobility and reliability performance measures are based on travel time, freeway route travel times are estimated from the spot speeds. Exhibit 8-20 illustrates the process whereby lane-by-lane volumes and speeds are used as the basis for estimating freeway route travel times and vehicle-miles of travel. The steps are as follows:

Exhibit 8-20. Estimating Directional Route Travel Times and VMT from Spot Speeds and Volumes.



Source: FHWA (*2*)

1. If data are reported by lane, the lane-by-lane data are combined into a "station" (e.g., all lanes in a direction). Traffic volumes are summed across all lanes, and traffic speeds are a weighted average, with weighting based on respective traffic volumes.

2. Link properties are estimated from "station" data by assuming that each detector has a zone of influence equal to half the distance to the detectors immediately upstream and downstream from it. The measured speeds are then assumed to be constant within each zone of influence, and travel times are calculated using the equivalent link lengths. VMT are also computed in this way using traffic volume.

3. Freeway links are then grouped with other similar adjacent links into analysis sections, which are typically 5 to 10 miles in length. The beginning and end points of analysis sections are typically selected to coincide with major highway interchanges or other locations where traffic conditions are expected to change because of traffic or roadway characteristics.

Travel times for these analysis sections then serve as the basis for all subsequent mobility and reliability measure calculations. The specifics of these performance measure calculations are contained later in this section. Readers should note that equations using travel time refer to the analysis section travel times as described above.

Several other aspects and definitions used in preparing the archived data for analysis are:

- Holidays are excluded from the weekday peak period analysis, as holidays are considered to be atypical of normal travel patterns. Holidays are included in several daily total statistics, which also include weekend days. The holidays that are excluded from weekday analyses include:
  1. New Year's Day,
  2. Martin Luther King, Jr. Day,
  3. President's Day/Washington's Birthday,
  4. Memorial Day,
  5. Independence Day,
  6. Labor Day,
  7. Thanksgiving Day (and the day after),
  8. Christmas (and day before or after, depending on the day of week), and
  9. New Year's Eve.

- Fixed and consistent time periods are defined for all cities. These were:
  1. 12:00 a.m. to 6:00 a.m.—early morning,
  2. 6:00 a.m. to 9:00 a.m.—morning peak,
  3. 9:00 a.m. to 4:00 p.m.—midday,
  4. 4:00 p.m. to 7:00 p.m.—afternoon peak, and
  5. 7:00 p.m. to 12:00 a.m.—late evening.

- Only mainline freeway detectors are included. Some cities reported ramp data, but these are dropped to maintain consistency across the cities.

8.2.2 Computing Congestion Measures with Real-time Data

The Mobility Monitoring Program (*2*) tracks traffic congestion using the three measures below. For most applications, these measures are reported for the peak periods (6 to 9 a.m. and 4 to 7 p.m.):

- **Travel Time Index—** (measures congestion intensity, also congestion duration when shown by time of day);

- **Percent of congested travel**—(measures congestion extent, also congestion duration when shown by time of day); and

- **Total delay—**(measures congestion intensity).

The Travel Time Index is the ratio of average peak travel time to a free-flow travel time (Equation 5-2). For MMP, the free-flow conditions are travel times at a speed of 60 mph. Index values can be related to the general public as an indicator of the length of extra travel time spent during a trip. For example, a value of 1.20 means that average peak travel times are 20 percent longer than free-flow travel times. For MMP, the Travel Time Index is calculated for directional freeway sections (as shown in Exhibit 8-20) and then combined into an areawide average by weighting each freeway section by the respective VMT.

