TECHNICAL WHITE PAPER

The Keys to Estimating Mobility in Urban Areas

3rd Edition – 2021

Applying Definitions and Measures that Everyone Understands

SUMA
Support for Urban Mobility Analysis

A technical white paper to

Support for Urban Mobility Analyses (SUMA)
FHWA Pooled Fund Study

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Executive Summary: Mobility Measurement Considerations

Mobility analysis offers key insights into how people travel and how they make decisions about traveling. People and shippers consider factors such as access to desired destinations, travel time, reliability of travel, cost, travel options, and travel quality when making transportation decisions. Understanding and measuring these factors will help planners, practitioners, and policy makers provide more secure, optimal, and equitable transportation systems—ultimately making areas more livable.

Measuring mobility, reliability, and congestion helps achieve a community's vision, goals, and objectives for its residents. Performance measurement and monitoring provides a snapshot of current conditions and trends, measures the effectiveness of enacted projects, policies, and programs, and evaluates proposed projects and policies. However, it all depends upon how the performance measures and analyses are being used and by whom.

This report provides guidance and context for performing a mobility analysis, selecting appropriate performance measures, and communicating the results of those measures and analysis.

Congestion, Mobility, Reliability, and Accessibility

Congestion is the inability to reach a destination in a time and cost that are satisfactory to the traveler and is the result of a travel supply/demand imbalance. The idea that there are conditions that are "satisfactory" is based on the expectations of the traveler and trip and is heavily influenced by the size and density of the area. What may be satisfactory in one circumstance may be unacceptable in another.

While people usually think of congestion in terms of auto travel, congestion can occur in any mode. Congestion has four elements that can be quantified and used in the larger transportation planning and policy discussion: duration, extent, intensity, and variation.

Mobility is the ease of movement from an origin to a destination and, like congestion, is broken into four elements that can be measured: time when mobility is provided or controlled, level, locations one can travel, and reliability of travel. Reliability of travel refers to how certain one can be that the trip will take an expected length of time regardless of congestion or unforeseen circumstances, like weather, construction, or crashes.

While both accessibility and connectivity are not the focus of this report, the concepts should be considered in addition to mobility and reliability when examining total system performance. Many often consider the former two concepts to be at odds with the latter two; however, these four concepts provide a more complete view of transportation performance and should be used appropriately in a complementary manner.

The Performance Measurement Process

Performing a mobility analysis and selecting performance measures represents a multi-part process organized into three primary stages: defining the issue and identifying a scope of possible solutions, identifying measures and analysis procedures, and performing the analysis and evaluating alternatives.

The first stage requires one to examine and identify the larger vision, goals, and issues in a community that the analysis and measures will ultimately address. In doing so, thought should be given to the different audiences: who will use the resulting information and how it will be used. This will inform how the results should ultimately be conveyed at the end. Additionally, give proper thought to the type of solutions that may be considered.

Stage two builds upon the community goals and the scope of the problem by developing a set of mobility measures and accompanying analysis procedures. Hasty selection of performance measures results in poor outcomes, as their results may be misused to overlook other aspects of transportation.

The final stage performs the analysis using real (directly collected or acquired from a third party), estimated, or modeled data. Upon the final test of solutions, accountability and result standards should be analyzed to ensure conditions and programs meet goals and unintended consequences do not impact mobility or non-transportation aspects of a community.

Selecting Mobility Measures

Choosing which measures to use in a mobility analysis can be performed once the vision, goals, audiences and their intended uses and scope of the issues have been identified. These provide a foundation one can build upon to measure transportation performance most effectively—and may reveal that other forms of analysis may be needed.

The choice of performance measure can either favor existing systems and compound existing issues or can address inefficiencies and inequity seen in both transportation and the surrounding community. No single measure will generate a full view of mobility or accessibility. Choose a suite of performance measures wisely because what gets measured matters. Elements left out of the mobility analysis like mode, routes, times, or costs, will likely not be considered in possible solutions.

The right balance of measures will include satisfy a set of criteria. Good measures will:

- Relate to goals and objectives.
- Clearly communicate results to the intended audiences.
- Be mode-neutral or include multiple modes and elements of system performance.
- Have consistency and accuracy.
- Be sensitive enough to detect and illustrate the effect of improvements.
- Be applicable to existing and future conditions.
- Be applicable at several geographic levels.
- Use person- and goods-movement terms.
- Use cost-effective methods to collect and/or estimate data.

Once the proper measures have been selected, one must select the appropriate periods and geographic scales for analysis. Additionally, certain types of analyses are more conducive to using specific measures.

Performance measures are organized into four categories: basic data elements, individual measures, area measures, and select accessibility and connectivity measures.

Target values should 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 quality of life and 2) the improvement strategies, programs, and projects that government agencies and private sector interests will implement. Remember that targets should be realistic and contextually relevant to where they are applied.

Data Collection and Databases

Until this past decade, many observation-based data sources used for calculating transportation performance measures were scarce or nonexistent, forcing planners and practitioners to heavily rely on modeled or estimated data. However, advances in mobile technology have allowed numerous third-party vendors to offer a wealth of data for mobility analysis.

Global positioning system (GPS), location-based services (LBS), and cellular probe data make three types of distinct data products that offer various strengths and weaknesses in performance measure computation. Most are provided at a cost from private vendors, but some are free or low cost.

Special attention should be given to roadway network files, as differing data sources may rely on different networks that may not be directly transferable. Networks may need to be conflated to create a crosswalk to accurately compare or combine data sources.

Other data sources may also provide context, calibration, or added value in the mobility analysis process. Sources from the U.S. Census Bureau, the National Household Travel Survey, or real-time/archived ITS and other operational data should be considered for use.

Communicating Performance Measures in a Meaningful Way

Communicating mobility analysis results is a vital step in illustrating system performance and demonstrating the need for transportation improvements. A failure to properly communicate mobility and congestion analysis results essentially negates much of the process: is the analysis worth doing if no one can understand or use the results?

Refer to the first steps in the analysis where the audience and how the audience will use the results of the analysis were identified. This will offer insight into the types of charts, illustrations, or visualization that should be used.

When communicating mobility analysis results and performance measures, be sure to place the values in meaningful terms that the target audience will understand. Ensure that all audiences have a common understanding of 1) what the measure is and what it means, 2) how it should be interpreted, and 3) how the measure value should apply in the specific analysis context. This may require placing the values in different equivalent terms.

When illustrating results, be careful not to place too much information on a single chart or graph. Using too many measures will not only create information overload issues, but also could create confusion and misinterpretation of the information. Additionally, readers may conflate multiple measures or create a mental link where no link should exist. Only display information that is specifically relevant to the reader.

Quick Reference Guide to Selected Mobility Measures

INDIVIDUAL MEASURES	
Average Speed	$\text{Average Speed} = \dfrac{\text{Total Distance}}{\text{Total Time}}$
Free Flow Speed	Free Flow Speed = Base Speed - Adjustment for Lane Width - Adjustment for Lateral Clearance - Adjustment for Median Type - Adjustment for Access Points
Percentile Speeds 85th Percentile	85th Percentile = Total Cars/Speed × .085
Person Throughput	$\text{Throughput} = \dfrac{\text{Person Volume}}{\text{Unit of Time}}$
Freight Volume	$\text{Throughput} = \dfrac{\text{Freight Volume}}{\text{Unit of Time}}$
Average Vehicle Occupancy & Ridership	$\text{Average Vehicle Occupancy Rate} = \dfrac{\text{Total Number of Occupants}}{\text{Total Number of Vehicles}}$
Person Miles of Travel/ Vehicle Miles of Travel	Person Miles of Travel = Person Volume × Distance Traveled
Travel Time	$\underset{\text{(person - minutes)}}{\text{Travel Time}} = \underset{\text{(minutes per mile)}}{\text{Actual Travel Rate}} \times \underset{\text{(miles)}}{\text{Length}} \times \underset{\text{(vehicles)}}{\text{Vehicle Volume}} \times \underset{\text{(person/vehicles)}}{\text{Vehicle Occupancy}}$
Target Travel Time	Target Travel Time = Desired Trip Length
Travel Time Traces	Travel Time Traces = Σ Segment Travel Times for a given Time Period
Average Travel Rate	$\text{Travel Rate} = \dfrac{\text{Travel Time}}{\text{Segment Length}}$
Target Travel Rate	$\text{Target Travel Rate} = \dfrac{\text{Desired Travel Time}}{\text{Segment Length}}$
Mode Split/ Percent Non-SOV	Mode Split or Percent Non-SOV = Total Number of (Non-Motorized and Motorized) Vehicles - Amount of SOV
INDVIDUAL MOBILITY MEASURES	
Delay Per Traveler	$\underset{\text{(annual hours)}}{\text{Delay per Traveler}} = \dfrac{\left(\underset{\text{(minutes)}}{\text{Actual Travel Time}} - \underset{\text{(minutes)}}{\text{FFS or PSL Travel Time}}\right) \times \underset{\text{(vehicles)}}{\text{Vehicle Volume}} \times \underset{\text{(person/vehicles)}}{\text{Vehicle Occupancy}} \times \dfrac{\textit{250 weekdays}}{\textit{year}} \times \dfrac{\textit{hour}}{\textit{60 minutes}}}{\underset{\text{(vehicles)}}{\text{Vehicle Volume}} \times \underset{\text{(person/vehicles)}}{\text{Vehicle Occupancy}}}$
Travel Time Index	$\text{Travel Time Index} = \dfrac{\underset{\text{(minutes per mile)}}{\text{Actual Travel Rate}}}{\underset{\text{(minutes per mile)}}{\text{FFS or PSL Travel Rate}}}$
Travel Rate Index	$\text{Travel Rate Index} = \dfrac{\left(\dfrac{\text{Freeway Travel Rate}}{\text{Freeway Freeflow Rate}} \times \text{Freeway Peak-Period VMT}\right) + \left(\dfrac{\text{Principal arterial street travel rate}}{\text{Principal arterial street freeflow rate}} \times \text{Principal arterial street peak period VMT}\right)}{\left(\text{Freeway Peak-Period VMT} + \text{Principal arterial street peak period VMT}\right)}$
Planning Time Index	$\underset{\text{(no units)}}{\text{Planning Time Index}} = \dfrac{\underset{\text{(minutes)}}{\text{95th Percentile Travel Time}}}{\underset{\text{(minutes per mile)}}{\text{FFS or PSL Travel Rate}}}$
Buffer Index	$\text{Buffer Index (\%)} = \left[\dfrac{\underset{\text{(minutes)}}{\text{95th Percentile Travel Time}} - \underset{\text{(minutes)}}{\text{Average Travel Time}}}{\underset{\text{(minutes)}}{\text{Actual Travel Rate}}}\right] \times 100\%$

INDVIDUAL MOBILITY MEASURES (CONTINUED)

Level of Travel Time Reliability	$\text{LOTTR} = \dfrac{\text{80th Percentile Travel Time}}{\text{50th Percentile Travel Time}}$
Truck Travel Time Reliability Index (PM3)	$\text{TTTR ratio} = \dfrac{\text{95th Percentile Travel Time}}{\text{50th Percentile Travel Time}}$ $\text{TTTR Index} = \dfrac{\Sigma \text{ Segment Length} \times \text{maxTTTR}}{\Sigma \text{ Segment Length}}$
Peak Hour Excess Delay (PM3)	$\text{Excessive Delay} = (\text{Average Vehicle Occupancy} \times \sum_{\text{Peak Periods}} \text{Delay})$
Cost per Commuter	$\text{Cost Per Consumer} = \text{Daily Passenger Vehicle Hours of Delay} \times \text{Value of Person Time \$ per Hour} \times \text{Vehicle Occupancy} \times \text{Annual Conversion Factor} \times \text{Daily Washed Fuell} \times \text{Gasoline Cost}$

AREA MOBILITY MEASURES

Total Delay	$\text{Total Segement Delay (person - minutes)} = \left[\text{Actual Travel Time (minutes)} - \text{FFS or PSL Travel Time (minutes)} \right] \times \text{Vehicle Volume (vehicle)} \times \text{Vehicle Occupancy (person/vehicle)}$
Delay per Mile	$\text{Delay per Mile (annual hours per mile)} = \dfrac{\left(\text{Actual Travel Time (minutes)} - \text{Free-Flow Travel Time (minutes)} \right) \times \text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy} \left(\frac{\text{person}}{\text{vehicle}}\right) \times \left(\frac{\text{60 minutes}}{\text{hour}}\right)}{\text{Road Miles}}$
Congested Travel	$\text{Congested Travel (vehicle - miles)} = \Sigma \left(\text{Congested Segment Length (miles)} \times \text{Vehicle Volume (vehicles)} \right)$
Wasted Fuel	$\text{Wasted Fuel} = \dfrac{\text{Vehicle Miles Traveled (VMT)}}{\text{Free Flow Travel Speed}} \times \left(\dfrac{\text{Free Flow Speed}}{\text{Average Fuel Economy}} - \dfrac{\text{Peak Period Speed}}{\text{Average Fuel Economy}} \right)$
Total Cost of Congestion	$\text{Annual Passenger Vehicle Cost} = \left(\text{Annual Passenger Vehicle Hours of Delay} \times \text{Vehicle Occupancy (person/vehicle)} \times \text{Value of Person Time (\$/hour)} \right) + \left(\text{Annual Gallons of Excess Fuel Consumed By Passengers} \times \text{Price Per Gallon of Gasoline (\$/gallon)} \right)$ $\text{Annual Truck Cost} = \left(\text{Annual Truck Hours of Delay} \times \text{Value of Time for Trucks (\$/hour)} \right) + \left(\text{Annual Gallons of Excess Fuel Consumed by Trucks} \times \text{Price Per Gallon of Diesel (\$/gallon)} \right)$
Accessibility	$\text{Accesibility (opportunities)} = \Sigma \text{ Objective Fulfillment Opportunities (e.g. jobs), Where Travel Time} < \text{Target Travel Time}$
Connectivity Index/ Network Completeness	$\text{Connectivity Index} = \dfrac{\text{\# of Roadway Links}}{\text{\# of Roadway Nodes}}$
Route Directness	$\text{Route Directness} = \dfrac{\text{Distance between Origin and Destination}}{\text{Actual Distance between Traveled Road Network}}$
Percent of Congested Travel	$\text{Percent of Congested Travel} = \left[\dfrac{\sum_{i=1}^{m} \left(\left(\text{Actual Travel Time (minutes)} - \text{FFS or PSL Travel Time (minutes)} \right) \times \left(\text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy (persons/vehicle)} \right) \right)_{\text{Each Congested Segment}}}{\sum_{i=1}^{n} \left(\text{Actual Travel Time (minutes per mile)} \times \text{Length (miles)} \times \text{Vehicle Volume (vehicles)} \times \text{Vehicle Occupancy (persons/vehicle)} \right)_{\text{All Segments}}} \right] \times 100$
Congested Roadway	$\text{Congested Roadway (miles)} = \Sigma \text{ Congested Segment Lengths (miles)}$

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 × a × b × c) / ([g x bp] + [a × b × c])
Initial Computations			
j	Person Volume	Persons	b × c
k	Vehicle-miles	Vehicle-miles	a × b
l	Person-miles	Person-miles	j × a
	Travel Rates		
m	Free-Flow Travel Rate	Minutes/Miles	60 / e
n	Speed Limit Travel Rate	Minutes/Miles	60 / f
o	Target Travel Rate	Minutes/Miles	60 / g
p	Non-incident Travel Rate	Minutes/Miles	60 / h
q	Estimated Actual Travel Rate	Minutes/Miles	60 / j
	Travel Times		
r	Free-Flow Travel Time	Person-Hours	(1 × m) / 60
s	Speed Limit Travel Time	Person-Hours	(1 × n) / 60
t	Target Travel Time	Person-Hours	(1 × o) / 60
u	Non-incident Travel Time	Person-Hours	(1 × p) / 60
v	Estimated Actual Travel Time	Person-Hours	(1 × q) / 60
	Total Delay Rate		
w	vs. free-flow	Minutes/Miles	q - m
x	vs. speed limit	Minutes/Miles	q - n
y	vs. target	Minutes/Miles	q - o
z	Std. Dev. of Actual Travel Time	Minutes/Miles	collected value
Recurring Delay Computations (Supports Mobility Measures)			
	Recurring Delay Rate		
aa	vs. free-flow	Minutes/Miles	p - m
	Recurring Delay (vs. free-flow)		
ad	Vehicle Travel	Vehicle-miles	(k × aa) / 60
ae	Person Travel	Person-miles	(1 × aa) / 60
Mobility Performance Measures Computations			
	Recurring Delay Rate		
ay	Person-Miles (vs. free-flow)	Person-Hours	Sum of congested person-miles (line l if line w 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-miles	ad / (1 - d/100)
bl	Person Travel	Person-miles	ae / (1 - d/100)
	Total Delay (vs. free-flow)		
bw	Person Volume	Person-Minutes	(bl × 60) / 1
bx	Mile of Road	Person-Hours	bl / a
	Total Delay (vs. free-flow)		
cc	vs. free-flow	Travel Rate Ratio	q / m

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Table of Contents

Table of Figures

Table of Tables

Chapter 1: Introduction to Mobility

The commuters and freight operators that move on the nation's transportation system make a series of conscious and unconscious decision whenever travel occurs. Understanding how people travel—the factors that are important to them—and the importance of measuring and monitoring travel helps planners, practitioners, and policy makers create transportation systems that run efficiently, effectively, and equitably in cities and regions across the nation.

Decisions that transportation agencies make regarding 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. But to do this effectively, agencies must understand both what is happening now and how mobility could change. This requires an understanding of how people travel.

How People Travel

The key to understanding mobility as a concept and as a series of measures requires a fundamental understanding of how people and goods travel and the factors that are important to them as they travel. Elements that may be important from a policy or network planning perspective may not be at the forefront for travelers and shippers. For them, the most important factors may include:

- **Accessibility of destinations**: *Is there a destination available that will satisfy my needs?* If so, is the destination reasonably close to me and relatively easy to travel to? This also includes the consideration of e-commerce, internet shopping, and delivery options: would it be better to purchase an item online and have it delivered to me instead of making a trip myself? Could a trip or delivery be avoided altogether? How quickly and urgently do I need it?

- **Door-to-door travel time**: *How long will it take to get to my destination (or how long will it take for my product to reach the customer)?*

- **Reliability of travel**: *How certain am I that I will arrive on time, every time?* How important is it (if at all) that a traveler arrives when they think they will? Similarly, how important is it that a product or shipment arrives at a designated time, especially in just-in-time supply chains?

- **Cost**: *What is the cheapest way to get there? How much will the trip cost me in dollars and time?* Trip cost may or may not be a critical decision factor in the travel decision. For many, this decision may already be made or made subconsciously by owning a private automobile or a frequently-used shipper. However, many elements factor into this decision, making a rational economic decision difficult.

  Travelers and shippers make travel cost decisions at two primary points: before the trip and during the trip. Before the trip, a traveler or shipper must decide whether to make the trip at all. When travelers or shippers decide to make the trip, they must then decide on mode. This choice is made easier with side-by-side comparisons in many apps and logistics systems available to consumers. A traveler can view the actual cost (in dollars and minutes) of a trip for transit versus on bike or with a transportation network company (TNC) like Uber or Lyft.

However, the true costs of an automobile trip are much more difficult to determine and compare. Most travelers only consider the cost of gas, travel time, tolls, and parking. In reality, a variety of factors add to each trip's cost: insurance, vehicle depreciation, maintenance, convenience, costs of ownership, and even state or local taxes, to name a few. Most travelers fail to account for these factors since these costs are separated from each trip.

- **Travel Options**: *What is the best way to get myself or my product to the destination?* This includes travel mode, travel time for that mode, and travel route, and both are affected by cost and availability. The combination of factors that determines 'best' will change for each trip, day, week, product being shipped, etc.

  Travelers must decide on the best mode for their trip. As seen earlier, cost plays an important role in this decision, but other factors may influence the decision as well. Factors such as exercise or health concerns, trip purpose, environmental concerns, urgency, and weather may influence how one travels. For shippers, mode is often determined by product sensitivity, urgency, environmental and corporate social responsibility concerns, and mode availability in addition to cost.

  Travel route also plays an important role in this decision. However, route is predominantly a function of trip cost and travel time optimization. Travelers and shippers make routing decisions both before and during a trip based on information available at the time. Travelers may choose to use a managed toll lane versus the main lanes based on traffic conditions.

  Availability of travel options is second to travel route and can be related to cost but should be considered separately. Some options may be unavailable to all or a subset of travelers before cost becomes a factor. And while a region or neighborhood may appear to have a series of options, those options may be unavailable or unusable to all travelers due to social equity, economics, policy, travel times, or cultural/historical reasons.

- **Quality**: *Is the trip even worth making at all?* How comfortable or worthwhile the trip is will play a varying role in the travel decision. In many cases, you have no choice but to go to work or take your kids to school, but other trips may be optional if the quality of the trip is not worth the effort. In many cases, these trips are recreational and are a large factor in induced demand (a concept discussed later).

Travelers and shippers assess each of these factors to varying degrees whenever they are about to make a trip or ship a product. Arriving at the destination on time and at the lowest cost can be considered a typical goal; however, the choices made from that goal are widely disparate and vary by non-economic decisions and personal taste. The importance of each factor changes from trip to trip, but their internal calculus generally remains constant.

Traveler Perceptions and Expectations

One important concept to remember is that people hold preconceived notions about each factor that delineates what is acceptable versus unacceptable. People build these mental thresholds over time—influenced by experiences and expectations about how transportation works for them. Understanding how these thresholds are created and what the thresholds are is critical to providing mobility solutions that are meaningful to travelers.

While the most important way to provide meaningful mobility solutions is to design and operate the system well, setting or resetting the preconceived notions and mental thresholds people hold by adjusting and setting appropriate expectations follows as a close second. Actively engaging with the public, listening to their concerns, and providing education about how transportation works, what is and is not reasonable for mobility, and the many options for travel will help set expectations at an appropriate level.

Traditionally, departments of transportation (DOTs), cities, counties, and metropolitan planning organizations (MPOs) approach and measure mobility at a regional, zonal, corridor, segment, or spot level of detail. While this approach works well for policy, planning, maintenance, and funding, it does not harmonize with the level of detail travelers and shippers approach mobility. Their paradigm uses travel routes and destinations.

While many mobility measures capture several factors listed above, there are very few measures that use a traveler's or shipper's native level of detail. As new data sources become available, additional mobility concepts and measures may be developed to shift some of the perspective to a traveler's route. Until then, be mindful throughout mobility measurement of how a typical traveler and shipper approach travel and put as many terms and measures as possible in a relatable language.

Why We Measure How People Travel

As you begin to measure mobility and how people and goods travel along a transportation network, it helps to understand how those measures are used—the 'why we care' element of how people travel and how well a transportation network operates.

