9 TRANSPORTATION ANALYSIS PERFORMANCE MEASURES

9.1 Introduction

Transportation analysis performance measures, sometimes referred to as measures of effectiveness (MOEs), are quantitative estimates on the performance of a transportation facility, service, program, system, scenario or project with respect to policies, goals and objectives. Some common performance measures used in traffic engineering include v/c ratio, level of service (LOS), crashes, vehicle delay, travel time, mode share and capacity. Performance measures in this chapter focus on the objectives of mobility **and** safety.

Performance measures can be based on empirical observations/data measurements of existing conditions or may be outputs of models that estimate or predict the performance of potential future scenarios, programs or alternative strategies.

Performance measures typically have some type of established threshold or target value or rating which defines the acceptable conditions for a facility. Any case where conditions do not meet that level is defined as a deficiency or need that should be reviewed. The term ‘need’ as used by transportation professionals has generally been defined as any case where the current or planned facility conditions fall below an established threshold.”

The greater the deviation of the measured value from the performance threshold, the greater the need. Thresholds provide a critical element of the decision-making framework for assessing deficiencies and improvement alternatives since they are developed to maximize overall system performance while limiting liability to the agency responsible for construction, operations and maintenance. Thresholds may be known as goals, targets, or benchmarks. Thresholds may be adopted by a jurisdiction as part of a plan or policy.

Most road authorities (state, county or city) maintain adopted performance standards for operational efficiency that identify specific performance thresholds. It is important to identify all applicable performance standards and corresponding performance measures and thresholds for study roadways to provide a basis for evaluating the results of transportation analysis and to determine if project goals and objectives are being achieved. Methods of calculation or tools may also be prescribed.

9.1.1 Selecting Performance Measures

Performance measures to be used in a system plan, corridor study, development review, or project alternatives analysis are driven by the goals and objectives of the project and are identified during scoping and methodology development. Appendix 9A is provided as a general guide to aid in the consideration of potential transportation analysis performance measures by plan or project type, including RTPs, TSPs, MMAs, Facility Plans, Development Review, and NEPA/project development. For each type of study, potentially applicable performance measures are noted and identified as best practice/recommended, supplemental, or for screening purposes.

Performance measures may require varying levels of efforts depending on factors such as project type and tools used. Refer to Chapter 2 for level of effort information.

Some analysis performance measures are required. For example, state highway project v/c ratios are needed in order to compare the performance of alternatives with ODOT Highway Design Manual (HDM) mobility thresholds. Other analysis performance measures are often necessary, depending on the needs of the project. These selected performance measures become project evaluation criteria by defining them specifically to the project. In addition, project-specific thresholds and desired confidence or significance levels may be defined.

Performance measures should be SMART: Specific, Measurable, Agreed upon, Realistic, and Time-bound. See Chapter 10 for guidance on the process of developing project evaluation criteria and performance measures. Performance measures need to be sensitive enough to differentiate between analysis years and alternatives, scenarios or options. For example, a highly congested area with v/c's in excess of 1.0 and LOS F will not be sensitive to an increase in volume. In this case, different/additional measures would be needed such as travel time, safety, and reliability.

There is no one-size-fits-all performance measure that can address all the policies or objectives of a plan or project. Many performance measures address only one dimension of a problem while ignoring other important considerations. For example, a ratio or percentage based performance measure such as v/c ratio by itself does not indicate the number of users affected. Two roadways, one with a high volume and one with a low volume, may both have the same v/c ratio, but the high volume roadway affects more users than the low volume roadway. Multiple performance measures are typically needed.

The applicability or priority of performance measures depends on the purpose, need, goals and objectives of the project or plan, as well as on the facility and area type. In some cases the same performance measure can address multiple objectives. For example travel time can be used to assess emergency vehicle trips, or freight, or other modes. The number of performance measures chosen for any particular aspect for a project should be minimized. Too many performance measures for a given area may create conflicts, confusion, unnecessary work, and may result in measures not being used for that decision process. Some measures may not be clearly understandable to the desired audience or practically creatable based on data and tools available.