The **percent of congested travel** is calculated as the ratio of congested VMT to total VMT (Equation 8-1). Note that this is a slightly different form than Equation 5-5 because occupancy for each section is not included. If occupancy values are not different across segments, Equation 5-5 and Equation 8-1 provide the same result. For MMP, a free-flow speed of 60 mph is used as the value below which VMT is considered to be congested.

$$Percent\ of\ \ Congested\ Travel\ (\%) = \frac{Congested\ VMT}{Total\ VMT} \qquad \text{(Eq. 8-1)}$$

Experience indicates that the use of a 60 mph threshold in the percent congested travel measure may over-represent the magnitude of congestion. In several cities, the spot speeds collected by point-based detectors are less than 60 mph even in light traffic conditions. These point-based detectors are also more likely to record lower speeds than longer distance travel time measurements, due to their common location near entrance ramps and the much greater variation in speed over short sections than long sections. These considerations suggest that a lower speed may be more appropriate for the congestion threshold in this measure when using point-based sensors. Unlike the other congestion measures, congested travel is a binary attribute—travel is either congested or it is not congested, no matter how close the speed is to the congestion threshold. Thus, for a given time period, the VMT is assigned as either congested or not congested, even if the average speeds are just below the congestion threshold. For example, if the nighttime speed limit on an urban freeway system is 55 mph, a significant portion of travel could be categorized as congested without heavy traffic being the cause.

Delay is calculated as the additional travel time that is incurred when actual travel times are greater than target travel times (Equation 5-1). The delay measure can also be expressed in person-hours in a multimodal context where person travel quantities are known.

8.2.3 Reliability Measures

The congestion measures in the previous section represent the average and total levels of congestion. In addition to average and total statistics, there is a growing recognition of the need to track the variability of congestion and the reliability of travel. The Mobility Monitoring Program tracks these measures for travel reliability:

- **Planning Time Index (PPI), and**
- **Buffer Index.**

The **Planning Time Index** is statistically defined as the 95th percentile Travel Time Index (Equation 8-2) and also represents the extra time most travelers add to a free-flow travel time when planning trips. For example, a Planning Time Index of 1.60 means that travelers should plan for an additional 60 percent travel time above the free-flow travel time to ensure on-time arrival most of the time (95 percent in this report).

For a specific road section and time period:

$$\text{Planning Time Index} = \begin{matrix} 95^{th}\ \text{Percentile} \\ \text{Travel Time Index} \end{matrix} = \frac{\begin{matrix} 95^{th}\ \text{Percentile Travel Rate} \\ (\text{minutes/mile}) \end{matrix}}{\begin{matrix} \text{Free-flow Travel Rate} \\ (\text{minutes/mile}) \end{matrix}} \qquad \text{(Eq. 8-2)}$$

The Planning Time Index is useful because it can be directly compared to the Travel Time Index on similar numeric scales. For example, assume that the peak period Travel Time Index for a particular road section is 1.20, which means that average travel times are 20 percent longer in the peak period than during free-flow conditions. Now assume that the Planning Time Index for that same road and time period is 1.60, which means that 95 percent of all travel times are less than 60 percent longer than during free-flow conditions. In other terms, the Planning Time Index marks the upper limit for the nearly worst (95 percent of the time) travel conditions.

The **Buffer Index** represents the extra time (buffer) most travelers add to their average travel time when planning trips (Equation 8-3). The Buffer Index is differentiated from the Planning Time Index in these two important ways:

- The Buffer Index is expressed as a percentage;
- The Buffer Index represents the extra time between the **average travel time** and near-worst case travel time (95th percentile), whereas the Planning Time Index represents the extra time between the **free-flow travel time** and the near-worst case travel time (95th percentile).

For a specific road section and time period:

$$\text{Buffer Index}(\%) = \left[\frac{\underset{(minutes)}{\text{95th Percentile Travel Time}} - \underset{(minutes)}{\text{Average Travel Time}}}{\underset{(minutes)}{\text{Average Travel Time}}} \right] \times 100\% \qquad \text{(Eq. 8-3)}$$

For example, a Buffer Index of 40 percent means that a traveler should budget an additional 8-minute buffer for a 20-minute average peak travel time to ensure on-time arrival most of the time (95 percent in the examples here). The 95th percentile travel time was chosen for these reliability measures to represent a near-worst case scenario. For example, the 95th percentile travel time corresponds to a 95 percent on-time arrival rate, which can be simply explained in non-technical terms as "being late for work one day per month." Other percentiles, such as the 85th or 90th percentile, could be used in this or other applications. Ultimately, the application of the reliability measure will determine the percentile used in its calculation.