Achieving a Community's Vision and Goals through Targets

The primary reason we measure how people travel is to broadly achieve a region's vision and goals for itself and to improve the overall quality of life and economic opportunity for those who live there. Every state, MPO, county, city, and neighborhood is unique, containing a distinct culture, history, topography, economy, and people group. Through the planning process, these communities develop a vision of what they want to become and the important elements to achieving that vision through goals. Transportation serves as a catalyst of activity and enables people and goods to move effectively about the region.

Mobility performance measures allow members of the community—policy makers, planners, the business community, and the traveling public—to evaluate how freely movement occurs. Performance measures provide a data-driven system to evaluate measurable and realistic targets that should be directly tied to the community vision and goals. Community goals should be examined often through the lens of performance measurement to ensure they are being met in an acceptable way in a timely fashion.

Many past vision and goal statements did not value the same things they do now, so while performance measures may have been tied to a community's vision and goals at the time, they achieved something different than what a community may want today. It is important to remember that each community may hold a different view of ***livability***. Some communities have rejected the idea of high-speed travel for increased density and accessible amenities while other communities embrace the idea, because it offers them opportunity to purchase a home and build wealth. Transportation performance in the past focused almost entirely on increasing the speed of travel, which in turn neglected to appreciate the differences in community desires.

Evaluating Projects, Programs, Policies, and Systems

The second and more specific reason we measure how people travel is to evaluate the actual or expected performance of projects, programs, policies, and systems meant to meet community targets and goals. Performance measures (of all types, not just mobility) allow policy makers, planners, and practitioners to determine how best to meet the transportation needs of a community in the most efficient way—ensuring the public gets the biggest bang for their tax buck.

Performance measures **provide a snapshot of existing conditions and trends** in a transportation network and are ideally connected with the factors that are important to travel (listed earlier). This snapshot can then be compared against community goals and targets to assess where gaps and deficiencies need to be addressed.

Performance measures may also be used to **measure the effectiveness of enacted projects, policies, and programs** as compared to a base condition. Evaluations of this type provide valuable context and information for future projects. Practitioners and policy makers may decide if a project should be continued, expanded, or discontinued.

These measures can also be used to **evaluate proposed policies and projects** using past examples and forecasting methods such as sketch planning tools and modeling. 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 a range and combination of options and attempt to optimize the expenditure of limited transportation funds to improve the system.

Who Uses These Measures?

Mobility performance measures are used differently by different groups of people. Understanding who uses the measures and how each group uses them will allow you to provide the right information to achieve the best outcomes. Chapter 3 will provide a deeper discussion on identifying users, but the following provides a general overview of users and how they use the information:

- **Legislators, executive members, and commissions** use mobility measures to set transportation policy, assess transportation funding needs, and broadly enable transportation funding mechanisms.
- **Public agencies, such as DOTs, MPOs, tolling agencies, and mobility authorities** use mobility measures to select projects and programs, prioritize and spend transportation funds, and monitor system performance.
- **The traveling public** use mobility measures to make informed travel decisions, such as which mode to use, what route to take, and when to leave.

- **Manufacturers, shippers, and other corporate users** use mobility measures to make supply chain, routing, and mode decisions or for site location and investment decisions.

Practitioners and policy makers should carefully consider the connection between a person's travel and the measures used for system performance. Any process should examine what is being measured and how different users may impact the goals and vision of a community. Performance measurement, travel, and land use decisions are closely interconnected, even though a clear connection may not be easily seen. Poorly chosen, executed, or explained measures with mismatched expectations could have a significant negative impact on a community's livability for generations.

Reading This Manual

Developing a set of performance measures 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 manual provides 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 transportation system or identify the key investments or policies for a particular portion of the system.

Each chapter of this manual identifies research and practices to provide a base level of knowledge to perform modal and multimodal mobility analysis. Note that many concepts presented in this manual have been simplified to maximize the understanding of the latest concepts, practices, models, procedures, and technologies. The concepts presented can be used by both technical and public audiences to advance a fruitful discussion about how a community can improve livability and movement for all citizens.

Each chapter tackles several concepts, starting more theoretical and progressing more practical. The following provides overviews of each chapter.

- **Chapter 2: Concepts of Mobility, Reliability, Accessibility, and System Performance**
  This chapter describes the core concepts of transportation performance measurement from a high level, defining congestion, mobility, reliability, accessibility, and connectivity. It also addresses common issues and misunderstandings about mobility and accessibility that make the concepts appear at odds with one another. Finally, the text addresses the concept of total system performance and the importance of a holistic approach tied to community goals and values.

- **Chapter 3: The Performance Measurement Process**
  This chapter describes the complete process of mobility analysis and performance measurement, including requirements for measurement, vision and goal definition, measure selection tied to targets and outcomes, data collection, improvement analysis, and measure dissemination.

- **Chapter 4: Selecting Mobility Measures**
  This chapter provides assistance in selecting the right measures for a mobility analysis. It gives the reader a framework by which he or she can choose an appropriate set of measures. The

chapter also provides guidance for determining the appropriate time periods, geographic scale, and user type by which to put measures in proper terms.

- **Chapter 5: Recommended Performance Measures**
  This chapter provides a detailed list of the primary mobility and reliability measures used in mobility analysis. It also provides context for each measure group and suggestions for proper measure use. Helpful reference tables provide measure definitions, equations, measure explanations, and units.

- **Chapter 6: Data Collections and Databases**
  This chapter discusses the different data types and sources used in the calculation of performance measures. This includes types of third-party data sources, transportation networks, non-traditional or explanatory data sources, and modeled or estimated data. Tips for data acquisition, storage, use, and disposal are also given.

- **Chapter 7: Communicating Performance Measures in a Meaningful Way**
  This final chapter discusses best practices for communicating measure and analysis results to specified audiences in the context of relating them back to the vision, goals, and targets that were identified earlier in the process. It includes examples of charts and illustrations most used in mobility analysis and other applications of performance measures. Finally, the chapter offers tips for ensuring communication efficacy to maximize understanding among various audiences.

Chapter 2: Concepts of Mobility, Reliability, Accessibility, and System Performance

The Introduction identified the factors that travelers consider; that information provides insight into what is important to their decision-making processes. Many, if not all, of these factors translate into concepts that transportation professionals, planners, and policy makers use to provide transportation solutions. The challenge for transportation professionals is to develop a connection to the factors that people consider in their trip-making activity and derive measures that produce consistent evaluations. Providing a foundation of these basic concepts will help professionals evaluate whether improvements are needed; which projects, policies or programs to pursue; and which transportation needs are served.

This chapter describes the core theoretical concepts of transportation performance and congestion measurement: mobility, reliability, accessibility, and connectivity. It also addresses common issues and misunderstandings about mobility and accessibility that make these concepts appear at odds with one another. Finally, the chapter addresses the concept of total system performance and the importance of a holistic approach tied to community goals, values, and equity.

What is Congestion?

Before moving on to other concepts, one should understand an important component of measuring mobility: congestion. Congestion is the inability to reach a destination in a time and cost that are satisfactory to the traveler. While people usually think of congestion in terms of auto travel, congestion can occur in any mode (e.g., think of packed buses, crowded sidewalks, or heavily used bike lanes). In short, congestion represents less-than-satisfactory travel due to travel supply/demand imbalance, regardless of mode.

Congestion has four elements that can be quantified and used in the larger transportation planning and policy discussion. These and the four mobility elements—discussed later and roughly congruent with each other—provide the foundation for what is measured when dealing with mobility analysis.

1. **Duration:** The length of time during which congestion affects the transportation system. Originally described as the "peak hour" or "rush hour," in many cities congestion lasts far longer and is now referred to as the "peak period(s)." This is measured by the amount of time during the day that travel speeds indicate unsatisfactory travel speed on a corridor or the entire system.

2. **Extent:** The number of people or vehicles affected by congestion and by the geographic distribution of congestion. The person-extent may be expressed 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.

3. **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.

4. **Variation:** This key component describes the change in the other three elements and is closely related to reliability. 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 more difficult to predict.

These elements help transportation professionals and planners answer key questions that can be directly used in planning and policy:

1. How long is the system congested?
2. How much of the system is congested?
3. How bad is the problem?

Note though that these do not answer broader questions such as, "Are people getting to where they want to go?" (accessibility), "Are all people equally able to travel where they need to?" (equity), or "Are people able to better their lives through connections and options?" (livability and connectivity). Also note that these questions, the answers, and the elements that create them are highly subjective based on the expectations of travelers and size of the area.

"Satisfactory" is Relative

The idea that there are conditions that are "satisfactory" is based on the expectations of the traveler and the trip. It is heavily dependent on the factors most important to how people or goods travel such as those discussed in **Chapter 1: Introduction to Mobility**: accessibility of destinations, travel time, reliability, cost, travel options, and quality of travel. For example, the speed of travel for a trip is not as important if the trip is short. Walking across the street to grab lunch does not have to be accomplished at 60 mph to satisfactorily achieve the trip objective. Similarly, paying a toll is not necessarily bad if the traveler believes the benefits—such as a reliable trip—outweigh the costs.

Additionally, the size and density of the area in question heavily influences these expectations. Congestion in a small town or rural area will look and be expressed differently than in a large urban metropolis. This heavily influences expectations from the public. All these elements speak to relative standards.

Attempting to define and measure what is satisfactory can be difficult but provides planners and policy makers with a better idea about the public's transportation goals or the freight movement priorities. What may be satisfactory in one circumstance may be unacceptable in another. The agreed-upon norm may vary by transportation facility type, travel mode, geographic location, and time of day (*1*). For example, expectations about how long a trip from the suburbs to downtown will be radically different from the expectations for how long one should wait to turn left out of a business or how long one should wait for the next bus or train to arrive.

Therefore, transportation professionals, planners, and policy makers should strive to understand a local definition of what is satisfactory through consistent and equitable public engagement. This definition, consistent with public opinion, should be clear enough to be used for program selection, prioritization, evaluation. Be aware that what is satisfactory will change over time and circumstance.

What (Broadly) are the Concepts We are Measuring

The first step in approaching transportation performance monitoring is to become familiar with the broad concepts from which all measures stem. Each of these should be represented in any performance monitoring program—relying on only one or excluding one will create a system that results in or perpetuates inequity, neglects to solve all issues holistically, or may even create new or worse transportation issues. These concepts include:

- Mobility
- Reliability
- Accessibility
- Connectivity

Mobility

Mobility is the ease of movement from an origin to a destination. More broadly, mobility is the ability of people and goods to move quickly, easily, and cheaply to where they are destined at a specified target speed that represents either free-flow or conditions matched with community goals (*1*). Think of water flowing through a pipe from the source to a faucet: how quickly and easily does the water flow through the pipe to the final destination? Are there objects in the pipe that impede the flow of water? Travel can be considered and measured in a similar way.

Therefore, in a performance monitoring context, "Mobility measures the ability to move from one place to another (*2*, *3*, *4*). This can be from any or all transportation modes and over many different paths. The concept generally measures travel based on some form of travel time (e.g., actual travel time, speed, or delay) with cost, modes, and number of trips being limiting factors.

Mobility is composed of four elements that create a framework for how mobility should be measured.

1. **Time when mobility is provided or controlled:** An expression of mobility during some time of 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 frequency travelers can get to their destinations in satisfactory travel times.

2. **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 some accessibility statistics.

3. **Locations one can travel:** The locations where mobility can take place. This element is important in land use and transportation analysis, equity analysis, and economic development—understanding how mobility varies across a region and how they compare to goals or targets is crucial to identifying solution strategies. Mobility cannot occur everywhere and understanding where it can occur is important. Descriptions of modal options, transit routes, travel options, or other services (including broadband internet access) are helpful for measuring total mobility.

4. **Reliability of travel:** The variation of the prior three elements—it indicates how the level of mobility may vary for the same trip each location or time it is taken. While reliability is one of mobility's four elements, it has grown to be a stand-alone concept that will be discussed next.

Strengths

Measuring transportation mobility offers several benefits.

- Mobility measures are usually simple to calculate or estimate using readily available or easily obtainable data.
- Measures and the concept can be easily scaled or modified to different geographic scales, transit systems, modes, of situations with little effort.
- Measures can be easily communicated to policy makers and the general public.
- Measures are intuitive and can be described in simple terms.
- Mobility measures can be easily translated into actionable policy and targets.

Limitations

While there are many practical benefits to measuring the concept of mobility, there are also a few key limitations.

- The most widely-used mobility measures focus heavily on increasing speed and tend to support auto solutions to address broad transportation problems. These measures have been misused over time to advocate for more, larger, and faster roadways instead of alternative or holistic solutions.
- Mobility measures do not inherently point to new or different solutions outside of the regular toolbox to improve transportation or livability more broadly.

Reliability

Travel time reliability (often referred to as just reliability) is "the consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day" (*5*). Reliability refers to how certain one can be that the trip will take an expected length of time regardless of congestion or unforeseen circumstances, like weather, construction, or crashes. This concept is important in several situations:

- People planning an important trip.
- Freight shippers and manufacturers who depend upon reliable travel conditions to properly schedule deliveries or assembly lines and plan the movement of goods.
- System operations staff who are responsible for determining the projects, programs, policies, and staffing levels that ensure a reliable transportation system.

To illustrate the concept, imagine a trip that would take 20 minutes with no traffic, but since there is always traffic on this route, it normally takes 30 minutes in the rush hour. If the trip always takes 30 minutes, it would be thought of as reliable. However, if this trip could take anywhere from 20 minutes to an hour, the trip would be considered unreliable due to the dramatic swings in travel time from day to day.

In this example, travelers would need to build in a "buffer time" to ensure on-time arrival. A buffer is the extra time cushion required to ensure on-time arrival—even if one arrives early on most occasions. For freight or work commute trips, on-time arrival can be critical to keeping a job or ensuring just-in-time deliveries are met. Large buffers are less than ideal—but required for unreliable trips—because that extra planned time could be used more efficiently doing other things.

Thinking back to those factors most important to travelers, reliability reveals an important idea: traffic congestion, while undesirable, is not as bad if it is *reliably bad*. Practically speaking, freight shippers and commuters generally understand average traffic congestion and can often adapt. It is more difficult, however, to adapt to erratic travel times because it consumes more of their valuable time. Additionally, travelers and those expecting deliveries are more likely to remember the times when travel was unreliable, as shown in Figure 1 (*5*). Therefore, some transportation professionals view reliability as a slightly more important concept than average mobility concepts.

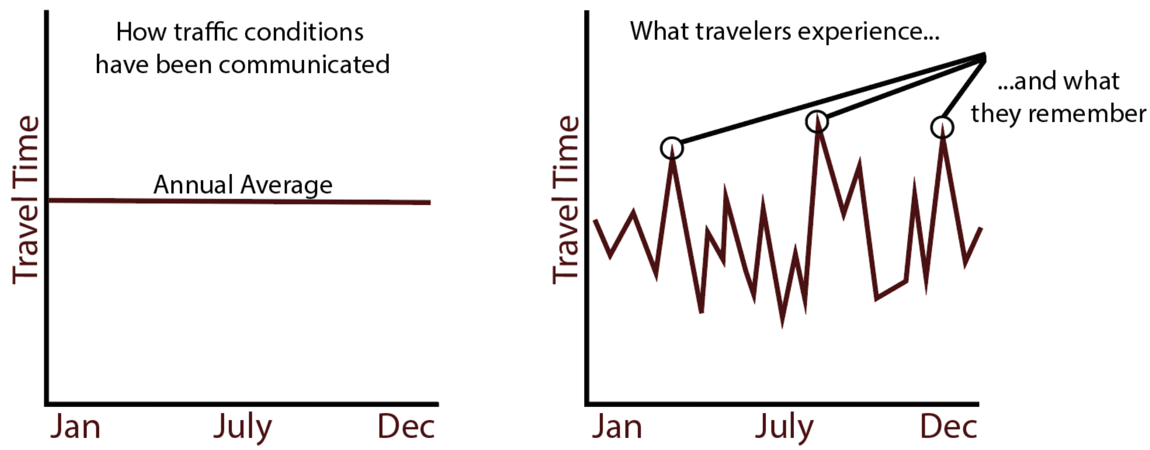

Figure 1: How Traffic is Communicated versus What People Remember.

Reliability as a component of a set of measures creates a more complete picture of transportation system performance.

Strengths

Reliability offers several of the same benefits as mobility (since the two concepts are heavily related).

- Reliability measures are usually simple to calculate though have higher data requirements than some other measures.
- Reliability can point to a menu of strategies that are usually faster to implement, less expensive, and foster equitable transportation.
- The concept and measures can be more easily adapted, especially to multimodal efforts.
- Measures can be easily communicated to policy makers and the general public.
- Measures are intuitive and can be described in simple terms.

Limitations

Reliability presents few limitations like mobility.

- Reliability measures can be easily misused and too heavily auto focused, even though reliability concepts are strong in other multimodal applications (e.g., transit on-time performance).

- Reliability offers only a portion of the total transportation performance picture and cannot identify congestion scale or severity like mobility or access.

Accessibility

Accessibility, first defined by Hansen, describes "the potential of opportunities for interaction." Stated plainly, accessibility has now come to represent the number of destinations or *opportunities* reachable from a particular (set of) place(s) in a given amount of time (*3*). This differs from mobility in that accessibility is less concerned about how (easily) one makes a trip and more focused on where that trip was made and when. This measure shifts the focus to land use and how it interacts with the transportation network.

From a mobility viewpoint, accessibility has been historically viewed as a quality measure (similar to level of service measures) that attempts to combine several elements into one descriptive term that can then be applied to segments or the greater transportation network. For example, speeds, travel times, network connectivity, congestion levels, and even level of service may be wrapped up as accessibility measures (*6*). Distilling the term in this manner greatly limits the actual meaning of accessibility and should not be used.

Mobility generally sees land use as a fixed variable while accessibility more greatly sees both transportation and land use as malleable and equally part of the solution. Therefore, accessibility measures in use—while still greatly concerned with trip cost and time—place less importance on improving travel speeds. Recommended solutions from using these measures might include providing more destination opportunities (e.g., more grocery stores in an area) and travel options (e.g., multimodal facilities, telecommuting policies, etc.) that may ultimately favor or at least be neutral to travel mode. For example, if you live 20 minutes away from the nearest grocery store, mobility would attempt to get you to the store faster while accessibility may advocate for building a new grocery store in your neighborhood that you can walk to in less than 20 minutes.

Similar to mobility, accessibility is defined by four components by which we can measure the concept (*7*).

1. Land use: The characteristics of how land is used and developed, including the physical location, density, characteristics, and use of both origins and destinations.
2. Transportation: The quality and performance of surrounding transportation networks and services, delineated by mode.
3. Temporal: The component that identifies when opportunities are available throughout the day and the variations of this availability within the day and between days.
4. Individual: This refers to the needs, abilities, behavior, and opportunities of individuals making trips. While often the most difficult component to measure, this can provide valuable insight.

An ideal accessibility measure would include each of these components but creating and using such a measure would be so complex that it would be both unachievable and impractical. Therefore, most accessibility measures focus on one or two components in heavily simplified terms. The complexity of accessibility measures has proven to be confusing for both professionals and the public. While basic point-location isochronal maps are intuitive and useful, broader and more complete accessibility measures are difficult to calculate and explain while strangely still being intuitive.

While this text focuses on measuring mobility and reliability, it is important to integrate accessibility concepts and measures into a performance monitoring plan—especially those that promote land-use solutions on equal footing with roadway improvements, equitable transportation for all travelers, and telecommuting and other multimodal travel options. No mobility plan should be considered complete without the consideration and integration of accessibility and accessibility measures. Note that most state departments of transportation do not control or influence land use, making many solutions difficult to implement. However, the integration of these concepts and measures into a mobility plan should foster and encourage closer collaboration with local and regional entities—increasing communication and partnerships between the state and the local areas.

Strengths

Measuring transportation using accessibility offers several benefits (*6*).

- Accessibility integrates both transportation and land use into one measure and has the potential to incorporate other complex systems such as travel behavior—showing the effects of a wide range of investments.
- Can more directly address equity, sustainability, or efficiency concerns into the transportation planning process.
- Can point to non-transportation solutions to solve transportation-related issues.

Limitations

- Measures do not provide an answer to why accessibility levels are low or high in an area and therefore provides little direction for action.
- Accessibility does not measure actual travel behavior, but instead conveys the universe of possible travel.
- The concept is difficult to communicate to policy makers or lay audiences and may not make intuitive sense.
- Measures are difficult to calculate, have high data requirements, and are difficult to convey meaning.
- Accessibility measures and concepts are difficult to use in creating actionable targets that bring about meaningful change.

Common Issues and Misunderstandings about Mobility and Accessibility

Just as there is no panacea to fix traffic congestion and mobility issues, there also is no single performance measure that adequately and accurately describes total system performance in a meaningful way. Planners and practitioners should use a suite of measures that both measure various unique aspects of the transportation system, but also hold some “explanatory overlap” with each other to verify their individual accuracy in performance monitoring. In other words, the suite of measures should tell a story about transportation performance that intuitively makes sense and reflects real-world conditions. For example, a reliability measure may describe some elements reflected in accessibility or mobility (Figure 2).

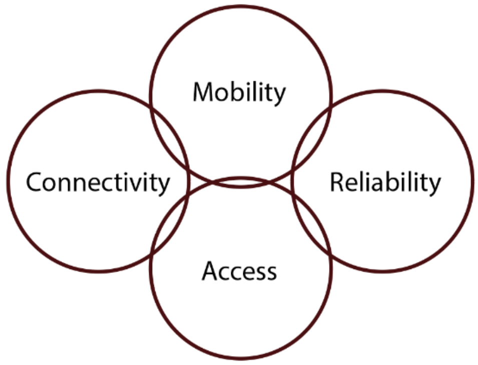

Figure 2: Performance Measures Should be Both Unique and Provide Explanatory Overlap.

There exists a common fallacy that mobility concepts ignore important elements of accessibility and vice versa, pitting one concept against the other. This viewpoint has caused some amount of tension between those who study transportation measurement and those who use the actual measures from day to day. However, this apparent “either/or” situation should not be the case; the issue arises in what measures and data are available for use and how these measures have been used practically in the past.

While these concepts are fundamentally different, they both provide good representations of what they attempt to measure. One should be careful to remember, though, that using only one of these concepts in transportation performance measurement will only provide a partial picture of the system and how solutions can improve overall livability and equity.

Carrying this idea one step further, a sole focus on one or the other can produce negative outcomes in the transportation system. The intense focus on and general misuse and misapplication of mobility measures over the last 40 years have been attributed to an increase in sprawl, decreased livability, and worsened health and environmental outcomes (*8*). However, critics of areas that focus more on accessibility concepts, such as Portland and Seattle, point out that economic output of the area may have been severely hindered due to decreasing mobility, increasing housing prices, and gentrification (all byproducts of some access strategies).