A matrix of typical analysis performance measures including definitions, purpose, modes, level of resolution, data and tool requirements is available in SPR Report 716[1].

[1] Development and Sensitivity Testing of Alternative Mobility Metrics, SPR 716, ODOT, John P. Gliebe and James G. Strathman, March, 2012, Table 3.1.

9.1.2 Purpose of this Chapter

Performance measures in this chapter are grouped into categories. Transportation can be measured in terms of its primary functions such as safety, accessibility and mobility. It can also be measured in terms of its impact or consequence, such as on the environment, and socioeconomics. It should be noted that while the performance measures identified below are assigned to a single primary category, some measures relate to multiple objectives and categories.

This chapter is limited to performance measures commonly reported out using APM methods and tools. These measures are used in plans and projects to identify needs, compare scenarios and alternatives, and identify benefits and impacts. The chapter focuses on facility level performance measures. System level performance measures generated by APM tools are discussed at a higher level. The performance measures covered are:

- Mobility
- Reliability
- Level of Service (LOS)
- Accessibility
- Safety
- Other Multimodal Performance Measures
- Infrastructure

The performances measures contained in this chapter are not an exhaustive list, but focus on those that are the most widely used and practical. Measures which have a good potential for application for a range of studies are also discussed. TPAU can provide assistance in selecting appropriate analytical performance measures for a specific project. A given project will use only a small subset of all possible measures. This chapter provides measure definitions, calculations, strengths and weaknesses, but leaves the application of performance measures to other referenced chapters. The use of performance measures to evaluate alternatives is discussed further in Chapter 10. For a broader discussion on mobility performance measures, see FHWA Traffic Analysis Tools Volume VI [(1)].

Not addressed in this chapter

- Factors that contribute to or are components of performance but are not typically reported out as stand-alone performance measures. Although not performance measures per se, in many instances these can provide additional useful information on the causes behind performance, which helps to understand or interpret the performance measure result. This includes analysis outputs used as inputs into performance measure calculations performed by other methods. For example, forecasted traffic volumes and speeds which are used to report out air quality and noise performance, or predicted crashes or delays which are used in economic analysis to report out reduced travel time or crash reduction cost performance.
- Preliminary screening criteria or flags are more intermediate in nature, such as those that are used as inputs into following steps and are not typically reported out as performance

measures, for example preliminary signal warrants or turn lane criteria. Refer to Chapter 10.

- Performance measures or evaluation criteria produced using methods or tools outside of the APM. For example, measures produced for managing the ODOT TSMO program such as average time to clear an incident. This also includes right of way, construction cost, funding, economics, design criteria, and environmental impacts.
- Performance measures relating to broad high level policy areas that are not specifically transportation-related, such as economic vitality; land use; environmental stewardship; quality of life, livability and health; equity; and funding and finance.
- Agency key performance measures (KPMs)/benchmarks/goals/targets for agency-wide or policy/strategic planning/investment strategies or monitoring purposes such as performance measure reporting required by the FAST Act; for example, ODOT Key Performance Measures. Refer to Chapter 18 for more information on the performance management planning and programming.

The broader KPMs are not comparable to analysis performance measures because they are different in purpose and resolution, and are likely to be based on different measurements, tools, level of aggregation, networks, assumptions, definitions, variables, data sources, formulas, and/or time periods. In contrast, analysis project alternatives are typically smaller in scale with greater resolution, focusing on study area roadway sections and intersections. Large scale performance measures would not be as useful on smaller projects and plans such as small city TSPs because they would not be likely to show a significantly measurable change in order to make comparisons useful.

9.2 Mobility

Mobility refers to the movement of both people and goods regardless of mode. Mobility performance relates to both supply and demand, as affected by land use and other policies. Supply could include the road network, transit routes, bicycle lanes, or any other modal infrastructure. Demand is the rate of flow which could include total persons, motorized vehicles, transit vehicles, etc., desiring to be able to traverse a point or section over a period of time such as an hour or a day. For additional detailed information on multimodal mobility related performance measures refer to HCM 6.