Equations 8-2 and 8-3 show the reliability measure calculations for a specific road section and time period. For these reliability measures, the road section and time period should be chosen in a way that accurately represents the reliability of interest. For example, an analysis of urban commuting reliability would likely consider freeway sections 5 to 10 miles in length whose endpoints correspond to major freeway or major arterial interchanges. Alternatively, an analysis of intercity travel reliability would consider much longer freeway sections whose endpoints correspond to popular city origins and destinations. The time period(s) should be selected to include conditions of a similar nature and interest to travelers. For example, a Buffer Index for a typical commuter audience will likely focus on periods throughout the day in which commute travel is made and should not mix travel times from these different periods. That is, travel times from the evening peak period should not be combined into the same distribution as the morning peak travel times when calculating a 95th percentile.

The average planning time or Buffer Index values (across several road sections, time periods, etc.) can be calculated by using the VMT as a weighting factor (Equation 8-4).

For several road sections and time periods:

$$\text{Average Index Value} = \frac{\sum_{i=1}^{n} \left(\text{index value}_n \times VMT_n \right)_{\text{each section and time period}}}{\sum_{i=1}^{n} \left(VMT_n \right)_{\text{each section and time period}}} \qquad \text{(Eq. 8-4)}$$

8.2.4 Other Considerations for Performance Measure Calculations

The performance measure analysis in MMP uses data in a standard format, which currently consists of 5-minute data (all times of the day and days of the year) for 5- to 10-mile freeway sections. This standard format corresponds with the bottom part of the diagram in

Exhibit 8-20. Combining the estimated travel time values or performance measures from each 5-minute time period is accomplished using VMT as a weighting factor for each time period.

Measures that do not use specific origins and destinations generally provide easier comparisons because these measures are length neutral and can be applied to a wider variety of situations. If trip-based measures are desired as examples for specific origins and destinations, the performance measures described here can be used with the estimated travel time for a specific trip. This combination of generalized, length-neutral measures, as well as specific examples, should provide statistics with which most audiences can relate.

There is no single best performance measure, and users should resist the urge to select a single measure or index for all situations. Each performance measure reported here addresses different dimensions of traffic congestion or different aspects of reliability. The "dashboard" concept of using a "few good measures" is appropriate (see Chapter 7), and performance monitoring programs should consider selecting a few (for example, two or three of the five presented here) measures for an executive summary or dashboard report.

This analysis defines fixed-length time periods in which to compute average peak period measures. No single time period will be correct for all analyses, but there are several considerations as follows:

- **Peak hour or peak period—**Transportation engineers have traditionally used a peak hour to describe congestion, but major urban areas now experience slow speeds for multiple hours in both the morning and the afternoon. In many areas, congestion growth occurs in the hours before or after the traditional peak hour. Use of a single peak hour misses the congestion that occurs during other times, prompting many areas to define a multi-hour peak period.

- **Urban area size—**Using a 3- to 4-hour peak period for all area sizes may mask congestion for the smaller urban areas. Smaller areas can probably develop useful statistics with only peak hour analyses.

- **City-to-city comparison—**A consistent peak-period length is necessary for any type of comparison between cities. Comparative studies between urban areas should probably use peak period analyses, rather than only a peak hour.

- **Daily or peak comparisons—**For national comparisons of reliability trends, a day-to-day comparison is appropriate. For local purposes, where individual trip planning is also an issue, it may be useful to also include travel reliability within an hour or for several segments of a multi-hour peak period.

8.2.5 Illustration of Mobility Measure Computation Using an ITS Data Source

Exhibit 8-21 shows the results of an investigation of the existing conditions along Southside Freeway assuming the data source is disaggregate ITS data that are aggregated to the peak hour as described in section 8.2 of this white paper. Because the data are from an ITS source that inherently includes incident conditions, there is no need for the user to enter a "percent incident delay" as with the other spreadsheet calculations shown in table form in this chapter.

Exhibit 8-21 also shows the computed TTI, BI, and PTI from the ITS data source. Because of the data source, computation of some of the performance measures is slightly different than prior tables; therefore, a column with a description of how each measure is computed is also included in Exhibit 8-21. One unique difference is that the 95^{th} percentile estimated actual speed is needed to compute the BTI and PTI per Equations 8-2 and 8-3. The average Buffer Index for this section of Southside Freeway is 15 percent and the PTI is 2.00.