A deep connection exists between economic development and the built environment: everything from freight flow, commuting patterns, and households are affected by businesses and where they choose to operate. Despite the wealth of access residents of Portland are granted through decades of accessibility efforts, transit, and bicycle infrastructure, three quarters of Portland’s population still drives alone to work. Transportation systems serve as the glue in economic development, but in Portland’s case, an increased focus on mobility for all modes could be developed to grant auto commuters better access to existing and developing opportunities (*9*).

As noted earlier, mobility measures are generally easy to calculate and use progressively more complete and available data. These concepts are intuitive and make for simple communication, policy development, and target setting. This has provided mobility with a strong track record among transportation professionals as being the concept of choice to use for its practicality. Additionally, many departments of transportation have historically approached transportation from the construction, maintenance, and safety perspective—only relatively recently viewing their task from a system performance, management, equity, and overall livability perspective. Accessibility measures, on the other hand, have only recently become feasible to calculate with some regularity due to data availability and theory development. These measures have long been favored by academics and planners but have had difficulty finding a foothold with practitioners.

Connectivity

Connectivity is the level of integration of transportation networks with each other and with the land surrounding them. As a concept, connectivity usually refers to two primary cases, though many others exist.

1. **Connectivity of the street network:** This form of connectivity represents how porous and resilient the road network is to traffic. Usually measured in the number of nodes or intersections, a highly-connected network provides multiple paths and opportunities for travelers to adjust their path. This can be mode-specific (i.e., pedestrian connectivity, bike route connectivity, transit connectivity, etc.) or viewed in urban/rural terms.
2. **Connectivity of transit services:** Transit connectivity represents "the level of integration of different public transportation systems, allowing them to provide [seamless] door-to-door service" (*10*, *11*). Sometimes referred to as "ease of transfer," this form focuses on how porous or resilient different travel options (usually between transit services—buses, trains, ferries, etc.) are to influxes of demand and destinations.

In some cases, connectivity is confused for either mobility or accessibility based on what measure is being used. For example, practitioners may measure "connectivity" in terms of access to transportation services (number of transit stops within [x] travel time). While this is technically an accessibility measure, it can be used as a transit mobility measure or generically be called transit connectivity (*6*).

Improving connectivity can have a significant impact on both accessibility and mobility by providing direct routes to a greater number of destinations. Additionally, connectivity can provide improvements by providing multimodal connections, increasing system redundancy and resiliency, and other intangible transportation benefits.

Because increases in connectivity are often evidenced by increases in biking and walking, a focus on connectivity can improve health, equity, and livability outcomes for cities. You might consider the health benefits of increased walking and biking, but other not-so-apparent benefits include increased access to healthcare services, grocery stores, and educational facilities; improved equity in travel times for work trips; and more time spent with family and friends.

Strategies to increase transportation connectivity look different than those for the other three concepts, but also have some overlap. These could include realigning streets into grids, creating "punch-throughs" in cul-de-sacs, transit schedule alignment, short block lengths, access management, and complete streets policies, to name a few (*12*).

Strengths

Integrating connectivity into transportation performance monitoring can offer some significant benefits.

- Connectivity can provide missing context to both mobility and accessibility measure to fill in the gaps and create a more complete picture of system performance.
- Measures are generally straightforward and simple to calculate.
- The concept, once defined, is easy to communicate to lay audiences.

Limitations

- Connectivity does not provide sufficient information about transportation system performance on its own and should not be used in isolation.
- While measures can be easily used to craft policy or targets, those policies may not greatly impact system performance.
- Many strategies to improve connectivity are difficult and costly.

System and Multimodal Performance as a Whole.

While mobility and reliability measurement and performance remain the focal point of this guide, these concepts are only two pieces of the larger picture of total system performance and the movement needs of people. Accessibility and related land use elements, connectivity, technology, and multimodal elements should also be considered to better understand how a community's transportation system is contributing to the health, wellbeing, and productivity of its residents. This and equitable access and movement wrap up to create a more *livable community* that improves the lives of the people living there—and improving livability should always be the primary goal.

But staying focused on improving livability and equitable outcomes can often get lost in the day-to-day details and processes of monitoring transportation performance. Measuring only mobility and making decisions based on a narrow view of the transportation system will ultimately continue past mistakes. Keep in mind that policies and decisions happen slowly—mistakes made today may not be discovered for decades, and solutions will cost future residents if they can be fixed at all.

As you will see in the next chapter, transportation performance monitoring efforts should be focused through the lens of the community's broader vision and goals. Even at the state or federal level, the impact to the local community's livability and equity should guide what policies get implemented and what types of performance should be monitored.

Chapter 3: The Performance Measurement Process

The concepts and ideas presented so far provide a conceptual foundation for performing mobility analysis. Understanding what is important to travelers, the concepts of mobility and reliability, and the idea of what is satisfactory will shape how you approach the mobility measurement process.

This chapter builds upon that foundation and provides a blueprint for mobility measurement and analysis—identifying the key necessary elements and steps involved. As with any process, the continuous evaluation of the process will lead to improvement; it is important to continually compare and evaluate the flow, the measures, how the measures are used, and the outcomes throughout the process and adjust the measures or their scale as necessary. The steps outlined in this chapter illustrate how mobility analysis can be performed from start to finish.

Mobility Analysis: 30,000 Feet Up

The mobility measurement and analysis process is organized into three primary stages with steps in each stage (Figure 3). Following this road map will allow you to properly measure and analyze mobility and reliability. Note that this process is iterative and requires continuous feedback from each step to better refine the mobility analysis process and to ensure that errors or unintended consequences are found quickly and remedied. The remainder of this chapter will discuss each stage and the contained steps in greater detail.

Figure 3: Illustration of the Mobility Analysis Process

Stage 1: Define the Problem and Identify Preliminary Scope of Solutions

The first stage centers around identifying the broad community vision, goals, and issues needing to be addressed in the analysis process. The audience meant to digest the information and how those audiences may use the information should also be identified in this stage, giving careful consideration to how measures—and their meanings—could be used to create policy, targets, and ultimately on-the-ground solutions to transportation issues and problem areas. Paying close attention to this first stage will save countless hours and potentially valuable funds or political capital by avoiding serious mistakes.

As with any framework, the mobility measurement and analysis process can be expanded to fit nearly any scale of measurement from spot treatment issues at an intersection to national mobility trends. Identifying the desired scale should be integrated into the following three steps in this stage.

Identify the Vision and Goals

As with any planning process, identifying and understanding a community's vision, goals, and core issues should be the first step; doing so will reduce the risk of creating a something at odds with the livability and equity goals put forth through broader planning processes. However, simply identifying and understanding these values and issues does not guarantee success and to assume that it does (or to check a box in the process by collecting the information) will almost certainly guarantee issues down the line.

An area's long-range plan ideally contains a clear description of the community that the public aspires to create. Each plan, regardless of the geographical scope and purpose, should have a vision and goals that are integrated and carried through all elements of the plan. These should promote overall livability and equity within the community. The goals should also be actionable, measurable, and realistic: goals, while still aspirational, should be tied to objectives that provide clear targets for success or failure within a given time frame.

While visioning and goal-setting exercises are not a traditional part of mobility analysis, you should carefully exam and be mindful of what exists through the lens of livability and equity. If no vision or goals exist, you should consider performing these exercises before moving forwards with the analysis.

Every plan should contain a transportation element that assesses transportation facilities and programs and identifies improvements (if at all). In order for these improvements and programs to move toward achieving the vision and goals, performance measures must properly monitor relevant conditions as accurately as possible and direct planners and policy makers to the proper type and scale of needed improvements to bring about that vision. Performance monitoring and the measures used then become a critical link between vision and real-world change.

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*) or satisfactory concept referred to in **Chapter 2: Concepts of Mobility, Reliability, Accessibility, and System Performance** can be used to make the link between the broad vision and 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 (*13*). Performance measures are key to controlling process outcome, whether the process is alternative selection, congestion management, growth management, system optimization, or another facet of mobility. 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.

Ultimately, performance measures and what is being measured should be harmonious with the area's vision, values, goals and needs. Poor measure selection will lead to poor outcomes; but when measures are paired appropriately, the desired results can be achieved using the analysis results (*14*). The continuous reevaluation of outcomes throughout the process is necessary to ensure what is being measured is translating to outcomes that align with that vision.

Identify the Uses and Audiences

Determining *who* will use the outcome of a mobility analysis and *how* they will use it stands to be two of the most crucial questions to answer before beginning the process. Understanding these two questions might change what measures you use and how you present them to each audience.

The analysis and potential targets from the measurement process must be determined before the mobility measures themselves can be selected. The measures used must be capable of illustrating both the problems and the effects of potential solutions—and both should be put in useful terms for a variety of audiences (*15*). Increasing the flexibility of the measures may also improve the ability to use the information beyond the analysis. For example, corridor statistics may also satisfy annual reporting requirements.

Determine the Who

First, identify who your audience will be. This largely stems from the scale and process you are performing. For example, an analysis of freight mobility at the federal level has a different audience than an analysis of traffic signals along a corridor. The former will likely be used by federal departments outside of transportation, economists, and policy makers focused on national or international issues. The latter will likely only be used by local traffic engineers or city planners.

Understand that your analysis *will* have an audience and will likely have more than one. The primary audience will be the main recipient of the analysis results (not including yourself). A secondary or tertiary audience will be other users of the analysis and likely the public. Analysis outcomes, targets, and statistics should be easily understood and used by each audience; this may require outputs in plain language, reformatting the value, or simply publishing the outputs in multiple ways. For example, a TTI value of 1.20 means nothing to policy makers or the public; however, “congestion adds four extra minutes to an average 20-minute trip” provides those audiences with useful information.

Before beginning any mobility analysis, prominently write out who the primary and secondary audiences will be. Refer to this at each stage of the analysis.

Determine the How

Once you have determined who will be using the results, you must then determine how the results will be used by each group. Understanding how the measures and results of the analysis will be used by each audience will guide the development of the analysis itself to avoid unintended consequences. This exercise may be simple for a primary audience but understanding how secondary audiences use the analysis results may require creativity and imagination.

First consider each audience and their role in relation to mobility and performance measurement. For example, if a primary audience includes policy makers, their relationship to the analysis would be to consume high-level information, allocate funding, or consider policy changes.

Second, relate the role to likely use cases. Do this by taking the role the audience plays in the transportation process and identifying how and where performance measures and analysis naturally lend themselves. In the previous example, policy makers use the results from mobility analysis and performance measures to inform policy, prioritize and fund projects, and create targets for improvement.

Be sure to consider the message and narrative that each performance measure in plain language may convey. Refer to where you wrote down who the audiences are and insert the use cases identified here. It may be helpful to reach outside your sphere of influence to members of those audiences to ask them directly what they need.

Consider Possible Solutions

The final step in the first stage is to consider the existing problem areas and possible solutions that could result from the use of specific performance measures. No other step has the potential to identify unintended consequences as this one.

Using the audiences and their potential uses identified in the previous step, continue the extrapolation one step farther and consider the policies or projects that could result from differing measure and analysis values applied to known problem areas. Does the “logical next step” adequately address the root of the problem? 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. Ultimately, solutions should address the root issue and avoid moving the problem down the road or shifting the burden onto a different group of people.

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, but it will also lead to selection of measures that can fairly evaluate the range of alternatives.

At this point, you should begin to see what outcomes and thresholds are acceptable and what constitutes as unacceptable transportation conditions or policy side effects within the community. Are there groups that are inequitably treated by the outcomes? Do different areas behave adversely under the same measure (and if so, is there a better [set of] measure[s] that reduce these consequences)? This should be a natural progression from the first and second steps of identifying the area’s vision and goals and then identifying the audiences and potential use cases. Identifying the uses, audiences, and subsequently linking how the measures will affect project selection and goals is crucial to avoiding negative outcomes.

Stage 2: Identify the Measures and Analysis Procedures

The second stage moves from the conceptual and hypothetical questions of the first stage into more analytical and actionable processes of mobility analysis and performance monitoring. At this stage, one selects the appropriate type of analysis that will be performed and then reviews and selects the performance measures that will be used for that analysis. The scale and unit of analysis and the required data are also identified at this stage.

Most analyses, especially multimodal alternatives or regional summaries, require more than one measure in multiple scales to adequately describe the problem or develop alternative solutions. However, some analyses are relatively simple, and it may be appropriate to use only one measure. For example, corridor improvements analyses might require travel time, speed, and reliability measures to be expressed in person and freight movement terms. Alternately, traffic signal timing analyses 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 at a minimum.

Poor measure selection 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 (*16*).

Remember that while only one or a few mobility or reliability measures may be required, other measures dealing with accessibility and connectivity may also be required in a separate but corresponding analysis. Also pay close attention to the potential results of each measure, specifically as they relate to the type of solutions they would naturally encourage, the impacts on equity among disadvantaged populations, and changes to livability overall.

Stage 3: Perform Analysis and Evaluate Alternatives

The third and final stage of the mobility analysis process involves both performing the analysis and evaluating the results of the analysis to ensure identified issues are being addressed and the vision and goals are being achieved. At this stage, data should be collected or estimated and then checked for quality before being used. The mobility measures identified in the previous stage can then be calculated and assessed to form mobility results. Finally, the results of the mobility analysis should be tested against possible solutions. This identifies if the measures and analysis promote solutions that address the transportation issues, vision, and goals.

Collect or Estimate Data Elements

Acquiring, collecting, or estimating data can and should only commence after mobility measures have been selected. While tempting to do so, selecting measures based on the available data may not provide a complete, accurate, or precise picture of mobility needed to address the correct issues or meet the stated vision and goals. Instead, important elements may be left out of the analysis and lead to a misrepresentation of travel conditions, perpetuate inequity, or cause further mobility issues. Using patience in this process may reduce the cost and time needed for data acquisition, limiting gathered or third-party data to what will only be used and reducing the archival costs once the analysis is complete.

Once the mobility measures have been chosen and the data needs correspondingly selected, the data can be acquired. Using the information gathered in the previous stage, document needed attributes about the data, including the type, mode, level of precision, and statistical reliability (or level of completeness). These attributes must be consistent with the uses of the information and with the data collection sources.

Where possible, real and observed data and direct measurement are better than estimates or modeled data. However, estimates and models may at times be required to estimate future or improved conditions or required to be used due to data cost, scale, and availability. Newer data sources, such as third-party data, can provide rich information that can be used in multiple ways and for various measures and goals. Estimates or models may be appropriate for forecasting future scenarios or for additions to traffic counts, travel times, and speed data collected or purchased elsewhere.

Statistical sampling procedures may be useful for wide area analyses, as well as for validating models and adapting them to local conditions when more complete data are unavailable. Direct data collection may be used from a variety of sources including specific corridor studies, real-time data collection, and annual surveys.

In many cases, data can be purchased from commercial data aggregators or be available through federal agencies. Public examples include the Federal Highway Administration's National Performance Management Research Data Set (NPMRDS) for speeds or National Household Travel Survey (NHTS) for travel behavior, the U.S. Census Bureau for population and other demographic information, the Federal Transit Administration's National Transit Database (NTD), the Bureau of Transportation Statistics, and the Bureau of Economic Analysis, to name a few. A more complete discussion of data options can be found in **Chapter 6: Data Collections and Databases**.

Areawide travel monitoring programs may already exist within your state; while the proliferation of detailed private datasets continue to grow, these programs will continue to serve an important role for private data validation and should not be neglected nor discontinued. The directly-collected data may be more expensive to obtain; however, many aspects can be controlled to meet analysis needs, and statistical sampling techniques may be used to decrease costs, improve reliability, and supplement missing areas.

Once data have been collected, take care to examine the data for quality. Establish procedures for dealing with missing data and establish protocol for handling the data throughout its usable life from collection to archival, destruction, or reuse.

Remember that available data may change over time; data limitations should not rule out performance measures chosen for mobility analysis. Other estimations approaches or modeling may be an appropriate path until the needed data become available.

Identify Problem Areas

With measures identified and data collected, measures can now be calculated, and their results analyzed against real-world conditions. While much effort should be placed on the measurement calculation itself, neither this, nor the development of the results, should be the primary focus of this step (note, this step is not called "calculate performance measures" or anything like it). The focus should rather be assessing the results of the measures in known problem areas of the transportation network to see if the measures accurately portray what is happening in the system. *Do the measures independently reveal bottlenecks, roads, intersections, etc., that consistently underperform within the context of the goals and vision for the community?*

Similarly, other non-transportation related avenues should also be explored with the measures to identify opportunities for system improvement. *Do the measures, applied to transportation, reveal issues or context about local economic development goals or social equity concerns? Are known issues in these non-transportation areas accurately reflected by the results of the measures?* This may require overlapping non-transportation data (e.g., socio-economic data from the U.S. Census) with the measures.

These “reasonableness checks” provide the basis for a feedback loop in the mobility analysis process to the preceding steps. This enables the analysis to be iterative and shows the users where in the process the analysis breaks down. How the analysis matches current conditions may point to a needed review of the vision and goals, measures used (or not used) and their appropriateness, or other basic elements of the analysis that may be missing (e.g., modes, freight, social equity concerns, etc.).

In summary, the measures should identify well-known problem areas and provide information about their relative size or seriousness. This will allow an initial prioritization for treatments.

Test Solutions

The final step of a mobility analysis involves testing potential solutions to address the mobility, economic, equity, or other issues identified in the visioning and goal-setting processes using the selected performance measures and pre-collected data. *Do the potential solutions to specific transportation issues adequately solve the problem according to the preliminary measure results?* Changes in the transportation system and the performance measures should provide reasonable results for a range of possible projects, programs, or policies and identify the benefits and costs of these projects and policies.

Mobility improvement strategies should be tested using sketch planning and modeling tools to determine the impact they may have on the transportation system. One should remember that there is no single strategy that can completely address a congestion or mobility issue; each problem area is unique and will require multiple strategies to provide a robust solution. Also note that capacity expansion should be viewed as a last resort to other methods, modes, or policy techniques. Mobility improvement strategies should also be used under the correct scale and context; some strategies may work well in one circumstance, but not in another.

The process of testing solutions should generally ask the question: *“How much would ‘the needle’ move if [X] strategy or [Z] set of strategies are implemented in the identified problem areas?”* These could include a combination of spot/corridor treatments as well as area-wide strategies or policy modifications. This process also provides a second feedback loop to determine the need to modify the mobility measures used in the analysis. Inconsistencies or irregularities in results are sometimes a signal that different procedures or data are required to produce the needed products.

The ultimate goal of this testing process is twofold: to identify potential effective solutions and to identify potential unintended consequences. It will not be enough to simply look at the results from a strategy implementation and determine if the ‘needle’ moved up or down. Mobility analysis requires one to examine the logical ‘next steps’ and relationships to changes in land use, travel behavior, policy, equity, the environment, the economy, or other areas. Implementing a solution that may address the transportation problem may accidentally create a domino effect of other issues. For example, the implementation of access management (reducing driveways and installing medians) may increase speeds in a high-pedestrian area, increasing safety risks. While it is impossible to tell the actual outcomes, one could reasonably reduce or eliminate several unintended consequences.

A Summary of the Mobility Analysis Process

Developing and deploying a set of mobility measures in a mobility analysis process stems directly from a public discussion of the vision and goals for a community and any identified issues. The process should be cast with a deep understanding of who will be using the analysis and how it will be used by those audiences. Potential solutions identified early on in the visioning process may more likely provide clues to community desires than actual mobility solutions; however, early-identified solutions may also inform what measures may be needed and what data should be collected.

Measures, procedures, and required data can then be selected based upon the scale and context of the identified vision and issues. Remember that poor measures will measure poorly, and elements not measured will be ignored in choosing solutions. Therefore, one should be conscious of the related impacts into non-transportation areas—a fix for traffic may severely damage the social, economic, or environmental fabric of a community.

Once data have been collected or estimated, measures can be calculated and tested by comparing the results against known problem areas. This provides an important feedback loop in an iterative process to refine the suite of measures used based on the community’s vision and goals. The analysis should clearly identify problem areas in a logical manner and begin to point to potential solutions. The measures should then test possible solutions and identify unintended consequences.

The mobility analysis process fits into the larger transportation planning process in multiple ways. Incorporating the process elements into a sequence of events leading up to a robust and equitable public discussion of alternative improvement plans might result in a series of steps like the following:

1. Long-range planning discussions identify the community’s vision, goals, and known issues.
2. Measures, scope, and scale are identified based on community goals and potential solutions.
3. Existing traffic and route condition data are collected via data purchase, direct collection, or estimation.
4. Measures are calculated.
5. Results are compared to target conditions that are determined from public comments during long-range plan discussion.
6. Problem areas that need improvement are identified.
7. Solutions are proposed. Areawide strategies should guide the selection of the type and magnitude of specific solutions.

8. A range of the amount and type of improvements is tested.
9. Mobility measures are estimated for each strategy or alternative.
10. Measures are compared to corridor, sub-area, and regional goals.
11. Individual mode, facility, land use, or policy improvements that fit with the areawide vision and goals are identified for possible inclusion in the plan, subject to financial analyses.
12. Improvements are deployed and monitored for success.

Chapter 4: Selecting Mobility Measures

Choosing which measures to use in a mobility analysis can be performed once the vision, goals, audiences and their intended uses, and scope of the issues have been identified (see Stage 1 in **Chapter 3: The Performance Measurement Process**). These provide a foundation one can build upon to measure transportation performance most effectively—and may reveal that other forms of analysis (i.e., accessibility, connectivity) may be needed. Selected measures should be logically and directly tied back to the community's vision and goals.

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 other measures that are inappropriate for certain analyses. Every use of mobility measures (or any measure) should 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.

What Gets Measured Matters

A word of caution before selecting measures: the decision to use a performance measure in mobility analysis grants a special importance to the mode of travel, route, and traveler (traveler, commuters, or freight) who move through the network. Therefore, the choice of performance measure, including what it truly measures and the required data elements, can favor existing systems while compounding inefficiencies and disadvantages or can address inefficiencies and inequity seen in both transportation and the surrounding community. **No single measure will generate a full view of mobility or accessibility**, but thoughtful performance measurement will provide a window into one interconnected facet of mobility. Follow a systematic process for choosing measures, so that the set of measures assesses all important aspects of the transportation system.

Choose a suite of performance measures wisely because what gets measured matters. Elements left out of the mobility analysis like mode, routes, times, or costs, will likely not be considered in possible solutions. Additionally, policies or targets crafted from areawide mobility analyses may exclude important elements and create or perpetuate systemic issues, ingraining them into standard processes. Finally, avoid multiple measures that produce unnecessary redundancy or convey roughly the same thing.