9.2.1 Volume to Capacity Ratio

The principal performance measure ODOT uses when evaluating motor vehicle operating characteristics on the state highway system is the volume to capacity (v/c) ratio, which is a measure of how close to capacity a roadway is operating. It reflects the ability of a facility to serve motorized vehicle traffic volume over a given time period under ideal conditions such as good weather, no incidents, no heavy vehicles, no geometric deficiencies. The volume to capacity ratio is the degree of utilization of the capacity of a segment, intersection or approach. The v/c ratio is not defined over 1.0. Under those conditions it is considered to be a demand to capacity ratio. A lower ratio indicates smooth operations and minimal delays. As the ratio approaches 1.0, congestion increases and performance is reduced. At 1.0 the capacity is fully utilized.

For example, when v/c equals 0.85, 85 percent of a highway's capacity is being used ; 15 percent of the capacity is still theoretically available. However, as the v/c ratio approaches 1.0, flow becomes unstable, speeds decrease, and bottlenecks can easily occur.

Performance measures

- Critical Intersection v/c ratio X_c (signalized intersections)
- Intersection Approach v/c ratio (unsignalized intersections)
- Segment v/c ratio (freeways, uninterrupted flow multilane highways and two-lane highways)
- Weave, merge, and diverge v/c ratio (freeways and uninterrupted flow multilane highways)

Example evaluation criteria

- Number of locations exceeding applicable v/c ratio standards
- Percent of intersections operating at V/C > 1.0

The generic formula for v/c ratio is as follows.

$$\frac{v}{c} = volume/capacity$$

There are other variations on calculating the v/c ratio. For example, for signalized intersections, Xc is used for total intersection v/c ratio as shown below. Refer to the HCM for fully detailed procedures.

Critical Intersection Volume to Capacity Ratio (for signalized intersections)

$$X_C = \left(\frac{C}{C-L}\right)\sum_{i\in ci} y_{c,i}$$

With

$$L = \sum_{i\in ci} l_{t,i}$$

Where

X_C = critical intersection volume to capacity ratio
C = cycle length (sec)
$y_{c,i}$ = critical flow ratio for phase $i = \frac{v_i}{(Ns_i)}$
$L_{t,i}$ = phase i lost time $= l_{1,i} + l_{2,i}$ (sec)
ci = set of critical phases on the critical path
L = cycle lost time (sec)

v_i = lane group flow rate for phase i
N = number of lanes for lane group i
s_i = lane group saturation flow rate for phase i

The v/c ratio can account for changes in either volume or supply (capacity). Volume is a measure of the rate of flow of traffic expressed as the number of vehicles passing a given point on a roadway over a specified time period, such as vehicles per hour or day. Volume is most commonly reduced at a location or facility by adding alternative routes or connections which may shift traffic to other routes. Other means of shifting volume include TDM or TSMO measures such as ramp metering, traveler information, tolling or congestion pricing. Procedures for developing traffic volumes are found in APM Chapter 5 for Existing and Chapter 6 for Future Year.

Capacity is the supply side measure of the ability of a facility to carry traffic. It is the maximum number of motorized vehicles per hour that can travel on a particular stretch of roadway under relatively ideal conditions such as proper lane widths, no parking, no bus blockages, etc. Capacity is a function of a number of variables including number of lanes, lane width, shoulder width, presence and type of control devices, free flow speed, and other features. Capacity may be calculated by HCM methods or measured in the field in locations and conditions where demand exceeds capacity. Procedures for calculating capacity and v/c ratios are found in the APM chapters on segments and intersections and are primarily based on methodologies in the Highway Capacity Manual and implemented by various software tools.