8.3 References

1. *NCHRP Report 398*. Quantifying Congestion—Final Report and User's Guide. National Cooperative Highway Research Program Project 7-13, National Research Council, 1997.

2. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data*. U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-HOP-05-018, December 2004. Available at: http://mobility.tamu.edu/mmp/.

Exhibit 8-21. Southside Freeway Existing Operation with ITS Data Source.

Roadway Name: Southside Freeway

Location: 71st to 130th Street (Suburban)

Travel Period: Morning Peak Hour

Travel Direction: Northbound (Peak Direction)

Alternative: Existing Operation (ITS Data Source)

Label	Measure	Units	Description	System Element 71st Street to 101st Street Auto/Bus	System Element 101st Street to 130th Street Auto/Bus	Total or Average
a	Length	Miles	input value	4.4	4.0	8.4
b	Vehicle Volume	Vehicles	collected value	5,800	5,500	
c	Average Vehicle Occupancy	Persons/Vehicle	collected value	1.20	1.20	1.20
	Speeds					
d	Free-flow Speed	Miles/Hour	collected value	65	65	65
e	Speed limit	Miles/Hour	input value	60	60	60
f	Target Speed	Miles/Hour	input value	45	45	45
g	Estimated Actual Speed	Miles/Hour	input value	40	35	38
h	95^{th} Percentile Est. Actual Speed	Miles/Hour	collected value	34	31	33
Initial Computations						
i	Person Volume	Persons	b x c	6,960	6,600	13,560
j	Vehicle-miles	Vehicle-miles	a x b	25,520	22,000	47,520
k	Person-miles	Person-miles	i x a	30,624	26,400	57,024
	Travel Rates					
l	Free-flow Travel Rate	Minutes/Mile	60 / d	0.92	0.92	0.92
m	Speed Limit Travel Rate	Minutes/Mile	60 / e	1.00	1.00	1.00
n	Target Travel Rate	Minutes/Mile	60 / f	1.33	1.33	1.33
o	Estimated Actual Travel Rate	Minutes/Mile	60 / g	1.50	1.71	1.60
p	95^{th} Percentile Est. Actual Speed	Minutes/Mile	60 / h	1.76	1.94	1.84
	Travel Times					
t	Estimated Actual Travel Time	Person-Hours	(k x o) / 60	766	754	1,520
	Total Delay Rate					
v	vs. free-flow	Minutes/Mile	q - m	0.58	0.79	0.68
w	vs. speed limit	Minutes/Mile	q - n	0.50	0.71	0.60
x	vs. target	Minutes/Mile	q - o	0.17	0.38	0.27
y	Std. Dev. of Actual Travel Rate	Minutes/Mile	collected value	0.5	0.5	0.50
Mobility Performance Measures Computations						
	Congested Travel Summary					
z	Person-Miles (vs. target)	Person-Miles	Sum of congested person-miles (line k if line v is greater than zero)	30,624	26,400	57,024
ac	Person-Hours (vs. target)	Person-Hours	Sum of congested person hours (line t if line v is greater than zero)	766	754	1,520
af	Miles of Congested Roadway (vs. target)	Miles	Sum of congested miles (line a if line v is greater than zero)	4.4	4.0	8.40
	Percent of Congested Travel					
ai	vs. target	Percent	(ac / t) x 100	100	100	100
	Total Delay (vs. target)					
al	Vehicle Travel	Vehicle-Hours	(j x v) / 60	246	290	536
am	Person Travel	Person-Hours	(k x v) / 60	295	348	643
	Total Delay (vs. target) per:					
ax	Person-Mile	Person-Minutes	(am x 60) / k	0.6	0.8	1.4
ay	Mile of Road	Person-Hours	am / a	67	87	154
	Travel Time Index					
bd	vs. target	Travel Rate Ratio	o / l	1.63	1.86	1.73
	Buffer Index					
bg	Buffer Index	Percent	((p - o) / o) x 100	18	13	15
	Planning Time Index					
bh	vs. free-flow	None	p / l	1.91	2.10	2.00

Note: See Section 5.4 for further explanation of speed terms and application guidance.