Striking the Right Balance

Recall from earlier the paradigm by which people travel. Changes in any of those concerns will affect mobility at larger scales and may change what needs to be measured and how. For example, an increase in accessibility may reduce trip length, expand mode attractiveness, or reduce transportation costs—all of which may or may not be adequately reflected with the selected measures of a mobility analysis. The selected strategies may also have the effect of increasing housing prices in denser areas—reducing equity and increasing travel times for low-income travelers. Similarly, worsening private vehicle trip reliability may make transit more appealing and/or make operations a cost-effective option.

The fundamental issue, then, is a possible imbalance between mobility measures for corridors, segments, individual modes, etc. and the way that travelers use multiple modes, corridors, etc. for their complete trip. The difficulty lies in creating a set of measures that illustrate the needs of travelers that are also able to be translated into policy, projects, and programs. A set of measures used in analysis should be sensitive enough to detect the effects of various strategies.

A good set of performance measures should focus on the needs of the traveler/shipper and the region's vision, goals, and mobility issues. This places an increased importance on the public engagement process to determine what is important to the community and what issues need to be addressed first. This process can also identify what level of congestion is satisfactory for different parts of a community or different modes (i.e., more congestion may be tolerated in a downtown area versus lower-density or rural areas). Once these community needs and expectations are established, evaluate the chosen measure to ensure the measurement process will be sensitive to these needs.

Create a prioritized list of specific needs for performance measures developed from the public engagement process that ties them to the vision, goals, values, and priorities as defined by the relevant audiences and that are applicable to potential uses.

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 (**Stage 1** of the mobility analysis process). Having an idea of what the possible solutions are will produce a more appropriate set of measures.

Select measures that meet all or most of following attributes. A good set of performance measures will accommodate the following elements, often doing so from multiple angles.

- **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.

  Measures should also indicate progress (likely indirectly) towards the broader community vision, such as economic, social equity, and environmental goals. These elements have often been ignored, and past analyses and measures have created unintended consequences.

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

- **Be mode-neutral or include multiple modes and elements of system performance:** Mobility is often a function of more than one travel mode or system; historical analyses have often neglected to include any mode other than autos. Measures should either be mode neutral or include multimodal elements. A mode-neutral measure does not inherently favor one mode over another and includes (or can include) aspects from all portions of a trip. Multimodal measures can either inherently include multiple modes or be a combination of smaller measures wrapped into a modal score.

The ability to analyze the entire system, as well as individual elements or modes, is useful in the selection of project alternatives. These project alternatives should also include operations, policy, or land use changes.

- **Have consistency and accuracy**: Similar levels of mobility, as perceived by travelers, should have similar mobility measure values. This is important for analytical precision and 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. Before-after studies should be institutionalized to verify field conditions after an improvement to ensure that simple procedures produced reasonable values.

- **Be sensitive enough to detect and 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 more often 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 effectively. When certain data items or constants are unknown, use default factors until methods of direct measurement can provide adequate data.

Defining the Right Measure for the Right Analysis

Equally as important as identifying the correct measures is to identify the correct time periods, scales, and geographic areas. This process helps define the extent of needed data and how measures will be used and interpreted.

Time Periods for Analysis

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. Other time periods also include overnight periods (useful for establishing free-flow conditions or in freight mobility), weekends and mid-day (or in between peaks). Some mobility indexes are computed relative to free-flow and may be used during an off-peak period to assess if congestion is beginning to spill into that period based on a pre-established target. Reliability measures could also be applied to the off-peak period in locations that might be experiencing nonrecurring congestion issues.

Daily Analysis

Analysis using daily averages is often less useful with most indexes for both mobility and reliability measures, though accessibility measures, mobility measures using total delay, or annual trend analysis may be most useful. Daily values tend to "wash out" the impact of peak-periods with the longer off-peak periods. And many reliability measures scale best when taken in a monthly or longer period (e.g., planning time index that indicates how much time is needed to only be late once a month). While measures in person- or vehicle-hours is less meaningful to an individual at a daily scale, the scale works well for trend analysis. Daily delay is used in the Federal Highway Administration-sponsored Mobility Monitoring Program (MMP) in this manner (*17*).

Seasonal Analysis

Investigating the seasons of the year may also be interesting. 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 the following chapter can be used in a mobility analysis that compares peak or off-peak period measure changes by month of year.

Note that certain types of month-to-month comparison should not be performed due to seasonal differences—especially month-to-month trend analysis or comparisons over the previous month. For this type of comparison, data must be seasonally adjusted to remove the seasonality. The U.S. Census Bureau has developed a free stand-alone product called X-13ARIMA-SEATS that will seasonally adjust data for you. More can be found at https://www.census.gov/data/software/x13as.html (*18*).

Geographic Scales for Analysis

Urban or Rural Analysis

Rural locations can also be the subject of mobility analyses. For example, there might be an interest in freight movements in rural areas. Social equity, special events, and tourism activities are also situations that may generate interest in a rural analysis.

Data availability for rural areas may be difficult, though many public and private data sources are significantly improving in rural areas. Similar to urban areas, continuous data sources provide speed (travel time), volume, and classification information in many rural areas. Rural freight operations may also find interest in point-to-point travel time information. As with travel conditions on an urban congestion map, such point-to-point travel time information would allow insight into rural freight operations.

Most measures discussed in the next chapter can now be used and are useful for rural applications. Other measures, such as connectivity and reliability, may play a more prominent role than delay-based measures as there often may not be a congestion issue, but rather other issues that tie into economic and equity concerns.

Special events and tourism may also invite mobility analysis in a rural area. Third party data sources have significantly improved and may offer adequate rural coverage. If real-time equipment is already installed, it could be used to obtain data to compare to a target travel rate. 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.

Freeway and Arterial Analysis

While most measures can be used interchangeably between freeways and arterial (or other types of) streets, measures using a -per mile, -per person, or -per trip and indexes work best when both streets and freeways are being analyzed together. Indexes are especially useful when multiple roadways and/or large numerical values make interpretation of relative conditions difficult. Be careful when mixing functional classes that the results can be accurately compared and still be meaningful.

Small Scale versus Large Scale Analyses

Some measures work better for small-scale analysis areas, like individual spot locations, short roadways sections, trails, and corridors than for larger-scale analysis areas, like neighborhoods, urban areas, regions, state, or the nation.

Basic data element, such as volumes, speeds, mode splits, and travel times, work best in the smaller-scale areas where numerical values are small enough to make sense and where those values may be required as inputs in potential solutions, like operational treatments. Basic index values may also work well, especially when spot locations are being compared with one another.

For larger areas, area measures (discussed in **Chapter 5: Recommended Performance Measures**) that show magnitude (e.g., total delay, congestion duration, total congestion cost, etc.) work best to show the relative size of the issue. Values placed in a -per traveler/commuter or -per vehicle make the most sense to general audiences and adjust for the relative size of each area, especially for comparison. Index values at a larger regional scale can still be used but make less sense than they do on a corridor level as much of the size, scope, and intensity of the issue gets washed out in averages. Highlighting the worst comparable corridors with an index within a region may better convey issues better than a regional index value.

Accessibility and connectivity measures tend to work well between small- and large-scale analyses. Though not discussed in this guide, some accessibility measures work especially well and make the most sense to a non-technical audience when used at a point or small neighborhood scale, though less so along a corridor. More aggregate accessibility and connectivity measures can be relevant at a larger urban area or regional scale but provide little context to the issues at hand other than establishing a benchmark by which future measures can be scaled against (i.e., did access or connectivity improve or worsen regionally after a policy or treatment). Local, regional, and transit entities also find these measures highly useful in transit and land use change analyses and proposals.

Freight, Commuter, and Traveler Analysis

While most measures work seamlessly between freight and commuter analysis, consideration should be given to what is relevant to the selected audience. Freight analyses will likely be geared to those who care about freight; therefore, most aspects of commuting would not be relevant (and vice versa). For example, use of the planning time index (PTI) is useful for both freight and commuters, but different versions should be used for each. PTI_{95} is better used for freight, because it indicates how much time is needed to avoid being late more than one time a month—useful for shippers to know. However, PTI_{80} is more useful to commuters because it indicates how much extra time is needed to avoid being late more than once a week.

While commuters focus on the to/from work commute or most people traveling during the peak periods, a focus on travelers broadens the analysis to include multiple modes and all times of the day (unless specified differently). While the distinction seems small, the scale of the measure results and ramifications may be quite large. Be careful to be distinct and differentiate the two.

For all three variations, the data needs will be different and require either modification or subsets of datasets or completely separate datasets. Keep data availability and the usefulness of data estimating procedures in mind for each type of analysis.

The Right Measures for the Type of Analysis

Choosing the right measures based on the type of analysis being performed is another consideration of which to be mindful. Some measures may not be the best or may not work at all for certain types of analyses. In choosing a set of measures, too many measures—especially if some are irrelevant to what is being analyzed—may ***distract*** or ***detract*** from the power of the analysis to communicate the issues or status of the vision and goals.

While it is difficult to cover every type of mobility analysis, Table 1 recommends primary and secondary measures for many common types of studies and information requirements. This illustration shows how the mobility measures may vary by scope of the analysis, but not necessarily by mode or facility included in the analysis (though there are circumstances where some measures do not work well for certain modes or facility types) (*1, 19*). Different values will be used for certain measures depending on the facility type or travel mode, but the calculation and application of the measures are identical.

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.

Table 1: Recommended Mobility Measures for Various Types of Analyses.

Uses of Mobility Measures	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
Adapted from NCHRP (***Error! Bookmark not defined.***)

Recall back to the discussion of why people travel from **Chapter 1: Introduction to Mobility**. Travel time and travel reliability make up two of the six primary aspects (and arguably cost as well) that determine how and why people travel. While mobility represents only a portion of these reasons, mobility measures can effectively illustrate a wide—but not necessarily complete—range of mobility solutions in a flexible manner.

While each measure individually will not meet all the criteria described earlier, the group of measures chosen should. Proportionate weight reflecting the community vision and goals should be placed on each measure to ensure elements of importance are not left out. If elements are unfilled or inadequately met, find ways to supplement those missing elements so that no part goes unmeasured or unaddressed.

Chapter 5: Recommended Performance Measures

As performance evaluation becomes a more vital component of transportation agencies' regular operations, choosing the right transportation performance measures and metrics (collectively "performance measures") is just as essential as the measurements themselves. Performance measures can paint a comprehensive picture of the studied transportation network and adjoining land use. There are hundreds of performance measures that transportation agencies can choose from; however, a handful of central measures are key to inform transportation policy makers of accurate information over the state of the network. Because performance measurement has become increasingly sophisticated over the years, clear communication and straightforward and concise performance measures can be an advantageous tool for agencies. A system of mobility and reliability 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 that could be deployed by using the measures.

> **Measure**: A number derived from taking a measurement (ex. your height/weight, travel speeds, traffic volume, etc.).
>
> **Metric**: A calculation between one or more measures.

This chapter provides an overview of the different types of performance measures that can be considered for use in mobility analysis. While primarily focusing on mobility and reliability measures at the individual level and areawide level, basic accessibility and connectivity measures related to mobility as well as basic data elements and explanatory elements will also be presented. These measures are useful for roadway systems, person and freight modes, and transportation improvement policies and programs. Although several analyses may not benefit from a broad focus, the user should consider the way that measures might be used and who might benefit from their results before selecting the appropriate set of mobility measures. Remember, as you select performance measures, be mindful of how they contextually fit the vision and goals of the stakeholders involved.

Chapter Organization

The following sections list performance measures that any agency can use in their performance evaluation process. Performance measures have been organized in four primary categories:

1. **Basic Data Elements**: These are variables that, on their own, provide valuable system information but also are primary variables in many performance measure equations.
2. **Individual Measures**: These measures are those most applicable to individual travelers or shippers and can be applied at smaller geographic scales and provide basic performance information that can be used for comparison, policy, problem identification, solution design, or operations management.
3. **Area Measures**: These measures are applicable only at a corridor-, area- or region-wide scale, providing broad information about system performance. Area measures have many uses, but are primarily used for transportation network analysis, policy, goal and target setting, total system performance, planning, and forecasting. Note that many of these measures are similar to several individual measures.

4. **Access and Connectivity Measures**: While this information may not be specific to mobility or reliability measures, they provide explanatory information and context that may modify or annotate any number of basic data elements, individual measures, or area measures. These measures should be integrated wherever possible.

Each category of performance measures will be presented in a standard format for quick reference. Each measure will include the information seen in Figure 4.

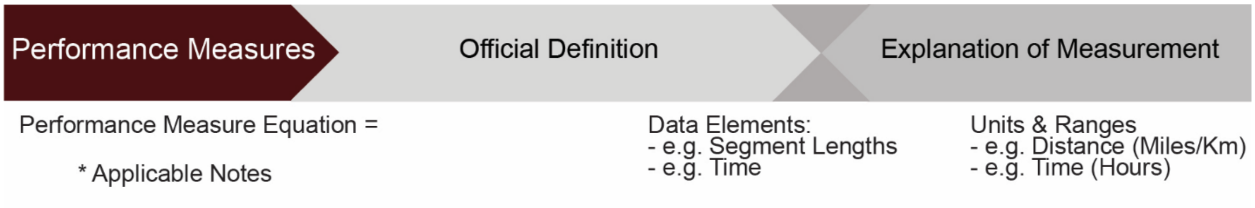

Figure 4: Performance Measure Example Format

After each table of measures within each category, certain performance measures will be highlighted giving further explanation or context due to their popularity of use.

Basic Data Elements

This section describes the basic data elements used to define mobility measures. The units are noted for typical urban analyses and differentiated as speed and volume, distance, and time elements to improve performance measure selection. It is key to understand these elements as building blocks of more intensive mobility trend equations as analysis increases in scale.

Speed Elements

Several speed terms are used in this guide and in the mobility analysis. This section and Figure 5 provide definitions of primary speed measures and guidance on their use in mobility analyses.

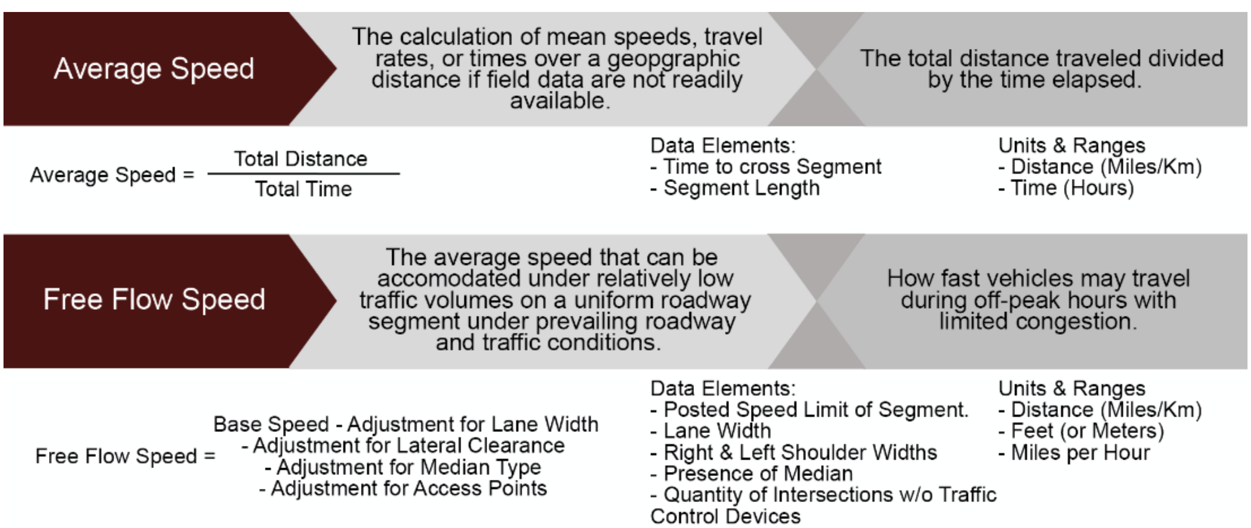

Figure 5: Speed Elements

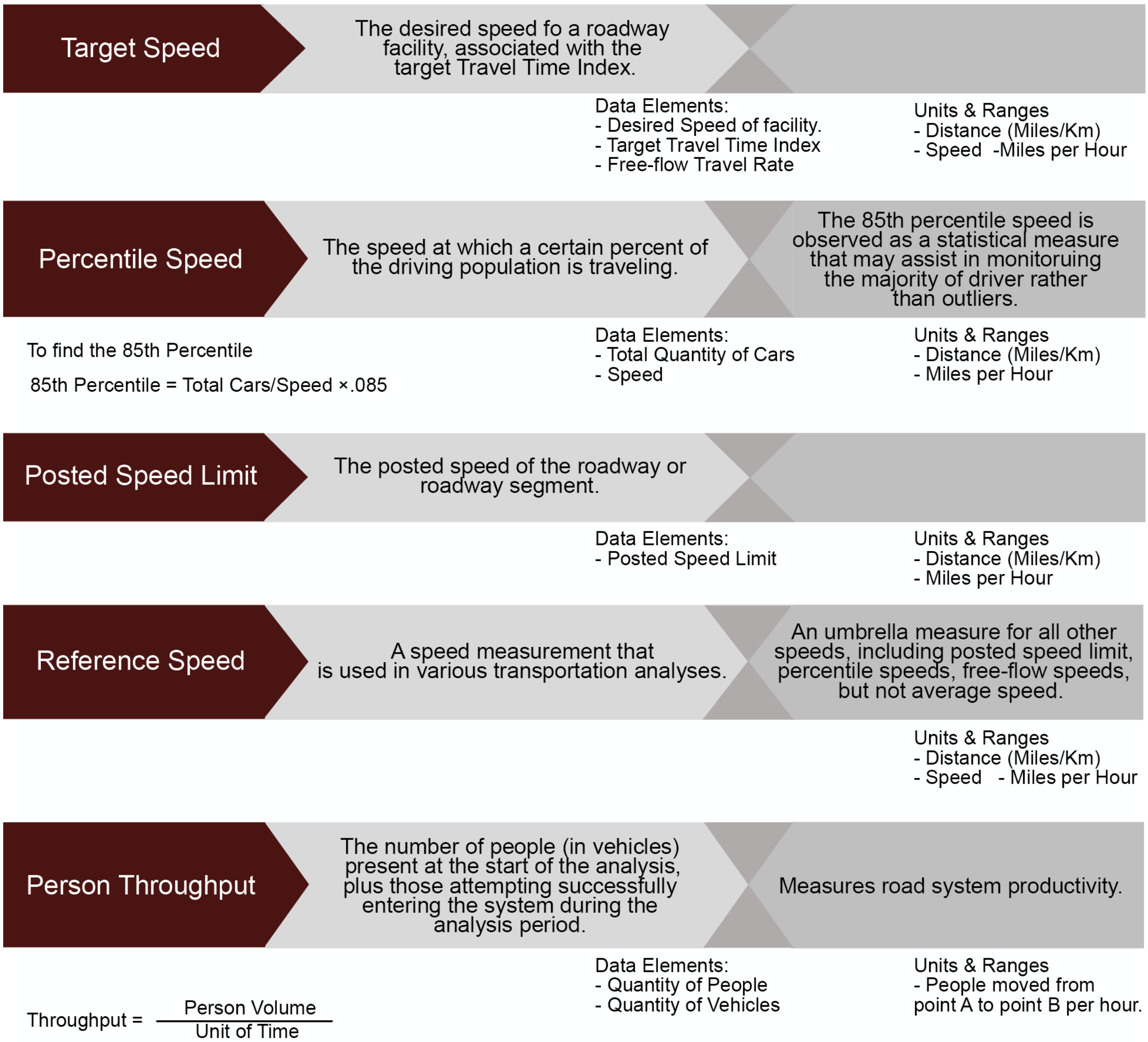

Figure 5: Speed Elements (Continued)

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.

In looking at speed measures—posted speed, free-flow speed, and reference speed—it may at first glance be difficult to justify the use of one over the other when analyzing speed of a roadway. Reference speed acts as an umbrella term to all threshold speed measures (except for average speed). Posted speed limits are sometimes set for public policy reasons rather than being tied to actual conditions, while free-flow speed is best for matching how people drive given the roadway operating conditions. For example, a commuter could portray their experience in free-flow conditions by saying, “I was 5 mph over the posted speed limit, and I was still being passed," and have their experience understood by others.

Note that posted speed limits are included in most roadway inventory files and should be readily available for analytical procedures; however, posted speed limits are not ideal for use in most mobility measures. Posted speed limits may produce a 'negative delay' value representing areas where speeding is common and can be easily filtered from the analysis if desired.

Free-flow speeds used to be difficult to obtain; new data products provide speeds with high granularity, making analysis much simpler. Free flow speeds are generally obtained by observing overnight periods after 10:00 pm but before 5:00 am. However, be careful on arterial streets where signals may distort free-flow speeds.

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

Delay and congestion index measures should be computed relative to free-flow speed. Using free-flow speed for these calculations 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 calculating 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.

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

The posted speed limit can also be used to calculate delay and index measures as well as 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.

Comparison of speed as well as congestion conditions through these measures can be difficult across regions and over time as infrastructures and throughput conditions change. 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 condition (free-flow speed or posted speed limit) in delay and index computations for the community and stakeholders involved with the analysis.

Volume, Distance, and Time Elements

Other basic elements, such as measures of volume, distance, and time, are also used extensively on their own or as basic elements in other performance measure equations. Like speeds, a key to understanding individual and areawide performance measures will be to fully grasp these elements. Figure 6 lists and details measures of volume, distance and time.

Person Throughput

The number of people (in vehicles) present at the start of the analysis, plus those attempting successfully entering the system during the analysis period.

Measures road system productivity.

$$\text{Throughput} = \frac{\text{Person Volume}}{\text{Unit of Time}}$$

Data Elements:
- Quantity of People
- Quantity of Vehicles

Units & Ranges
- People moved from point A to point B per hour.

Freight Volume

The amount of goods moved on a transport segment or system.

How much freight is physically moved as to measure reliability and other costs across markets.

$$\text{Throughput} = \frac{\text{Freight Volume}}{\text{Unit of Time}}$$

Data Elements:
- Freight Volume

Units & Ranges
- Freight (Lbs./Kg) moved from point A to point B per hour.

Average Vehicle Occupancy & Ridership

The volume of individuals per vehicle on a given roadway segment being studied.

The average number of occupants present in a vehicle during a trip.

$$\text{Average Vehicle Occupancy Rate} = \frac{\text{Total Number of Occupants}}{\text{Total Number of Vehicles}}$$

Data Elements:
- Quantity of People
- Quantity of Cars

Person Miles of Travel/ Vehicle Miles of Travel

The magnitude of travel on a section of the transportation system or on several elements of the system.