ODOT uses v/c-based measures for reasons of application consistency and flexibility, manageable data requirements, forecasting accuracy, and the ability to aggregate into area-wide targets that are fairly easy to understand and specify. In addition, since v/c is responsive to changes in volume as well as in capacity, it reflects the results of demand management, land use and multimodal policies. Other advantages of v/c ratio include:

- Standardized calculation methodologies and tools
- Easily applied and forecasted
- Planning level methods are available to estimate segment v/c ratios. Volumes are estimated using AADTs along with K_{30} factors and directional factors. Capacity estimates can include the use of default values in estimating v/c ratios with the results reported out as below, near, or at capacity, as example, HERS-ST performs this level of v/c ratio analysis (refer to Chapter 7). For urban signalized arterials, segment capacity can be estimated using approximate green time to cycle time (g/c) ratio assumptions.
- Can be calculated for segments, intersections, approaches, and turn movements
- Travel demand models calculate a link-based demand to capacity ratio (d/c). Refer to Section 9.2.5 on model based demand to capacity ratios.

Requirements/Limitations

- Does not directly apply to or address safety, non-motorized vehicle modes, operational improvements, and other policy objectives often under consideration because these aspects of the transportation system cannot be directly measured in terms of vehicle demand and vehicle capacity.

- Identifies when capacity is exceeded, but does not address the extent or duration of congestion or queue spill-back effects. By definition, the volume of traffic using a roadway cannot exceed the roadway's capacity. When demand exceeds capacity, a demand-to-capacity (d/c) ratio may be used (see section on Demand to Capacity Ratio). A d/c ratio that exceeds 1.00 indicates that more vehicles would use a roadway in a given time period if capacity constraints were not present.
- Is focused on a recurring peak period and does not address non-recurring congestion such as from incidents, weather, or special events.

9.2.2 Oregon Highway Plan Mobility Targets

ODOT has adopted specific v/c ratio thresholds for identifying current and future needs in the Oregon Highway Plan (OHP) which are used for identifying needs in planning. These are different from the performance thresholds for project design in the Highway Design Manual (HDM), which are accepted by FHWA for design and need to be lower than the planning need threshold in order to allow for the project to have a design life.

Volume to capacity ratio was selected as the performance standard for motor vehicle mobility on state highways in the Oregon Highway Plan (OHP) after an extensive analysis of candidate highway performance measures. The review included the effectiveness of the measure to achieve other policies (particularly OHP Policy 1B, Land Use and Transportation), implications for growth patterns, how specifically ODOT should integrate transportation policy with land use, flexibility for modifying targets, and the effects of Portland metro area targets on the major state highways in the region.

Targets for state highway motorized vehicle mobility needs are established in the current OHP Policy 1F. Tables 6 and 7 within Policy 1F contain the v/c ratio targets for various combinations of highway classifications and surrounding land uses, with Table 7 applying to the Portland metropolitan area and Table 6 applying to the remainder of the state.

The targets vary the priority for mobility according to facility, area and designation type; mobility is a high priority on freeways, expressways and freight routes, but is a lower priority on District highways or local interest roads in Special Transportation Areas (STA) and Metropolitan Planning Organizations (MPO). It should be noted that the text within Policy 1F contains exceptions to the targets listed in these tables and, therefore, must be consulted as well. Furthermore, the OHP Registry of Amendments webpage should be checked for amendments to the OHP mobility policy where alternative mobility targets have been adopted; for an example refer to the report US 101 Seaside Alternate Mobility Standards.

The analyst should refer to OHP Policy 1F for appropriate application of the OHP mobility targets in specific contexts. For plan amendment applications also refer to TPR 0060.

9.2.3 Oregon Highway Plan Alternative Mobility Targets

The v/c ratio targets were generally designed to provide continued operation in an under capacity condition. Increasingly in urban areas, there are roadways that are projected to be over-capacity, or that are currently operating in an over-capacity mode. Circumstances exist where v/c targets cannot reasonably be met due to financial, environmental or land use constraints. In these circumstances, where it is not feasible or desirable to make infrastructure investments to fully accommodate the existing and projected vehicular demand, it is possible to explore alternative mobility targets.

If meeting OHP v/c ratio targets is not practical or feasible due to financial, environmental or land use constraints or impacts, OHP Action 1F.3 contains provisions for creating alternative mobility measures and targets through a planning process and adoption by the Oregon Transportation Commission (OTC). Adjustments to the OHP targets may include changing the v/c ratio target (increase or decrease), changing the analysis methodology (e.g., from 30th highest hour to average annual traffic volumes or adjusting peak hour factors), and/or acknowledging that a facility will likely operate at capacity for more than just a single peak hour. Alternative (non v/c-based) performance measures may involve other analysis methods that address safety performance, travel time reliability and delay.

The process for consideration of alternative mobility targets is detailed in the Planning Business Leadership Team PBLT Operational Notice PB-02. This process involves the participation, commitment and mutual agreement of local and regional jurisdictions and includes exploring a variety of transportation-related solutions, including a number of system and demand management activities to maximize the efficiency of transportation movements and to identify solutions that are realistic to implement and have the potential to be effective. Under most circumstances, local jurisdictions must adopt appropriate local policies, codes and ordinances that are necessary to help support and implement the alternative mobility target and achieve other policy and performance objectives.

In some cases such as a rural interchange area management plan, more restrictive alternative v/c ratio targets may be adopted as part of OHP Action 1F.4. More restrictive targets may help to maintain mobility in an identified area. This can be an effective tool where it is desirable to further preserve a significant investment, such as in the vicinity of an interchange.

Developing OHP Alternative Performance Targets or Measures

The following v/c-based methodology is recommended as a first option when developing alternative mobility targets for state highways outside the Portland Metro area. OHP policy and current analysis practices use a v/c-based methodology as the initial measure to standardize and simplify implementation through a quantifiable, consistent and reproducible measure. Where v/c-based approaches may not meet all needs and objectives, developing alternative mobility targets using non v/c-based measures may also be pursued. Any alternative mobility target per the OHP, including new methodology, will not be final until adopted by the OTC.

1. In cases where v/c is forecasted to be greater than the OHP mobility target but less than capacity (v/c = 1.0) during the design hour using standard analysis procedures, establish the proposed alternative target consistent with the v/c values used in the OHP (0.75, 0.80, 0.85, 0.90, etc.).

2. In cases where v/c is forecasted to be greater than or equal to capacity during the design hour using the standard analysis procedures evaluate the actual peak hour traffic volume for future year design hour projections rather than expanding the peak 15 minutes to be the design hour traffic volume (e.g. peak hour factor) for projection purposes. If v/c is less than 1.0, establish the proposed alternative target.

3. In cases where v/c is forecasted to be greater than or equal to capacity during the design hour using the actual peak hour projection of traffic and in areas where design hours are affected by high seasonal traffic volumes, evaluate the Annual Average Weekday PM Peak as the future year design hour rather than the 30th highest hour. If v/c is less than 1.0, establish the proposed alternative target.

4. In cases where v/c is forecasted to be ≥1.0 using the Annual Average Weekday PM Peak as the future design hour, determine the duration of the period during which the future Annual Average Weekday PM Peak hour will have a v/c ≥1.0. Establish the proposed alternative target by increasing the number of hours that v/c can be ≥1.0 (i.e., v/c ≥1.0 for not more than 1 hour, or not more than 2 hours, etc.).

If a v/c-based mobility measure does not by itself meet the needs of the jurisdiction, the state or the particular facility under consideration, then it is reasonable to explore non v/c-based measures for defining mobility on the state highway system. At a minimum, all non v/c-based measures must:

1. Be consistent with OHP Policy 1F, with particular attention to Actions 1F.1 and 1F.3;

2. Follow the PBLT Operational Notice PB-02 Attachment A Checklist; and

3. Develop a measurable and defensible target value, with defined geographic limits and a defined analysis methodology that can be compared between alternatives, recognizes data needs, availability and quality, and considers requirements for implementation including the availability of analysis tools, staff responsibilities and associated costs.