When one person travels five miles, five person miles of travel result. When four people travel the same distance, twenty miles of travel result.

Person Miles of Travel = Person Volume × Distance Traveled

Data Elements:
- Number of People
- Number of Miles/Kilometers

Units & Ranges
- Distance (Miles/Km)

*A particular useful measure in corridor and area-wide analyses where total travel demand is used in calculations.

Miles of Facilities/ Lane Miles

The quantity of miles a given facility or corridor measures in length by lane.

Data Elements:
- Facility Length

Units & Ranges
- Distance (Miles)

Segment Length

The linear measure of the studied roadway network.

*Data can be collected through Geographic Information Systems or other geo-spatial processing software.

Data Elements:
- Distance of roadway networks.

Units & Ranges
- Miles/Kilometers

Travel Time

The time required to transverse a road segment or complete a trip.

The amount of time it takes a person to travel from point A to point B.

Travel Time = Time (in minutes) / from origin to destination

Data Elements:
- Trip Time

Units & Ranges
- Time (Minutes/Hours)

*Times may be measured directly using field studies or can be estimated using empirical relationships with traffic volume and roadways characteristics, computer network models, or the intended effects of improvements.

Target Travel Time

The time that indicates a system of mode is operating according to locally determined performance goals.

The target or desired quantity of time it takes an individual to move from point A to point B.

Target Travel Time = Desired Trip Length

Data Elements:
- Trip Time

Units & Ranges
- Time (Minutes/Hours)

Figure 6: Volume, Distance, and Time Elements

Element	Definition	Description
Travel Time Traces	A method to analyze travel times over varied time periods or geographies.	The time required to travel a route, typically along a roadway, when trip start times vary by day, week, or road segment.

Travel Time Traces = Σ Segment Travel Times for a given Time Period

*Units of time and ranges depend on area analysis

Data Elements:
- Segment Travel Times

Units & Ranges
- Time (Minutes/Hours)

Element	Definition	Description
Total Travel Time	The door-to-door sum of all travel times regardless of mode or travel path.	Aims to decrease trip times when traveling by any or multiple modes as it factors in telecommuting & dense land use types.
Average Travel Rate	The rate at which segment traversed, or a trip is completed.	The ratio of time it requires to traverse a given roadway segment as measured in minutes per mile.

$$\text{Travel Rate} = \frac{\text{Travel Time}}{\text{Segment Length}}$$

Data Elements:
- Travel Time
- Segment Length (in Miles)

Units & Ranges
- Minutes per Mile

*Travel rates may be determined directly using travel time field studies, of can be estimated using transit schedules or empirical relationships between traffic volume and roadway characteristics.

Element	Definition	Description
Target Travel Rate	The maximum rate at which a segment is traversed or a trip is completed without experiencing an unsatisfactory level of mobility.	The slowest speed at which a segment is traversed without experiencing an unsatisfactory level of mobility.

$$\text{Target Travel Rate} = \frac{\text{Desired Travel Time}}{\text{Segment Length}}$$

Data Elements:
- Distance of roadway networks.

Units & Ranges
- Miles/Kilometers

Element	Definition	Description
Travelers/Commuters/ Population	Total number of mobile individuals in a given area.	
Mode Split/Percent Non-SOV (PM3)	A ratio of different transportation modes in the total journey on a given road segment.	The number of vehicles on the roadway facility that are not single occupancy vehicles including buses and bicycles.

Mode Split or Percent Non-SOV
= Total Number of (Non-Motorized and Motorized) Vehicles
- the Amount of SOV

Data Elements:
- Mode Share

Units & Ranges
- Mode Split
(Measured in Percentage)

Element	Definition	Description
Peak Period Definition	The periods during the day which travel speed indicates congested travel on a system element or entire system.	

Figure 6: Volume, Distance, and Time Elements (Continued)

Volume elements with similarities to highlight include miles of facilities/lane miles and segment length—both linear measurements of a study area with the ability to isolate or elongate an analysis area. Miles of facilities/lane miles should be used for a corridor study with a greater breadth as opposed to spot treatments or analyses with shorter segment lengths. If measures seem to be similar in scope when preparing to choose one for analysis, be sure to compare geographic elements, performance standards (or lack thereof), and required data elements to assist in performance measure selection.

Other Data Elements

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

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. Transport system reliability is a particular concern in analyses of incident management programs, value pricing projects, and freight movement.

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, 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.

Individual Measures

This grouping of performance measures (Figure 7) is applicable and meaningful to individual travelers and are the core basis for most mobility analyses. Individual measures area calculated using many of the previously discussed data elements, such as speed and volume. These measures offer ample flexibility as they can be used at multiple geographies, mobility aspects, and to some extent, multiple modes. The analysis of individual data elements and calculation 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.

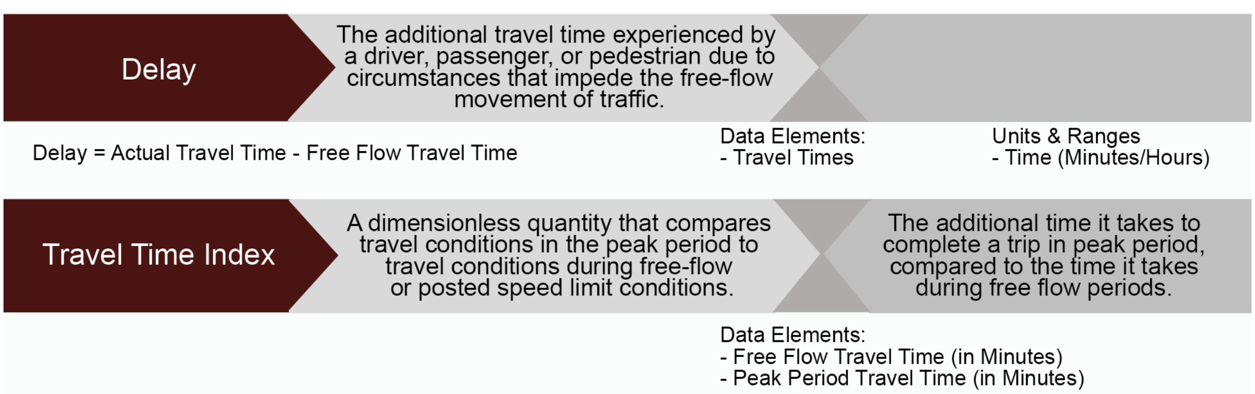

Figure 7: Individual Measures

Travel Rate Index

Similar to TTI, 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.

The rate of additional time needed to complete a trip in peak period congestion, compared to free-flow periods.

$$\text{Travel Rate Index} = \frac{\left(\frac{\text{Freeway Travel Rate}}{\text{Freeway Freeflow Rate}} \times \text{Freeway Peak-Period VMT}\right) + \left(\frac{\text{Principal arterial street travel rate}}{\text{Principal arterial street freeflow rate}} \times \text{Principal arterial street peak period VMT}\right)}{\left(\text{Freeway Peak-Period VMT} + \text{Principal arterial street peak period VMT}\right)}$$

Data Elements:
- Freeway Travel Speed & Rate (free-flow & peak period)
- Principal Arterial Travel Speed & Rate (free-flow & peak period)
- Freeway VMT (peak period)
- Principal Arterial VMT (peak period)

*A TRI of 1.20 means it takes 20% longer during congested periods than in uncongested conditions. PMT could also be used instead of VMT to better assess other modes.

Planning Time Index

Represents the total travel time that should be planned when an adequate buffer time is included.

How much time a traveler should plan to ensure on-time arrival or lateness only during extremely congestion.

$$\text{Planning Time Index} = \frac{\text{Nth (95, 80, 50) Percent Travel Time}}{\text{Free Flow Travel Time}}$$

*A value of 2.50 means that for a 30-minute trip in light traffic, 75 minutes should be planned.

Data Elements:
- Segment Travel Time (peak period & free-flow speeds)

Units & Ranges
- 50% typical day/median
- 80% when trip constraint is similar to work trips
- 95% when the trip is emergent

Buffer Index

A measure of trip reliability that expresses theamount of extra “buffer” time needed to be on time for 95 percent of trips.

This measure seeks to find the extra time cushion that travelers must add to their trip to ensure on-time arrival.

$$\text{Buffer Index} = \frac{\text{Planning Time Index}}{\text{Travel Time Index}}$$

Data Elements:
- Segment Travel Time (peak period & free-flow speeds)

Level of Travel Time Reliability (PM3)

Percentage of person-miles of the National Highway System that is considered reliable, in terms of interstate and non-interstate NHS roadways.

A segment is considered 'reliable' when the 80th percentile travel time/50th percentile travel time is less than 1.50.

$$\text{LOTTR} = \frac{\text{80th Percentile Travel Time}}{\text{50th Percentile Travel Time}}$$

Data Elements:
- Travel Times
- Road Segments & Segment Length
- AADT
- Occupancy Factor

*LOTTR metrics are evaluated over four periods in a day, if a period has a travel time ratio of >1.50, the segment is considered unreliable.

Truck Travel Time Reliability Index (PM3)

The TTTR Index is calculated by multiplying each segment’s largest travel time ratio of the five periods by its length, then dividing the sum of all length-weighted segments by the total length.

The performance of freight movement on interstates.

$$\text{TTTR ratio} = \frac{\text{95th Percentile Travel Time}}{\text{50th Percentile Travel Time}}$$

$$\text{TTTR Index} = \frac{\Sigma \text{ Segment Length} \times \text{maxTTTR}}{\Sigma \text{ Segment Length}}$$

Data Elements:
- Travel Times
- Road Segments & Segment Length

*TTR metrics are evaluated over five time periods in a day and the maximum travel time ratio is used to calculate the measure.

Peak Hour Excess Delay (PM3)

The extra time spent in congested conditions defined by speed thresholds that are lower than a normal delay threshold at the Urban Area Level.

For the purposes of this rule, the delay threshold is 20 miles per hour or 60 percent of the posted speed limit, whichever is greater.

$$\text{Excessive Delay} = \left(\text{Average Vehicle Occupancy} \times \sum_{\text{Peak Periods}} \text{Delay}\right)$$

*Delay is calculated in 15 minute increments during the AM (6AM - 9AM) and PM (3PM - 7PM or 4PM - 8PM) peak periods

Data Elements:
- Travel Times
- Road Segments & Segment Length
- AADT - Occupancy Factor
- Posted Speed Limit
- Urban Area Code

Units & Ranges
- Measured at the Urban Area Level

Figure 7: Individual Measures (Continued)

Cost per Commuter	The cost of extra time spent at congested speeds rather than free-flow speeds by individuals	The cost an individual experiences during congested conditions while traversing a transit or roadway segment.

Cost per Commuter =

Daily Passenger Vehicle Hours of Delay × Value of Person Time $ per Hour × Vehicle Occupancy * Annual Conversion Factor × Daily Washed Fuell * Gasoline Cost

Data Elements:
- Value of Person-Time
- Amount of Time Delayed
- Vehicle Occupancy
- Amount of Waster Fuel
- Gasoline Cost

Units & Ranges
- Monetary Value (in Dollars)

Figure 7: Individual Measures (Continued)

Individual Measure Nuances and Explanation

Individual performance measures can be expressed in a variety of units and ranges as well as qualifying acceptable thresholds and performance goals, therefore it is vital to understand the variety of dimensionless quantities expressing individual mobility.

Travel Time Index (TTI) and Travel Reliability Index (TRI)

The travel time index (TTI) is an example of a dimensionless quantity expressed in real numbers as opposed to monetary values or time. TTI 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 normally taking 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. TTI and travel rate index (TRI) are very similar measures as they are both used to compare travel conditions across infrastructure type and reference speed; however, TTI includes incident conditions while TRI does not. The TRI is best used to calculate congestion levels from the travel demand planning model because conditions caused by collisions are not considered.

Both measures 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.

Note a major weakness of the TTI and TRI measures is that they favor solutions that increase travel speeds versus decreasing total travel time. This is especially an issue when assessing urban versus suburban commuters: urban commuters may experience more delay and slower speeds but have an overall shorter travel time than suburban commuters going to the same place. For example, consider the following two commuters:

- A suburban commuter who travels 20 miles to work in 24 minutes on freeways.
- An urban commuter who travels 2 miles to work in 10 minutes on streets.

Based on the summary statistics of these two commuters in Figure 8, of the four measures typically used to evaluate transportation service (shaded rows), three of them favor the suburban commuter trip. Only the travel time measure shows a benefit for the urban commuter—14 minutes less travel time, either because of not driving or because of a shorter trip.

Measure	Suburban Commuter	Urban Commuter
Distance (mi)	20	2
Free-flow speed[a] (mph)	60	30
Free-flow travel time (min)	20	4
Travel time (min)	24	**10**
Average speed (mph)	**50**	12
Delay (min)	**4**	6
Travel time index[b]	24/20 = 1.20	10/4 = 2.50

NOTE: Bold font indicates better value (as normally defined by traveler desires) of quantities normally used as performance measure.
[a]Average speed of a functional roadway class during overnight period (10:00 p.m. to 5:00 a.m.), capped at 65 mph on freeways.
[b]Ratio of travel time in peak period to travel time at free-flow conditions. A value of 1.30 indicates a 20-min free-flow trip takes 26 min in peak period.

Figure 8: Example of Two Commuters and Measure Use

In this example, the suburban commuter can travel at higher speeds and experience less delay in congestion. The urban commuter travels at slower speeds and experiences more delay but gets to work in 14 fewer minutes of travel than the suburban commuter (*20*).

This comparison reveals a weakness of TTI and focuses on an element that travelers seem to care about—short travel times. Of course, commuters care about many factors related to housing location, but this example should provide users of delay-based measures reason for caution in relating measures to community goals.

Planning Time Index (PTI) and Buffer Index (BI)

When performing an analysis on the extra time travelers allow for congestion, one may use planning time index (PTI) or the buffer index (BI) measure, but they are different measures (defined in Figure 7). A PTI represents the total travel time that should be planned for when an appropriate buffer (indicated by the BI) is included. Thus, the PTI compares near-worst case travel time to a travel time in light or free-flow traffic. For example, a PTI of 1.60 means that for a 20-minute trip in light traffic, the total time that should be planned for the trip is 32 minutes (20 minutes $\times$ 1.60 = 32 minutes). PTI is useful because it can be directly compared to a TTI on similar numeric scales while aiming for a high percentile or reoccurrence of on-time arrival with a 95th percentile calculation.

The BI expresses the amount of extra buffer time needed to be on-time 95 percent of the time (or at a 95th percentile); however, in a corridor or area analysis, it is not expressed in time or distance, but rather as a weighted average using vehicle-miles or person-miles. 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.

A BI can be calculated for multiple road segments or a particular system element and appears to relate well to the way travelers make decisions. Conceptually, travel decisions proceed through questions like:

- "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 must be allowed for uncertainty in the travel conditions. For this reason, the BI is impactful on time allowance decisions by a traveler, and PTI is ideally suited for traveler information, but not across multiple geographic areas.

Most performance measures or indexes expressed in a manner beyond units may abide by performance goals according to percentiles or scales of percentiles including 80th, 90th, and 95th percentiles. Most often tied to reliability or the frequency at which a traveler would like to arrive on time to a destination, a percentile will indicate how bad delay will be on the heaviest travel days. For example, the 95th percentile represents how bad delay will be on the worst day of traffic in a month. Alternately, if a person cannot be late to work more than one day a week, they could use a PTI 80th percentile. Percentile travel times are reported in minutes and seconds and should be easily understood by commuters familiar with their trips. For this reason, this measure is ideally suited for traveler information.

Reliability index measures have the disadvantage of not being easily compared across trips, as most trips will have different lengths. It is also difficult to combine route or trip travel times into a subarea or citywide average.

Several statistical measures of variability have been suggested to quantify travel time reliability, such as standard deviation and coefficient of variation. These are discouraged as performance measures, as they are not readily understood by non-technical audiences nor easily related to everyday commuting experiences.

Area Measures

While individual mobility measures described in the previous section mainly relate to the individual traveler, area measures (Figure 9) relate to an area, corridor, or region and how mobility conditions impact travelers at a large scale.

Total Delay

The sum of time lost due to congestion expressed in person or vehicle hours.

Identifies the real congestion conditions of an urban area or segment.

Total Segment Delay (person - minutes) =

$$\left[\begin{matrix}\text{Actual}\\ \text{Travel Time}\\ \text{(Minutes)}\end{matrix} - \begin{matrix}\text{Free-Flow}\\ \text{Travel Time}\\ \text{(minutes)}\end{matrix}\right] \times \begin{matrix}\text{Vehicle Volumes}\\ \text{(vehicles)}\end{matrix} \times \begin{matrix}\text{Vehicle Occupancy}\\ \text{(persons/vehicle)}\end{matrix}$$

Data Elements:
- Actual Travel Time & Speed
- Free-flow Travel Time & Speed
- Vehicle Volume
- Vehicle Occupancy

Units & Ranges
- Person-Hours

Delay per Mile

This measure used to compare congestion levels across road segments of varying length.

A measure of the time an individual spends in traffic expressed in miles.

Delay per Mile (annual hours per mile) =

$$\frac{\left(\begin{matrix}\text{Actual}\\ \text{Travel Time}\\ \text{(minutes)}\end{matrix} - \begin{matrix}\text{Free-Flow}\\ \text{Travel Time}\\ \text{(minutes)}\end{matrix}\right) \times \begin{matrix}\text{Vehicle}\\ \text{Volume}\\ \text{(vehicles)}\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Occupancy}\\ \left(\frac{\text{person}}{\text{vehicle}}\right)\end{matrix} \times \left(\frac{\text{60 minutes}}{\text{hour}}\right)}{\text{Road Miles}}$$

Data Elements:
- Actual Travel Time & Speed
- Free-flow Travel Time & Speed
- Vehicle Volume
- Vehicle Occupancy

Units & Ranges
- Person-Hours per mile

*This measure helps best identify the most congested roadway segments.

Total Peak-Period Travel Time

A measure to estimate the duration of all trips made across a variety of modes during a peak-period travel times.

Assess travel time across land use and modal types as to measure trip duration rather than preference automobile use.

Data Elements:
- Travel Times during peak hours.

Units & Ranges
- Time (Minutes/Hours)

Congestion Duration and Length/Congestion Hours

The amount of time spent in less than free-flow travel conditions.

Data Elements:
- Time Spent in Congested Conditions

Units & Ranges
- Time (Minutes/Hours)

Congested Travel

A binary measure to categorize traffic flow as congested or otherwise dependent on the congestion threshold.

Congested Time =

Any 15 minute period with a speed of less than 75% of the arterial free flow speed or 80% of freeway free flow speed.

Data Elements:
- Travel Times
- Arterial Free Flow Speed
- Freeway Free Flow Speed

Units & Ranges
- Time (Minutes/Hours)

Figure 9: Area Measures

Wasted Fuel — Extra fuel consumed during less than free-flow travel conditions — The gas or diesel that is used when a vehicle is stuck in congested conditions.

Wasted Fuel =

$$\frac{\text{Vehicle Miles Traveled (VMT)}}{\text{Free Flow Travel Speed}} \times \left(\frac{\text{Free Flow Speed}}{\text{Average Fuel Economy}} - \frac{\text{Peak Period Speed}}{\text{Average Fuel Economy}}\right)$$

*Gasoline and diesel metrics should be calculated separately.

Data Elements:
- VMT
- Free Flow Speed
- Peak Period Speed
- Average Fuel Economy

Units & Ranges
- Gallons or Liters

Total Cost of Congestion — The invoice of two congestion effects, delay or extra time spent on a roadway and extra fuel used to complete the trip. — The cost of congestion is an attempt to quantify the overall uncertainty travelers and freight experience due to congestion.

Total Congestion =

Annual Passenger Vehicle Costs + Annual Truck Costs*

Data Elements:
- Hours of Delay
- Vehicle Occupancy
- Gallons of Excess Fuel
- Price per Gallon of Fuel

Units & Ranges
- Dollars

$$\text{Annual Passenger Vehicle Cost} = \left(\begin{matrix}\text{Annual Passenger}\\ \text{Vehicle Hours of Delay}\end{matrix} \times \begin{matrix}\text{Vehicle Occupancy}\\ \text{(person/vehicle)}\end{matrix} \times \begin{matrix}\text{Value of Person Time}\\ \text{(\$/hour)}\end{matrix}\right) + \left(\begin{matrix}\text{Annual Gallons of}\\ \text{Excess Fuel Consumed}\\ \text{By Passengers}\end{matrix} \times \begin{matrix}\text{Price Per Gallon}\\ \text{of Gasoline}\\ \text{(\$/gallon*)}\end{matrix}\right)$$

$$\text{Annual Truck Cost} = \left(\begin{matrix}\text{Annual Truck}\\ \text{Hours of Delay}\end{matrix} \times \begin{matrix}\text{Value of Time}\\ \text{for Trucks}\\ \text{(\$/hour)}\end{matrix}\right) + \left(\begin{matrix}\text{Annual Gallons}\\ \text{of Excess Fuel}\\ \text{Consumed by Trucks}\end{matrix} \times \begin{matrix}\text{Price Per Gallon}\\ \text{of Diesel}\\ \text{(\$/gallon*)}\end{matrix}\right)$$

Figure 9: Area Measures (Continued)

These measures may be less meaningful to individual travelers and their mobility choices, but concepts such as total delay, expressed in person- or vehicle-hours, allow for an analysis of mobility trends. The concepts of total delay, wasted fuel, congestion cost, congestion duration, and total travel time can be used to identify the total extent of a mobility issue or assess the impacts of major improvement projects to a corridor or region. Expressing total delay across segments with a common denominator (e.g., delay per mile) allows for a direct comparison and ranking of corridors or region.

Area measures are especially adept in large policy and funding discussions and may be used for creating targets. However, these measures on their own generally are not meaningful to the general public other than to show the relative magnitude or ranking of the issue.

These area measures should be used in conjunction with accessibility, connectivity, and other measures that create a more complete picture of regional transportation. It may be most helpful to use delay to identify mobility problem areas and then other area measures, accessibility measures, or connectivity measures to find and test solutions.

Access and Connectivity

Congested conditions are not a new phenomenon, nor are they created by the simple movement of people and goods. This section and Figure 10 will delve into limited access and connectivity measures with a focus on connectivity and land use types to demonstrate acceptable time frames and the distances necessary to reach destinations.