Recognize that, even when exploring non v/c-based measures, there may still be advantages to keeping v/c measures as well. The v/c ratio along with other measures provides a complete picture of operations.

9.2.4 Highway Design Manual Mobility Guidelines

Motor vehicle mobility thresholds for design of modernization projects are identified in Exhibit 10-1 of ODOT's HDM. These v/c ratios (the functional equivalents of the LOS standards in the American Association of State Highway and Transportation Officials [AASHTO] Green Book) represent the level of operation for which state facilities are expected to be designed and are intended to be applied to an analysis year occurring 20 years beyond the year of completion. These thresholds are applicable to future build alternatives on state highways associated with all project types except Traffic Impact Studies associated with development, unless an interchange or interstate freeway is involved. It should be noted that for ramp terminals, the HDM mainline maximum v/c ratio is the standard that applies. There is no equivalent ramp terminal v/c ratio in the OHP as there is in the HDM.

Exhibit 9-1 illustrates the appropriate sources of adopted mobility performance measure standards for different project types.

Exhibit 9-1 Sources of Adopted Mobility Targets/Standards for State Highways by Study Type

	TIS/TIA	Projects	TSPs	Corridor and Refinement Plans
Existing Conditions	OHP	OHP	OHP	OHP
Future No-Build	OHP	OHP	OHP	OHP
Future Modernization Build(s)	OHP	HDM	HDM (OHP in Portland Metro Area[1])	HDM

[1] In the Portland metropolitan area, future modernization build alternatives on state highways are scoped and analyzed in corridor plans, refinement plans or projects rather than as part of TSPs.

HDM mobility thresholds are generally more restrictive than the OHP mobility targets; however, there is a design exception process that allows variation from the HDM when appropriate. Transportation System Plans (TSPs) generally identify needs and the function, mode, location, and parameters (e.g. number of lanes) of solutions. The precise location, alignment, and preliminary design of solutions is typically deferred to refinement studies or project development.

HDM FHWA-ODOT MOU

In order to be used as baseline standards for future project design, alternative mobility targets being considered as an amendment to the OHP must be established in coordination with FHWA. This process is described in the Memorandum of Understanding (MOU) between ODOT and FHWA, provided as an attachment to PB-02. Through this process, the alternative mobility target may be adopted as an amendment to the HDM.

9.2.5 Supplemental Vehicle Mobility Measures

Many of the mobility analysis procedures summarized in the APM have direct (or equivalent) v/c ratio results for performance assessment. The compliance with the appropriate target (maximum v/c ratio thresholds defined in the OHP) is the first tier of the evaluation. The other category of performance measures focuses on travel time/speed, including progression analysis, arterial analysis and selected outputs of many simulation models. The vehicle speed outcomes can be compared to target or design speeds to assess relative benefit, but there is no direct comparison with v/c ratio in these analyses. It is recommended that these types of measures be used in conjunction with either intersection or segment analyses that do have v/c ratio related outcomes to compare to mobility targets.

Typical travel demand model-based performance measures are calculated using model generated outputs that yield general system performance of the scenario. Scenarios would be considered relatively the same if there is no significant difference in the performance measure (less than 10%) because of the model’s limited accuracy. Performance measures can be system-wide or segregated into select facilities, corridors, areas, or zones.

Quantity of Travel

Quantity of travel represents the amount of use of a facility or service. It is both a performance measure and an input into the calculation of other performance measures. Quantity of travel is usually expressed as the number of motorized vehicles, persons, pedestrians, bicyclists, or transit vehicles per unit of time. Methods to estimate the quantity of travel range from simple historical trends to cumulative analysis to complex urban, regional or statewide travel demand models.

For more information refer to APM Chapters 6 and 7 and the ODOT Planning Section Technical Tools webpage.

Percent Change in Volume

Percent change in motor vehicle volume is used to compare different scenarios or alternatives such as No Build versus Build, different land use scenarios, or multiple Build alternatives. Build alternatives that increase capacity and/or reduce travel time often result in network volume changes, for example due to demand shifting between competing routes. Volume change is commonly obtained by comparing similar segments across screenlines or difference plots between two scenarios from a travel demand model, or can be estimated using deterministic methods. Volume change can be used as a high level analysis or preliminary screening measure. Changes of more than 10% are generally considered the minimal level of significance. Changes of more than 20% have a large impact, depending on the absolute volume level.

Performance measures

- Design hour volume on segment or screenline

Example evaluation criteria

- Percent change in volume crossing screenline
- Percent change in volume on link
- Diversions or neighborhood cut-through traffic due to temporary/permanent lane closures including road diets, work zones, congestion, incidents.

Vehicle-Miles of Travel (VMT)

VMT is the amount of vehicle travel on a system in terms of both vehicle volume and distance. VMT is the relationship of the total vehicle volume on the specified links multiplied by the total link lengths. VMT is typically a system performance measure reported for large-scale, regionally significant changes or regional/MPO areas and should generally only be used in high-level planning analyses. Although VMT can be calculated on any facility, it is not typically reported out. VMT is also calculated as part of energy analyses in Environmental Impact Statements.

Performance measure

- Vehicle-miles of travel on segment or facility

Example evaluation criteria

- Change in area/region VMT
- Change in facility/corridor VMT
- Change in segment VMT

$$VMT = AADT \times length$$

> *VMT is typically reported as a daily value but may be specified as an average annual value based on 365 days a year. The analyst should be aware that VMT can be calculated based on different data sources, tools or methodologies. For example, gasoline sales based VMT (when combined with average vehicle MPG), official VMT from HPMS used in HERS (link-level, statewide, state-owned facilities only), RSPM (all days average, household-based, all roads), or from a travel demand model (average weekday, mostly state system, within model area only).*

VMT is typically reported as an annual average daily value per segment:

$$Daily\ VMT = AADT \times Length$$

VMT is also commonly reported for an entire facility, system or subset of roads by summing individual segment VMTs:

$$Facility\ or\ System\ VMT = \sum Segment\ VMTs$$

For trucks,

$$Truck\ Miles\ Traveled = AADT \times length \times \%\ trucks$$

Oregon historical VMT data at a state facility level or broad regional level, reported as part of the Highway Performance Monitoring System (HPMS), may be obtained by contacting ODOT Road Inventory & Classification Services.

Regional VMT within an urban area is a common travel demand model measure. Reporting can be for the entire model area or for roads within a sub-area (e.g., UGB, MPO boundary), for all trips or a portion of the trips (e.g., internal-internal (I-I) trips only, truck-only). Model produced VMT may be reported by mode and by trip purpose. Even where total demand is the same, VMT can increase due to changes in trip lengths, such as a scenario where trips lengthen when land use growth is mainly on the fringe of the urban area, or increasing road congestion may result in either shorter trips or forces trips to take alternate routes which may be longer.

VMT is closely related to both the demand and the supply side of the urban setting. Levels are lower in communities that are more walkable and compact and in communities that have a strong public transport system. Increasing population density can lower VMT as well, although increased density may increase the VMT in the local area but may reduce the overall system VMT. VMT can also drop due to economic downturns, when unemployment is high and people have a smaller shopping budget. Vehicle operating costs including fuel costs, per mile fees and vehicle MPG, can also significantly impact VMT. Population shifts or new population estimates can change VMT trends significantly. Many of these factors are outside the agency’s control.

VMT results can be subject to misinterpretation as many factors can contribute to a particular increase or decrease in the value. For example, a VMT increase could be due to more people driving, but it also could be due to new growth on the fringe of an area with a subset of the population having to drive longer distances.

The TPR requirement of VMT per capita is limited to internal trips only, even though models can produce VMT per capita for all trips. The TPR measure can be skewed based on the relative size of the model area, the proportion of external trips, or other individual characteristics of the urban area such as demographics (i.e., high retiree population). The measure can also be skewed when population forecasts change.