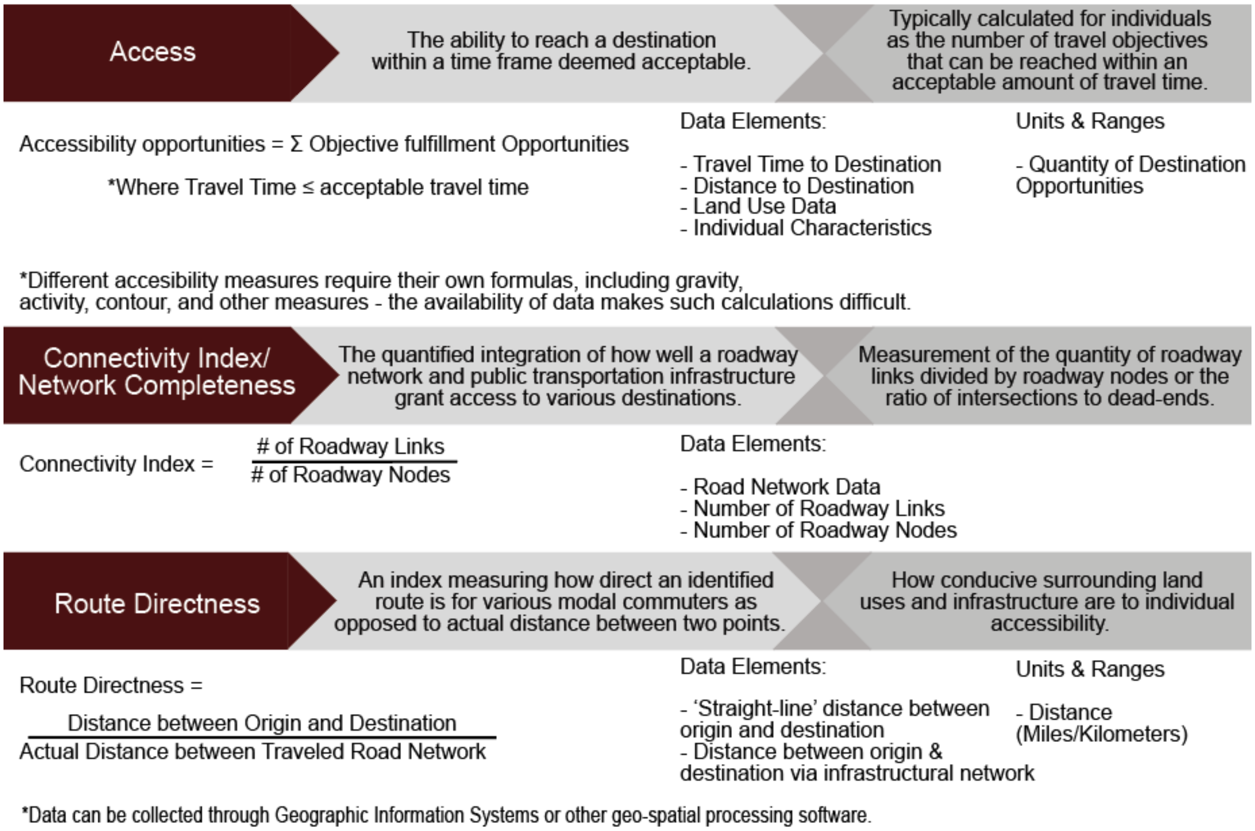

Figure 10: Select Accessibility and Connectivity Measures

Accessibility is a measure of the number of opportunities that can be reached in a given time. Most often, accessibility is expressed in terms of number of jobs reachable from a home origin in a certain amount of time. Note that most accessibility measures do not measure actual behavior; instead, they measure the universe of possible destinations, which may not be useful for many policy or transportation applications. To fix this, consider using origin-destination data to show actual travel behavior.

Creating Targets and Their Relation to Computed Measures

Target values should 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 quality of life 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 a mobility or congestion assessment.

Urban areas should approach the use of a target with a corridor and system strategy. The target value may be developed for every mode, facility, or geographic area as a way to identify individual performance levels, but the key application will be as a corridor or system target. Individual facility deficiencies can then be addressed through improvements to that mode, route, or region or by other travel mode improvements, strategies, or policies. For example, freeway main lanes may not satisfy an identified 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.

Remember that targets should be realistic and contextually relevant to where they are applied. It may be unreasonable to have a target of “no congestion” for an entire urban area. It might also be irresponsible to set a target at a worse mobility level, giving the illusion that there is no problem.

Conclusion

It is difficult to cover every type of mobility analysis with a limited set of performance measures, but those summarized throughout this chapter are recommended for many common types of studies and information requirements with the ability to illustrate a range of mobility solutions. Determining the geographic or subject scale of a mobility concern is one of the first steps in selecting the applicable performance measure. Analyses where small areas are analyzed or quick answers are needed use simple measures and more complex analyses—those that typically cover larger areas or multiple modes and those targeting non-technical audiences—use index measures and summary statistics.

Any performance measure should relate to the reasons people travel (**Chapter 1: Introduction to Mobility**), like 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. Total travel time imparts a more complete door-to-door analysis of a trip including aspects like pedestrian impediments, transit delays, or parking shortages as well as demonstrates the importance of land use decisions.

Chapter 6: Data Collections and Databases

Until this past decade, many observation-based data elements used for calculating transportation performance measures were scarce or nonexistent. This caused many measures to stay in the realm of theoretical but not possible or practical. In many cases, data were estimated or modeled from small site studies to calculate prominent measures. Other datasets were created from vast and costly transportation survey programs or studies that directly measured travel and travel behavior in small areas or corridors. While many of these direct-collection and survey programs still exist, new sources of high-quality data have emerged that greatly expand the ability to monitor congestion and mobility.

The high saturation of smart phones has dramatically changed the transportation data landscape into one of big data. Most of the core data used for transportation and mobility come from GPS, location-based services (LBS), or cellular probe data collected anonymously and at high frequency from car GPS systems, freight systems, or personal cellphone use. The explosion of data has allowed transportation measures to switch from largely modeled or estimated results to real-world conditions, often with a higher degree of accuracy and lower latency. This allows transportation professionals to see a better portion of the transportation picture and implement better, more targeted solutions.

While past methods of direct data collection, estimation, and modeling were often limited by cost, privacy issues, data storage, or scale, a strong need still exists to create and collect data. While this chapter will not discuss these methods at length, it is important to know that a strong business case still exists for direct data collection programs—most notably in validating, calibrating, and adjusting larger datasets, project evaluation, future conditions research, and collecting specific non-traditional information.

This chapter will discuss the types of data most commonly used in congestion and mobility analysis:

- U.S. Census data for demographic and population information.
- Bureau of Transportation Statistics data for general topics, including freight, safety, environmental, and infrastructure information.
- Bureau of Economic Analysis data for economic and freight information.
- National Household Travel Survey for travel behavior.
- Vehicle probe, location-based services, and cellular data for speed information.
- Real-time and archived intelligent transportation systems (ITS) data for roadway conditions.
- Roadway network data for roadway segmentation.

Each section will describe what the data are, how they are collected, helpful tips to know about each type of data, and any other useful information needed to work with the data to calculate performance measures.

Demographic, General, Economic, and Travel Behavior Data Sources

Population and demographic data, economic data, freight data, travel behavior data, and other general types of transportation data provide a foundation for many of the measures described in the previous chapter. These datasets provide context for the other types of data required and how they should be used. Additionally, these data often provide broader context about the study area and can be used to normalize areas of different sizes. One should become intimately familiar with the following sources, the data they provide, and how these data can best be integrated into the selected measures.

U.S. Census Bureau Data

The U.S. Census Bureau is the primary data provider for population and demographic information that are used in transportation performance measurement. The Census not only provides basic population data, but also information about work commute trips, mode splits, car ownership, commute flows (into/out of a zone), and data about home-based workers all through their Journey to Work program.

Census data can be accessed through their data portal: https://data.census.gov/. Data can be found for **urban areas** (the preferred geography to use when examining mobility in a metropolitan area, because it excludes rural land in a metropolitan statistical area [MSA]) by any year using the American Community Survey (ACS) 1-Year data.[1] Smaller geographies should use ACS 5-Year data.

For Journey to Work data, search "Journey to Work" in the Census data portal. **Table S0801 (Commuting Characteristics by Sex)** is the primary table that provides most commuting characteristics; however other tables provide relevant commuting and freight data.

The American Association of State Highway and Transportation Officials (AASHTO) in conjunction with several state DOTs has historically sponsored the Census Transportation Planning Products Program (CTPP) to produce special tabulations from ACS data specific to transportation planning and performance (*21*). Data are compiled by residence-based trips, workplace-based trips, and flows between zones. Other demographic and commuting information can also be retrieved. Note however that tabulations use ACS 5-Year data and have not been updated since the 2012 to 2016 data years.

State demography offices also offer good sources of demographic data specific to a particular state. These datasets are often updated more rapidly than U.S. Census data but may be much more limited in scope. However, state demographers offer the best option for population projections and estimates.

Bureau of Transportation Statistics Data

As part of the Federal Department of Transportation (DOT), the Bureau of Transportation Statistics (BTS) is the primary source of broad transportation statistics, including commercial aviation, multimodal freight activity, transportation economics, and bridge and infrastructure data (*22*). While most data are reported at the national or state level, some data can be retrieved at the county level and combined with other counties. Access the BTS data through their geospatial data portal: https://data-usdot.opendata.arcgis.com/.

Bureau of Economic Analysis Data

Under the Federal Department of Commerce, the Bureau of Economic Analysis (BEA) is the primary source of economic, trade, and commerce data (*23*). Transportation-relevant information includes statistics on employment, household income, freight and industry outputs, employment, inflation, and other niche topics.

[1] The ACS program releases data in 1-, 3-, and 5-year datasets. For year-over-year comparisons, use 1-year data; **do not use overlapping 3- or 5-year datasets**, because samples overlap and may be duplicated. 1-year data are the least granular option (but will work for urban area, county, MSA, and state geographies), while 5-year provides data down to the block level.

National Household Travel Survey Data

The National Household Travel Survey (NHTS) is the primary source for all travel behavior data conducted by the Federal Highway Administration (FHWA) (*24*). This extensive national survey provides insight on multiple topics, including:

- Vehicle-based statistics
- Person-based statistics
- Household-based statistics
- Vehicle trips
- Person trips
- Vehicle miles
- Person miles
- Workers
- Drivers

While nearly all variables are national, some states have access to custom state-specific datasets with the same variables. All data are based on the most recent survey performed in 2017; surveys are conducted infrequently and may not be conducted again for several years.

The NHTS website (https://nhts.ornl.gov/) provides an extensive data portal with the ability to create highly customized tabulations using multiple variables. Review the NHTS comprehensive user guide and codebook of variables to understand what data are available for use.

Vehicle Probe, Location Based Services, and Cellular Data

Traditional (now rarely used) methods of collecting or estimating average speeds of vehicle streams such as the floating car method, license plate matching, the spot speed method, etc., are now mostly limited to validation or spot-checking of other, more cost-effective, and efficient sources of travel time data. Based on the source technology and characteristics, these emerging (and now more commonly used) travel time data sources can be categorized as follows:

- **Global Positioning System (GPS)**: positional information gathered through GPS satellites by mobile device applications, vehicle navigation units, or commercial fleet-tracking and telematics.
- **Location-Based Services (LBS):** positional information derived from mobile device application (app) software development kits (SDKs) that rely on a variety of technologies with various levels of precision and accuracy to locate the devices.
- **Cellular:** data derived from Call Detail Records (CDR) that are generated through the interaction of mobile devices with a cellular network.

LBS relies on a combination of technologies like GPS, Bluetooth, Wi-Fi, cellular triangulation, etc., to locate devices as best as it can. If a smart device cannot acquire a GPS signal because it is located deep within a building, then the application SDK will try the next best option—Wi-Fi combined with cellular triangulation to create the best guess of where the device is located.

Some technologies directly represent vehicles moving through time and space (e.g., GPS), whereas others are smart devices that are being located intermittently based on its user or the software application (e.g., cellular or LBS).

Crowdsourced data is passively gathered from the public using these technologies, as opposed to point-to-point sensor technologies, such as stationary Bluetooth and Wi-Fi detectors, which are more limited in scope and applicability. Table 2 and Table 3 provide an overview of crowdsourced passive data technologies described above, along with their respective strengths and weaknesses (*25*, *26*).

Table 2: Overview of Crowdsourced Passive Data Technologies.

Technology	Popular Data Providers	Popular Tools/Products	Data Summary	Relative Sample Size (Relative Unit)
GPS	• INRIX • ATRI • HERE • TomTom • Wejo	• StreetLight • Moonshadow • Independent Expert Analyses	• GPS ping; time-stamped coordinates of vehicle waypoints and trip ends. • GPS begin and end points of vehicle trip. • Can distinguish cars and trucks. • Can determine travel speed and time. • Daily/Monthly GPS pings of a unique vehicle (ATRI).	• Small (Passenger Vehicle) • Small (Service Trucks) • Medium (Heavy Trucks)
Location Based Services (LBS)	• Cuebiq • SafeGraph • Quadrant • Telenav • Skyhook • Groundtruth • Foursquare • PlaceIQ • Factual	• AirSage • StreetLight • Independent Expert Analyses	• Varies depending on device application. • GPS points or locational reference points based on interaction with Wi-Fi, cellular towers, or geographic location where app is used. • Data are usually provided as trip matrices for geographic zones provided by purchaser. • Raw LBS data can also be obtained for custom analysis. • Cannot distinguish cars and trucks. • Can determine approximate travel speed and time.	• Large (Total Population)
Cellular	• Wireless Carriers	• Verizon Traffic Data Services • Teralytics • Kido • Cellint	• Raw data are disaggregated and are collected from cell tower based on CDR. • Data may represent the location of the cell tower that interacted with device or the device's position relative to cell tower coverage. • Data are usually provided as trip matrices for geographic polygons provided by the purchaser. • Cannot distinguish cars and trucks. • Cannot determine travel speed and time.	• Large (Total Population)

Table 3: Strengths and Weaknesses of Passive Data Technology.

Technology	Strengths	Weaknesses
GPS	• Can distinguish between passenger and truck/freight vehicles • Is well suited for truck/freight studies	• Unable to distinguish between resident and non-resident travel. • Is biased toward truck/freight vehicles. • Has low penetration rate for passenger travel.
Location Based Services (LBS)	• LBS data have better positional accuracy than cellular. • Good sampling rate for passenger vehicles (i.e., devices. • Good source for external-internal (E-I) or internal-external (I-E) data. • Can distinguish between some trip purposes. • Can distinguish between non-resident, commuters, and residents.	• Cannot discern vehicle type. • Travel routes cannot be easily ground-truthed to an urban-scale. • Provides no direct link between LBS data and subscriber demographics.
Cellular	• Same as LBS strengths, except that sample size is larger.	• Same as LBS, except for relatively low positional accuracy.

Fleet and connected car GPS, aggregate LBS/cellular, disaggregate LBS, trade data, and fare card records data/API are just some of the sources with many different vendors (for example, AirSage, INRIX, or Streetlight) offering one or many of these. While fleet and connected car GPS data have the highest spatial and temporal granularity, the sample penetration for such data is usually on the lower side (0.5 to 2.0 percent sample penetration). Aggregated LBS/cellular data are zone-based with low sample frequency and 15 to 20 percent sample penetration. Disaggregated LBS data have high sample penetration (12 to 20 percent) but low sample frequency. Probe-based travel time data typically employ a combination of these different sources.

Real-Time and Archived ITS Data

Depending on the need, purpose, and application of data collection, travel time, and speed (thus delay and congestion), data can be stored and used for decision-making in either real-time or archived for later use. Real-time traffic monitoring is usually employed to tackle operational issues, bottlenecks, incidents, etc., while archived travel time data are usually employed to track congestion and reliability patterns, short-term and long-term trends, for project planning and programming purposes, or other uses. The following sub-sections discuss these in more detail.

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, 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) (*27*). These technologies establish a small, fixed “zone of detection,” and the measurements are taken as vehicles pass through this zone. For example, many cities now use Bluetooth readers to identify when Bluetooth-enabled devices pass between points, providing highly accurate travel times between sensors.

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:

- 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 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 (little aggregation) to 15 minutes. In some cases, the data are also aggregated across all lanes in one direction at a sensor location.

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 and return to service for data collection devices.

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 because 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 data resolution used by TMCs is quite coarse; it supports their traditional operations activities, such as incident detection and ramp meter control.

Archived Travel Time Data

As discussed earlier, archived travel time data are typically used for transportation planning and programming purposes. Such databases are updated and maintained periodically. Several data vendors provide similar archived travel time datasets, including but not limited to HERE, INRIX, TomTom, StreetLight, and other vendors. Each of these might have similar but slightly different characteristics in terms of data sample composition (e.g., truck mix in the overall probe vehicle sample), data sources (proportion of GPS vs LBS vs cellular data), sample penetration and spatial coverage, mode choice (motorized vehicles vs pedestrians and bicyclists), or other attributes and can be studied further for suitability depending on use-case.

For example, the National Performance Management Research Data Set (NPMRDS) is an archived speed and travel time database (including associated location referencing data) that covers the National Highway System (NHS) and additional roadways near 26 key border crossings with Canada (20 crossings) and Mexico (6 crossings) (*28*). This database is updated each month and is based on actual reported vehicle data, exclusively—no imputation is included. Three data sets are available as part of the NPMRDS that include speeds and travel times at 5-minute intervals, 24 hours a day, on over 400,000 road segments: data for passenger vehicles only, trucks only, and passenger vehicles and trucks combined. The database also includes an indicator for data quality based on sample size for each time period of observation. The NPMRDS is procured by the Federal Highway Administration (FHWA) specifically to help state and local governments with performance measurement research. It is provided free of charge to DOTs, MPOs, and to groups working on behalf of DOTs and MPOs to be used as the baseline dataset to meet the federal congestion and freight performance reporting regulations (PM3).

Roadway Network Information

Just as there are different types of data, there are also different types of geographic networks that must be taken into consideration for compatibility and transferability. A brief description for the common terms and types of roadway networks is provided below:

- **Traffic Message Channel (TMC):** TMC is the industry standard nomenclature and spatial reporting unit of measurement used by traveler information providers to define the roadway system. For example, the NPMRDS uses the TMC standard to uniquely identify each road segment for data collection. Typically, these are short, homogenous roadway segments for which travel data are collected and reported.

- **HPMS/NHS/ARNOLD:** The Highway Performance Monitoring System (HPMS) is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways. The National Highway System (NHS) is a network of strategic highways within the United States, including the Interstate Highway System and other roads serving major airports, ports, military bases, rail or truck terminals, railway stations, pipeline terminals and other strategic transport facilities. All Road Network of Linear Referenced Data (ARNOLD) is a requirement by FHWA for State Departments of Transportation (DOTs) to submit their Linear Referencing System (LRS) to include all public roads.

- **INRIX XD/HERE TMC:** INRIX XD (eXtreme Definition) are segments that cover more miles of road than TMC segments, generally with greater granularity, and with the ability to adapt more quickly to changes in the road network and the addition of new roads. XD segments break at significant intersections. Significance is determined primarily by the relative importance of the intersecting roads (*29*). INRIX XD segments are like TMC segments in that they delineate a specific section of roadway; however, they address some of the limitations of TMC Segments, such as road coverage, the ability to cover new roads more quickly, segment overlap and gapping,[2] and segment resolution.[3] Both the INRIX XD and HERE TMC networks are proprietary networks.

- **State Road Inventory:** State DOTs publish and submit their statewide roadway inventory data annually to the Federal Highway Administration as part of the HPMS program. For example, TxDOT's Roadway Inventory File (RIF, formerly Roadway-Highway Inventory [RHiNo]) data includes GIS linework and all roadway inventory attributes (*30*). These datasets are primarily used for traffic volume data on state-maintained roadways.

Very rarely do the roadway networks from two different sources (vendors or agencies) overlay perfectly. To add to this challenge, roadway networks evolve as more granular segments, roads, and data elements are added over time. Since there are different types of maps with different roadway segmentation, practitioners must use a process called **conflation** to create a "crosswalk" that allows comparison and communication between datasets.

Conflation is the process of spatially joining the attributes of two datasets to import the desired characteristics from both (and eliminate unnecessary characteristics from the resultant conflated [i.e., combined] dataset during the process). Conflation is necessary, for example, to combine vehicle travel time and volume information for road segments. This involves combining the road networks for the traffic volume and speed data sources, such that an estimate of traffic speed and traffic volume is available for each desired roadway segment.

The combination (conflation) of the traffic volume and traffic speed networks is accomplished using Geographic Information Systems (GIS) tools. For example, in the case of Texas, TxDOT's traffic volume network (RIF) serves as the base network and a set of speeds from the XD network used by INRIX is applied to each segment of the traffic volume network. Similarly, at the national level, the INRIX roadway network ("Join Map"), which is based on the TMC mapping network is conflated to the HPMS roadway network ("Base Map") based on the individual roadway shapefiles provided by each of the state departments of transportation to FHWA (*31*). The two roadway networks contain various levels of roads including freeways, tollways, arterial streets and several streets of lower roadway functional classes. For purposes of producing the NPMRDS road network, only the NHS roads are considered.

[2] In some cases, a segment line may not start exactly where another segment ends. Overlapping occurs with a segment goes past the next segment and overlaps with that next segment. Gapping occurs when a segment ends before touching the next corresponding segment.

[3] Some TMC networks have relatively long segment lengths that may stretch past intersection, interchanges, or natural break points, making custom analysis difficult. Higher segment resolution indicates that segments are smaller and can be more easily combined to a desired segment length. More metadata may also be available at higher resolutions.

A more detailed understanding and procedure for performing the conflation process can be found in the NPMRDS conflation procedure guide (available at https://npmrds.ritis.org/static/help/docs/Conflation%20Guide.pdf).

Modeled and Estimated Data

Sampling, modeling, and estimation techniques can provide useful speed, volume, and travel information with limited data collection budgets. Advanced technologies and probe data already provide a significant improvement in travel data; the number of transportation analyses that use this information is growing, and the need for estimating data is diminishing.

If travel time, volume, and speed data are not available with the sources described earlier, they 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 estimation 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* (*32*).

Data Acquisition and Use Process

As discussed earlier, data should be collected only after the community's vision and goals have been established and any preliminary issues have been identified. Without this understanding, much effort and expense could be wasted by collecting, acquiring, or estimating data that may not ultimately be relevant or useful in mobility analysis.

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** (many of which are free or relatively low cost); data collection should not be the determining factor about which measures are used. 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.

Measures should first be determined based upon the needs of the users and what would be satisfactory for analysis purposes. Once this has been completed, identify what data would be required to calculate these measures. Also identify the scales by which data are needed to calculate the measures (i.e., What geography is needed? Should measure be describer in terms of person, vehicles, or households? What time frames are relevant? Etc.). It may be helpful to document this information to create a checklist of necessary data elements based on measure needs.

Once data needs have been established, determine if any of the data are already available within the organization from past analyses. This could include preexisting contracts with data providers to deliver data services in an ongoing basis, archived data from past direct collection efforts, stored demographic, economic, survey, or travel behavior data, or data estimates used in modeling and forecasting efforts. In many cases, some of the needed data may be readily available for use and reuse.

Note that some purchased datasets have strict use restrictions about how and when the data may be used. Check with your database administrator or data custodian to determine if there are any restrictions or issues related to use of these data.

Reexamine the checklist of required data to determine if any other data are required or need to be collected. Do not collect or use data simply because you can; remember that all data must be processed, stored, and eventually archived or destroyed. Excess data may increase the overall cost and effort required.

Once data have been acquired, transform the raw data into a final usable form if necessary. This would include conflating data to a common road network, creating new summary or aggregate data, or performing any preliminary calculations.

Additionally, data should be consistently checked for quality and reasonableness. While many governmental and private data sources have undergone significant quality control processes, errors are still common and may dramatically skew measure and analysis results. Look for missing values, extreme values, zero values that may affect equations, or any unusual values. Also look for differences in how variables are defined, especially if examining data from different states, as each DOT may collect, process, and define data differently. It may be necessary to perform an exploratory assessment of the dataset to discover potential issues with the data.

After measures have been calculated, examine the results for reasonableness, specifically looking at the highest and lowest values. Walk through what the measure values mean in terms of a typical traveler (or whatever the unit/scale may be). For extreme and unreasonable values, perform another quality review of the data that created the results to further ensure data quality.

Finally, consider how all data will be stored once the analysis is complete. Pursuant to use agreements, purchased data should be stored and recorded in such a way that it does not get forgotten and can be reused in other analyses. Data that contains personally identifiable information (PII) should be destroyed.

Chapter 7: Communicating Performance Measures in a Meaningful Way

Communicating mobility analysis results is a vital step in illustrating system performance and demonstrating the need for transportation improvements. A failure to properly communicate mobility and congestion analysis results essentially negates much of the process: is the analysis worth doing if no one can understand or use the results?

Additionally, effective graphical presentation of mobility results typically includes spatial and/or temporal aspects, which can be difficult to balance with readability. This chapter discusses how to communicate mobility analysis results, illustrates some premier examples of communicating temporal and spatial congestion characteristics, and provides some best practices and considerations for developing impactful visualizations.

Refer Back to the Audience and Use

Upon completion of a mobility analysis, the primary question then *shifts back* to one answered at the beginning of the process: "How do you best use and communicate the results of the analysis to others?" Much of this question can readily be answered using the steps taken before the analysis began (refer to **Chapter 3: The Performance Measurement Process** and **Chapter 4: Selecting Mobility Measures**). Ultimately, this represents the primary purpose of the analysis, the intended use, and the identified stakeholders or audiences.

To best communicate the results to others, refer to the vision, goals, objectives, issues, or targets that were identified in the first step of the analysis. Start with the broadest concepts and work towards more specific objectives. Write these out if necessary; it is crucial to keep broad concepts at the forefront of your mind throughout the communication process as this will keep potential strategies, policies, and solutions from straying from the process intent.

Next, refer to the measures used in the analysis itself: what was the primary purpose of each measure? In other words, how does each measure directly relate to the vision, goals, or issues identified in the previous step? If a measure or combination of measures represent a sub-step to create an element that is directly related, note that connection. This will hinder too much emphasis being placed on a relatively unimportant measure or output rather than what is directly related.

For example, consider a community that places a high value on travel reliability and would like to ensure all residents can reliably travel to increase time with family, friends, or productivity at work (i.e., a subset of their vision and goals). Measures used in an analysis likely would include free flow speed, average travel times or speeds (including the 80th percentile or 95th percentile), planning time index (PTI), buffer index, etc. While free flow speeds and average travel speeds may be relevant in calculating the PTI and may also be reported in the final analysis, they do not necessarily connect well with evaluating mobility and reliability to the community's vision and goals. However, PTI and the buffer index do possess a direct nexus with the vision and goals and can easily be used to take the discussion to the next level (e.g., "How can we measure policies or strategies that will take us closer to our vision?").

Note that some measures may have different uses and purposes for different audiences. Some measures used in an analysis may be suited for internal use only or for technically savvy audiences while others might be more useful for traveler information, policy discussions, media presentations, or other external uses. Be mindful about how the measures' outputs could be used. In some cases, measures may serve a dual purpose: an index like TTI or PTI means nothing to a lay audience but can be transformed to be meaningful under the right circumstances.

The output of this logic chain exercise will provide guidance on which measures to report to different audiences and how best to do so. Additionally, measure results will be directly linked back to the vision, goals, issues, or other priorities, which will provide clarity for post-analysis direction by others.

For public audiences, communication methods could include providing useful methods to help travelers make informed decisions. Methods could also help the public understand elements of congestion and system performance to inform strategies and new policies.

For internal or more technical audiences, communication methods could focus on benchmarking, target achievement, system performance monitoring, or strategy selection.

Illustrating Results

Illustrating and communicating mobility and congestion should be done with intention, answering direct questions of linking specific information to the measure's purpose. The following sections provide examples of how data and mobility analysis results can be illustrated to effectively communicate information to others.

While data tables are useful to convey large amounts of data, tables are usually the least-communicative means to convey meaningful information. Tables serve a specific purpose: to provide users with high levels of detail for a specific item. They fail to adequately convey summary information, trends or spatial information. Tables should be reserved for the following purposes:

- Providing full data outputs as reference material in an appendix
- Providing explanatory detail as part of a visualization where a diverse audience wishes to view what is important to them.
- Providing a means of accessibility or Section 508 compliance to persons with disabilities.

Static Displays/Infographics

Static charts, displays, and infographics represent the most basic and most used type of illustration for mobility information. These charts and graphs represent basic mobility information that is not related to a time series or spatial element. These are best used for quick summary information that are highly relevant to the user, especially when the audience type does not matter as much. Figure 11 provides an example from Texas' Most Congested Roadways visualization (https://mobility.tamu.edu/texas-most-congested-roadways/) of how basic summary information can be displayed (*33*).

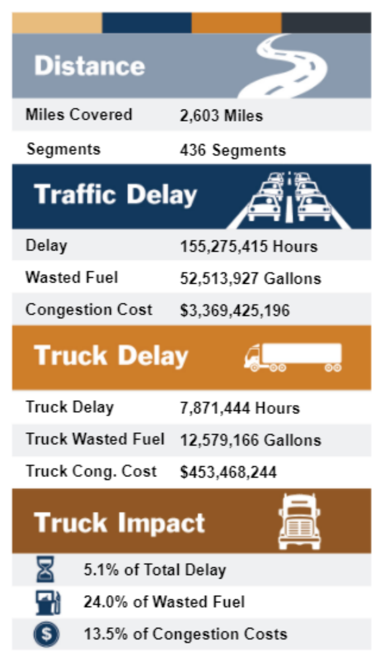

Figure 11: Static Display of Measures

Infographics can be especially useful in conveying a specific message more overtly by combining graphical elements with text to make a specific point. This helps keep analysis results from being misinterpreted, especially as graphics are copy/pasted and used in other reports or discussions that are dissociated from the original analysis. Infographics should be designed to be shared easily. Figure 12 provides an example of how high-level mobility statistics can be displayed in an easily shareable and easily readable format (*34*). Note how performance measures have been transformed from a simple measure to a highly relevant story element.

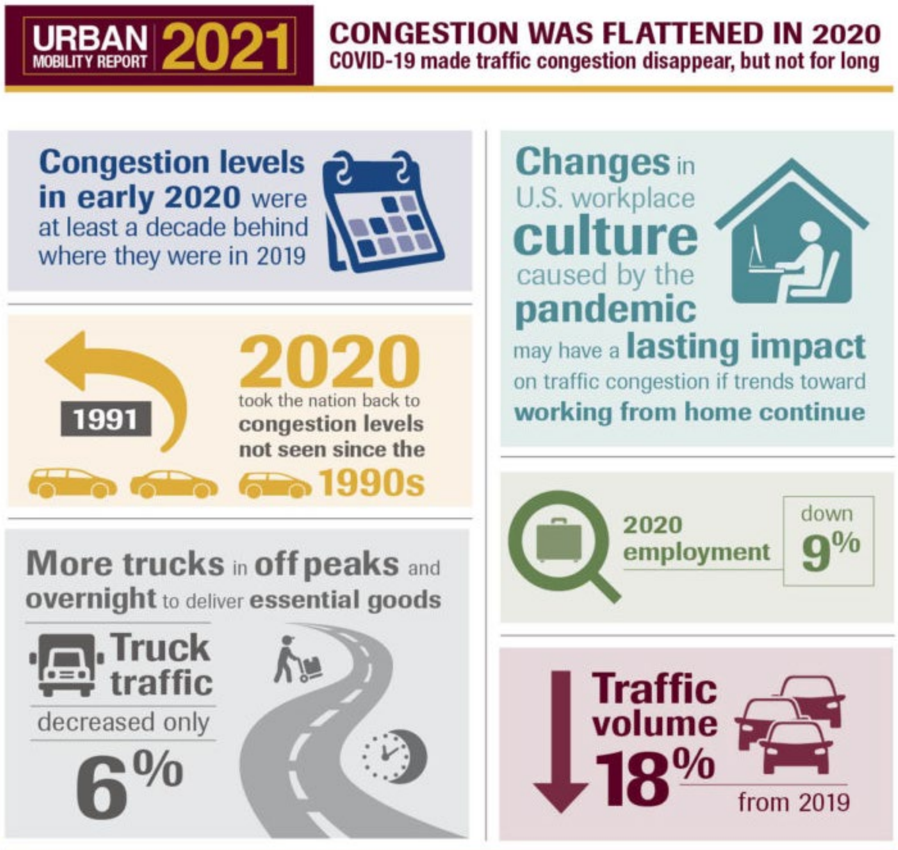

Figure 12: Infographic Displaying Measures in an Easily Readable Format

Temporal Displays

The second most-used chart type for mobility analysis and measures include a temporal element, or simply values charted over time. This can be used at nearly any scale from hourly to annual trends and are usually location specific (an intersection, corridor, area, etc.) rather than comparing multiple locations at once.

The bottom portion of Figure 13 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. Figure 13 illustrates an incident on IH 95 in Maryland in the northbound direction (*35*). Heat maps and lane diagrams can easily be combined with other data like dynamic message sign outputs and emergency response data to provide traffic management centers with near real-time and highly useful information. Note that this example is particularly suited for a technically savvy audience.

In this example, data from multiple systems have been synchronized over time in five windows to assist a traffic management center (TMC) in handling an incident. The uppermost window displays TMC communications and actions taken by the TMC while the window directly below displays first responder actions and the duration each type of response is on the scene of the incident. The lane diagrams below display which lanes/shoulders of the interstate were closed and for how long. The second to the last window displays dynamic message sign messaging. Finally, the heat map at the bottom displays northbound speeds (and correspondingly delay) over time where the center horizontal line is the location of the incident. Colors above that line represent miles before (or upstream from) the incident and below the line are miles of roadway after (or downstream from) the incident. Notice how speeds slow severely from the incident to about six to ten miles upstream but clear immediately after.

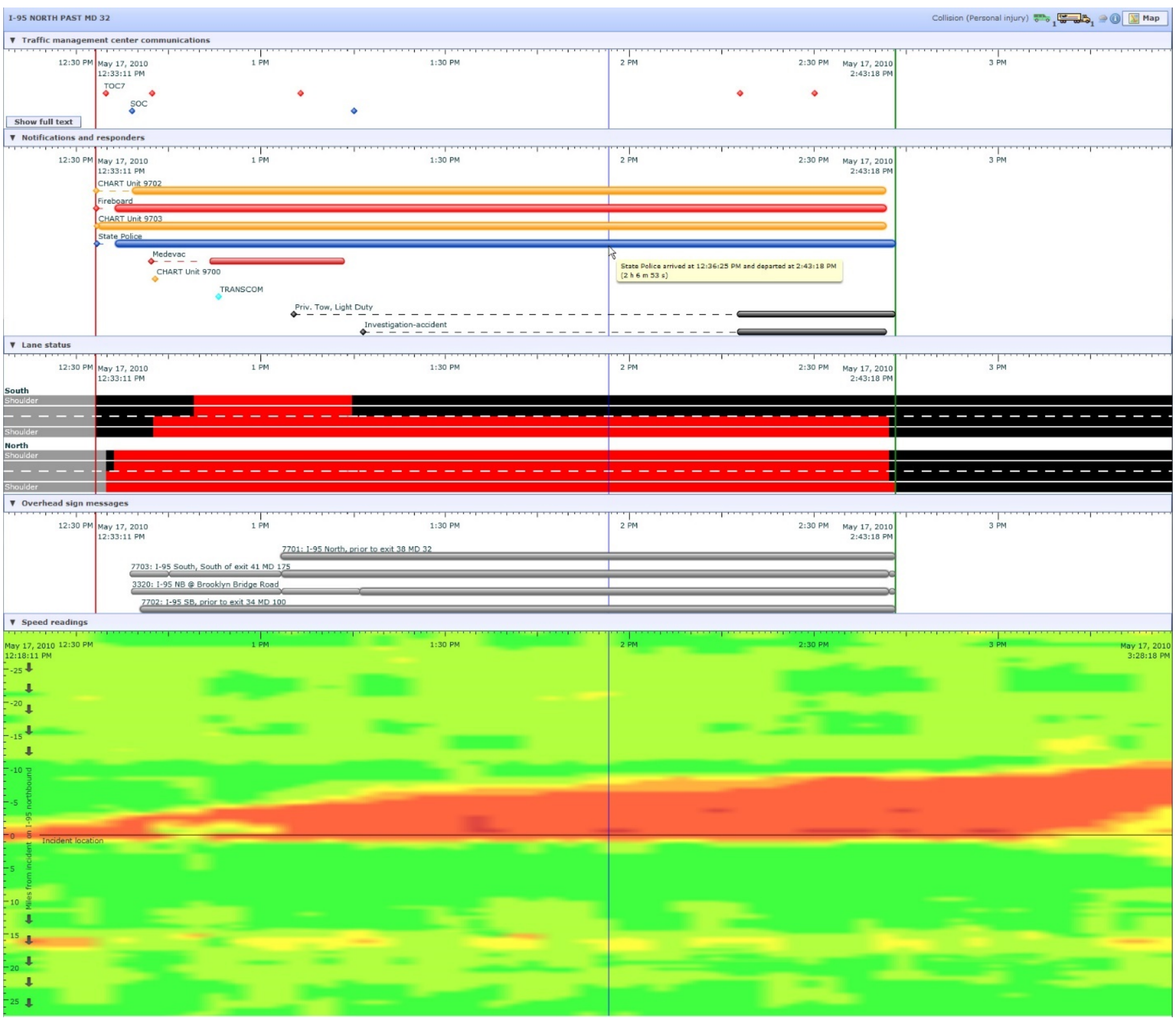

Figure 13: Heat Map and Multilayered Visualization Displaying Incident Congestion Severity

Figure 14 presents a different way to present measures and data over time. This example from Texas' Most Congested Roadways visualization (https://mobility.tamu.edu/texas-most-congested-roadways/) represents the average speed and delay by direction during a typical day along a busy corridor in Houston, TX. Note that these two charts are roughly the inverse of each other: as speed goes down, delay goes up. Charting data in this manner provides valuable information to both technical and lay audiences, indicating congestion is significantly worse during the evening peak period and near equal for both directions.

Similarly, Figure 15 presents roughly the same information in different geographic and temporal scales from TTI's Urban Mobility Report (https://mobility.tamu.edu/umr/congestion-data/) (*36*). In this example, average weekly delay for the entire Houston, TX, urban area is charted hourly over the course of a week showing what days and hours experience the worst delay. For Houston in 2020, most delay occurred on Fridays between 2:00 pm and 7:00 pm with similar levels of delay occurring from 3:00 pm to 6:00 pm on other weekdays.

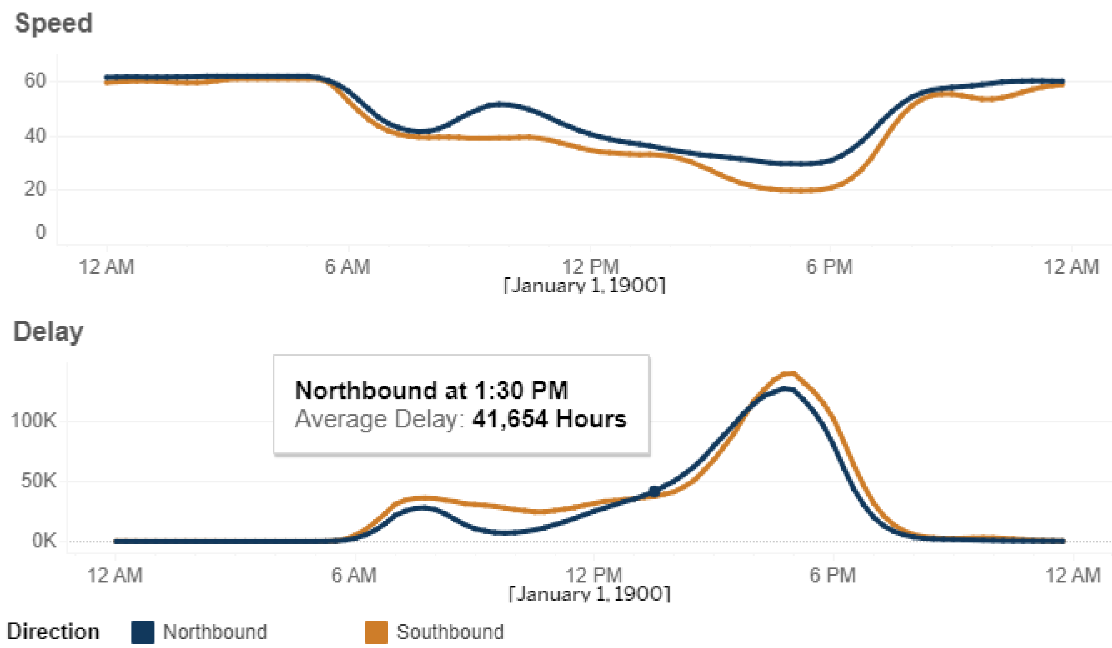

Figure 14: Speed and Delay Over Time Displayed in a Line Chart

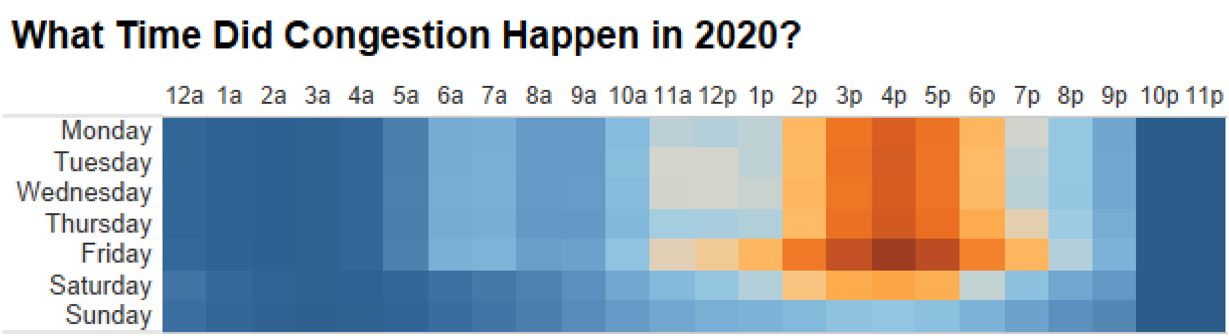

Figure 15: Weekly, Daily, and Hourly Delay Displayed in a Heat Map

Figure 16 illustrates the travel time index and planning time index values by time of day for Los Angeles in 2003 (*37*). The chart shows areawide congestion and reliability patterns during a typical day. The difference between the solid line (TTI) and the dashed line (PTI_{95}) is the additional "buffer" or "time cushion" that travelers must add to average trip times to ensure 95 percent on-time arrival. Figure 16 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. A similar graphic could be created for specific locations. Also, because this graphic displays index values, it should not be presented to lay audiences without context and annotated guidance.

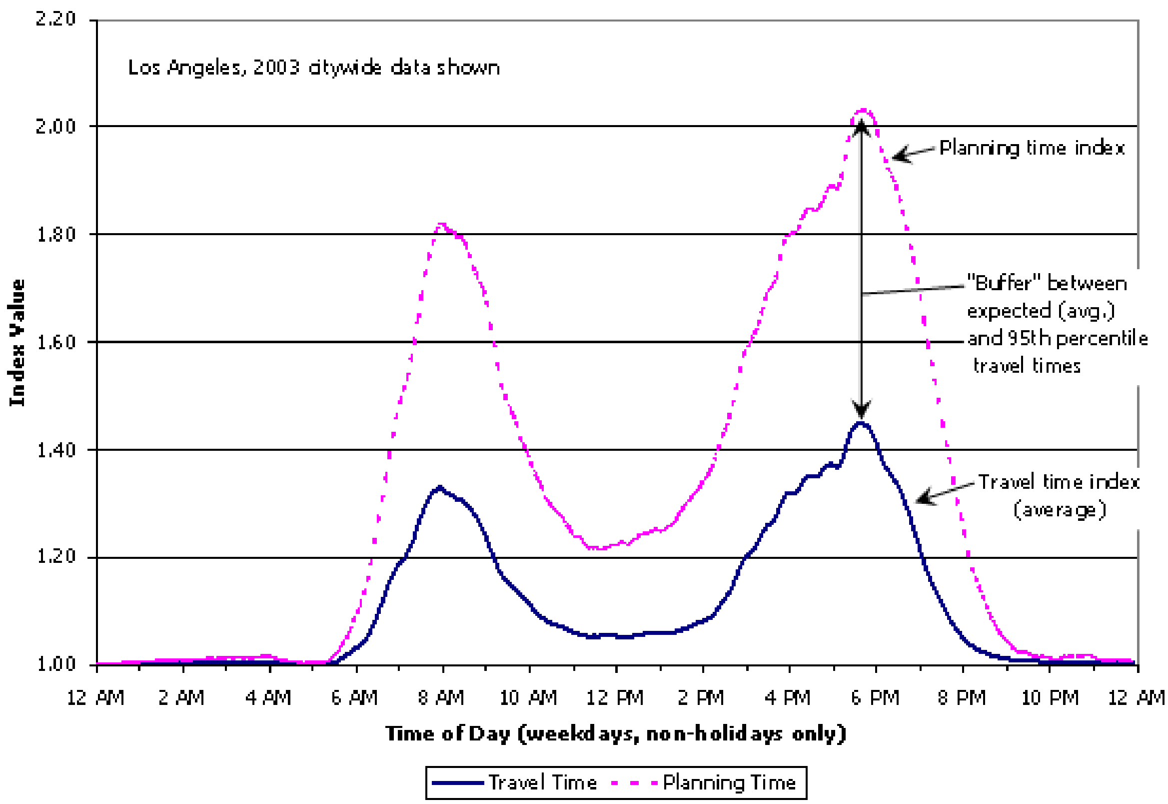

Figure 16: Illustration of TTI and PTI Over an Average Day in Los Angeles

Figure 17 illustrates basic daily volume data for bicyclists and pedestrians at a single location in Dallas from Texas' Bicycle and Pedestrian Count Exchange (BP|CX, https://mobility.tamu.edu/bikepeddata/). This chart provides daily, monthly, seasonal, and annual trends. Note that this example likely displays too much data and should be simplified for readability.

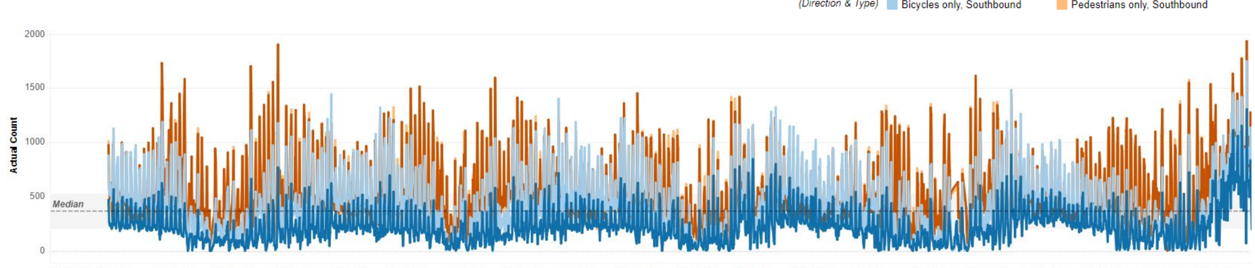

Figure 17: Daily Volume Totals for Bicyclists and Pedestrians at a Single Location in Dallas

A final word about temporal charts: pie charts in general are a poor chart type and should never be used to display temporal information. Pie charts work best with more than 2 but fewer than 6 slices, categorical parts of a whole, or where precision is less important. Additionally, if percentages are used, they should always equal 100 percent.

Geospatial Displays

Most of the temporal illustrations 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. The examples in this section include illustrations of spatial maps that illustrate congestion levels.

Figure 18 spatially illustrates mobility measures on a map from FHWA's Freight Mobility Trends (FMT) tool (https://ops.fhwa.dot.gov/freight/freight_analysis/mobility_trends/index.htm) using roadway segments of the National Highway System (NHS) (*38*). Each segment is colored according to the severity of the measure using a colorblind-friendly palate of blue to red. Mapping roadway segments to performance measures is likely one of the best methods to compare and visually display transportation networks. Alternatives could also include a binary color scheme to illustrate if a roadway is or is not within a certain category (e.g., is or is not a bottleneck on the roadway network). If the map is developed in Tableau or other interactive software package, maps can provide additional context using tooltips (also known as pop-ups).

Color can also be used with or substituted for size/width of the segment line. However, as in all network and segmentation maps, reduce the number of lines and increase the size of the segment as much as possible to fit the scale. For example, a national network map cannot be easily read if TMC segments are mapped; conversely, an urban view may make less sense if each segment was a single-roadway designation with no breaks.

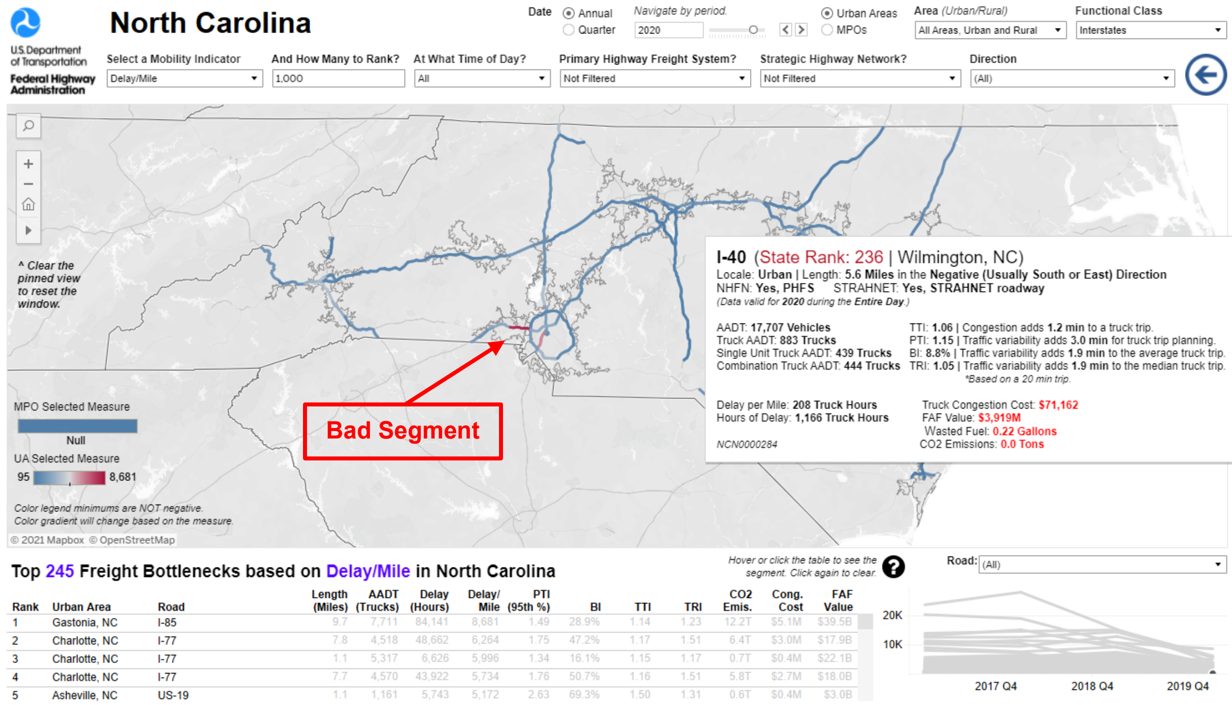

Figure 18: Freight Mobility Bottlenecks Displayed in a Map and Table Using Tableau

Performance measures can also be mapped more categorically and without using a roadway network. For example, Figure 19 displays how urban areas changed in relation to 3 mobility metrics (conveyed as a simple index) from the previous year in FHWA's Urban Congestion Report (https://ops.fhwa.dot.gov/perf_measurement/ucr/) (*39*). In this case, one can easily tell which cities improved or worsened from the previous year, though detailed information is not available. This type of map works well for lay audiences, but technical audiences would expect supplemental or additional explanatory information.

Mobility and congestion data does not necessarily need to be mapped to convey spatial information. Figure 20 illustrates freight import and export movements from five major countries using a chord diagram (could also be performed using a Sankey diagram) (*40*). These charts are particularly useful as interactive visualizations but work well to convey simple to complex movements. Consider using this chart for trip origin/destinations analysis, regional movements, freight movements, and other similar uses.

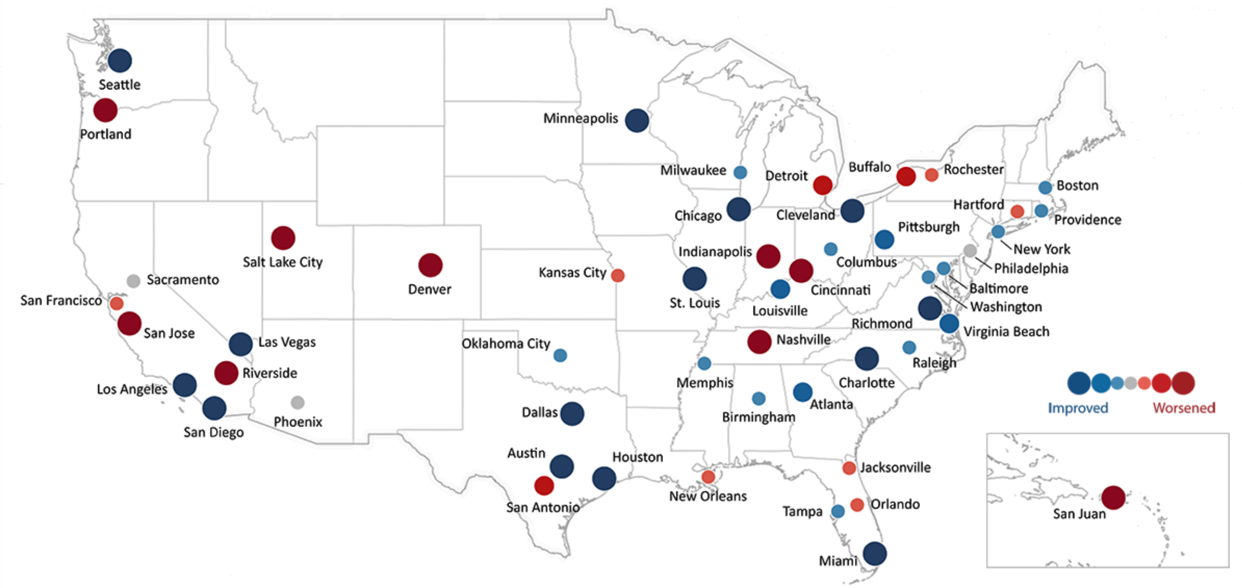

Figure 19: National Urban Area Performance Using a Simple Map Display

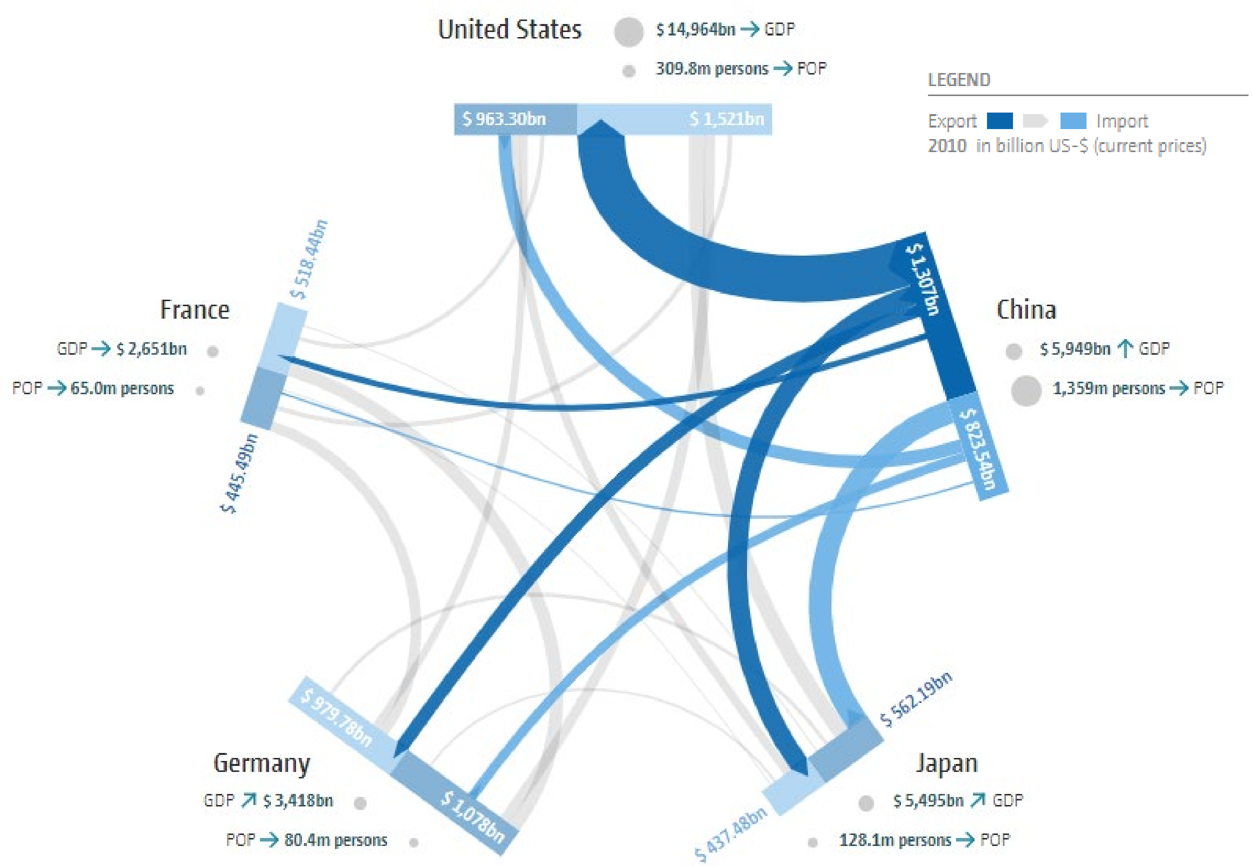

Figure 20: Trade Flows between Countries Using a Chord Diagram

Finally, spatial information can use a combination of mapped and abstract graphical representations to convey large amounts of technical and non-technical information. Figure 21 compares two freeway routes in Austin, TX—one tolled and one non-tolled—for through-movement truck traffic volume (*41*). The premise was that most truck traffic moving along IH 35 in Austin was through movements (did not have a local destination) and could be moved to a bypass (SH 130). However, as this chart effectively reveals, the overwhelming majority of both light and heavy truck traffic on IH 35 have local destinations. This illustration effectively communicated its purpose and informed policy moving forward.

This illustration takes elements from the thermal map in Figure 13 and other graphic concepts to convey very complex mobility information. Note that with charts like this and of similar complexity, proper annotation will be required to ensure the results of the analysis are communicated to the designated audience.

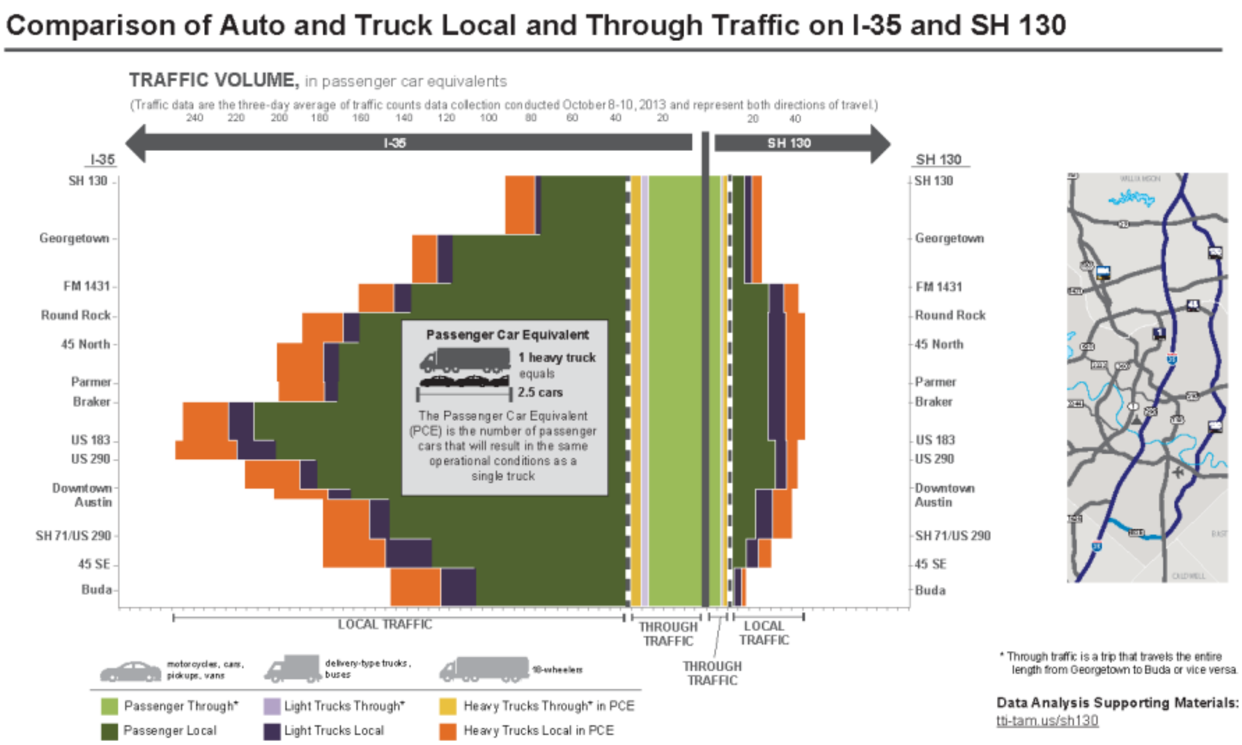

Figure 21: Comparison of Auto and Truck Local and Through Traffic on I-35 and SH 130

Illustration Best Practices and Considerations

Regardless of the method used to illustrate and communicate mobility performance, basic display guidelines should be followed to ensure analysis results and messages are received correctly by the intended audience. The remainder of this chapter will discuss these basic concepts.

Place Measure Results in Meaningful Terms

Likely one of the most important concepts to remember when communicating the results of a mobility analysis is to place measures and their results in terms that each audience finds meaningful and can easily understand. This largely requires a general understanding of the technical knowledge of the audiences.

For example, many transportation planners doing mobility analysis likely know what a TTI value of 1.25 means and how it relates to another value of 2.37. However, these values mean little to the public. Policy makers, engineers, or even other transportation professionals may not know what the values mean—or may have a rudimentary understanding but have some misconceptions about the values' meaning and how to apply it.

Therefore, it is crucial to ensure that all audiences have a common understanding of the following:

1. What the measure is and generally what it means.
2. What the measure value means and how it should be interpreted.
3. How the measure value is applied in the specific analysis context.

Stating what the measure is and what it means requires placing the measure's name and technical definition in an easy-to-see location on the page or screen for reference. This is especially helpful when readers find the measure itself confusing (like TTTR or LOTTR discussed in **Chapter 5: Recommended Performance Measures).** Giving the audience a means to educate themselves both adds clarity to the analysis and empowers deeper discussions in the future.

Second, there are usually multiple ways that mobility measure values can be displayed to be more easily understandable to both technical and lay audiences alike. For example, while displaying an index value may be required, placing the index into terms that are meaningful to a traveler or shipper will greatly add clarity. For example, the TTI value of 1.25 could also be displayed as, "A trip normally taking 20 minutes takes 25 minutes in traffic." Similarly, a PTI value of 2.33 could be stated as, "To ensure on-time arrival, travelers should plan 47 minutes for a trip that takes 20-minutes in low volume conditions." There are a variety of approaches, but the goal should always be to provide a meaningful definition and interpretation simultaneously to the reader.

Other measures may need to be downscaled or placed in other terms to be meaningful. For example, total delay is generally most useful for conveying the size of a total problem, but the number may be so large that it becomes difficult to comprehend (e.g., 257,953,000 person hours of delay). Two ways to address this would be to place it in terms of per-traveler or -commuter or to reduce the number to something more meaningful. In this example, it could be that the total delay is 120 hours per commuter per year. While this number now means more to an individual, it has lost its ability to show total scale of the problem (it is helpful to show total delay in addition to delay per commuter). Delay per commuter may still be difficult for some audiences to understand and could be reduced even further: "Commuters spend (for the 120 hours) an average of 15 vacation days per year stuck in traffic." This number becomes much more impactful and useful in conveying the measure result and telling the mobility or congestion story to the audience.

Note that it may also be necessary to overtly state what the measure does not mean or indicate or any contexts that it should not be used. While this is highly dependent upon the measure, be thoughtful about how the measure results could be used incorrectly. This may mean wording surrounding measure results very carefully or adding specific qualifiers to the interpretation.

Regardless of how measures are displayed, they should always be clear and succinct to the audience. Review any illustrations, charts, or verbiage to ensure they accurately convey the results of the analysis.

Reduce Information Overload

A common error in graphic design is to place too much information on a single illustration, chart, or graph. This causes much of the important information to get lost in the graphic. Humans can generally only process three to five elements visually at a time. Therefore, when displaying mobility analysis results, pay careful attention to how much information is being placed in any one location.

Illustrate only one measure on a chart at a time. Using too many measures will not only create information overload issues, but also could create confusion and misinterpretation of the information. Additionally, readers may conflate the two measures or create a mental link where no link should exist.

Only display information that is specifically relevant to the reader. This could mean reducing the number of roadway segments or neighborhoods on a map or only displaying measures above a certain threshold. Think about the purpose of the illustration and what is needing to be communicated; then try to find a way to display the bare minimum required to convey that message. Have others review the illustration or results and provide feedback about what they gleaned.

Graphic and Illustration Tips

While there are several tips for visually communicating mobility analysis results, a couple stand out as common issues that should be improved.

First, be mindful of persons with color vision deficiency. It is common in transportation to use red-yellow-green color palates for many illustrations and graphics. However, this is likely the most difficult color palate for color-deficient readers to see. Additionally, if graphics must be Section 508 accessible, this color palate would make the entire graphic fail in compliance. Instead, use blue-orange or greyscale color palates. You may also find color calculators online that can select vision-friendly color palates that may suit the graphic's needs better.

Second, ensure that all graphics and illustrations are easily reproducible and sharable. Many times, illustrations use complex fonts, contain ungrouped objects, or are either too small or too large. This makes graphics difficult to copy-paste from one document or webpage to another without losing context, scale, or readability.

Every graphic should be self-contained: regardless of where it is placed, it should not lose its meaning or context to the reader. Simple ways to accomplish this include the following:

- Add a descriptive title into the graphic itself that conveys the meaning of the graphics.
- Ensure fonts are simple, sans serifed, and large enough to be scaled and still readable and crisp.
- Reduce the noise on the graphic by eliminating borders, superfluous lines, unnecessary text, or other elements that detract from the meaning. Less is usually more.
- Avoid illustrating highly detailed road networks that are difficult to see at small scales.
- Add labels that explain the conclusions.
- When in doubt, include a summary table with the graphic to compliment the visual elements.

Finally, where possible, consider creating an interactive data visualization. These graphical tools can often better illustrate complex data or results while keeping the illustration simple and easy to read. Tools like Tableau or Microsoft's Power BI can be used to create engaging and descriptive visualizations that are easy to maintain and share.

Other Resources for Transportation Graphics.

There are many resources for creating transportation-specific illustrations and graphics. These can provide helpful tips and guidelines or simply provide inspiration for different ways others have chosen to convey transportation information.

NCHRP 08-36 Task 128 – Data Visualization Methods for Transportation Agencies provides extensive resources and examples for illustrating transportation information (*42*).

DataPine produced a blog discussing reporting best practices. While focused on management and accounting, the principles largely apply to transportation and can be easily transferred. Additionally, several examples display best practices for graphic design, especially for key performance indicators (*43*).

Finally, the Transportation Research Board created the standing committee on Visualization in Transportation (AED80). The committee's website (https://sites.google.com/view/trbabj95/home) provides links to several helpful resources for creating transportation-specific graphics and interactive visualizations.

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