Person-Miles Traveled (PMT)

PMT is similar to VMT except that person travel is measured rather than vehicle travel. Person travel includes motorized vehicle drivers, passengers, transit riders, rail passengers, pedestrians or bicyclists. For motorized vehicle travel, person-miles traveled is typically calculated as follows:

$$PMT = AADT \times length \times vehicle\ occupancy$$

<u>Performance measure</u>

- Person-miles of travel

<u>Example evaluation criteria</u>

- Change in area/region PMT
- Change in facility/corridor PMT
- Portion of drive-alone mode (SOV) trips

Total PMT on a facility would need to add non-motorized vehicle person trips. The typical method of calculation involves use of travel demand model VMT divided by mode share.

The amount of person travel a corridor or system serves, PMT is directly related to VMT as it is VMT multiplied by a vehicle or transit occupancy factor. PMT should only be used for high-level planning processes because of the high level of estimation required. PMT can also be calculated for modes on a regional basis if the mode split is known like from a MPO travel demand model. Bicycle and pedestrian counts could also be used to determine PMT if trip lengths are known on a facility basis. PMT has the same limitations as VMT. Calculating PMT may be difficult as occupancy factors may not be available or not enough bicycle/pedestrian counts may be available. OSUM models assume a static value for auto occupancy by trip purpose. In JEMnR and SWIM models, auto occupancy reacts to land use and transportation policies and projects and can be reported. The analyst should coordinate with the modeler as to the applicability of its use.

A commonly reported mode share performance measure is the portion of travel by drive alone mode, or single occupant vehicle (SOV). This can be reported for a region or corridor.

$$Portion\ of\ Drive\ Alone\ Mode = \frac{SOV\ VMT}{Total\ VMT}$$

Portion of SOV trips can be used to evaluate alternatives that encourage non-drive alone trips, such as park and ride lots.

<u>Throughput</u>

Throughput is the hourly volume of traffic that a facility serves or discharges.

<u>Performance measure</u>

- Throughput on segment or intersection

Example evaluation criteria

- Change in facility/corridor throughput
- Segments and time periods where demand is metered due to upstream bottlenecks
- Intersections and time periods or number of cycle lengths where green time is starved due to upstream bottlenecks

Vehicle throughput is also a calibration measure used in microsimulation. Refer to APM version 1 Chapter 8. Vehicle throughput as reported in SimTraffic is known as “Vehicles Exited”.

Throughput is sometimes confused with capacity. Even where peak hour demand equals or exceeds capacity, vehicle throughput is often less than capacity for several reasons, including:

- Metered volume – volume at an approach to a segment or intersection may be metered or constrained due to an upstream bottleneck or similar condition, so fewer vehicles can be served than otherwise could be.
- Congested bottleneck – once traffic flow has broken down on a free-flow facility, the queue discharge flow rate from the bottleneck is less than the capacity of the freeway.
- Other temporary conditions such as inclement weather, incidents, and work zones.

Degree of Utilization/Congestion

Degree of utilization is the percent of a facility’s capacity that is being used by the traffic volume, typically for a peak hour. The most commonly used measure is the v/c ratio. As the degree of utilization increases, mobility (freedom of movement) and speed decrease and density increases. Eventually, as volumes increase beyond a certain level, vehicles become impeded enough that traffic flow breaks down, and speeds drop to near zero and the facility is considered congested.

Degree of utilization is sometimes reported for other modes such as pedestrians, bikes, and transit. In Oregon, with a few exceptions, pedestrian and bicyclist degree of utilization is not typically reported because most pedestrian and bicycle volumes do not typically approach the physical capacity of the facility.

Duration of Congestion

The measures discussed in this section evaluate recurring congestion. See Travel Time Reliability section for measures that evaluate non-recurring congestion. Duration of congestion reflects the temporal extent of congestion. Hours of congestion has been used as an alternative mobility performance measure per OHP 1F.3. It is the period of time, that a segment, facility or area is congested. A facility or area may experience multiple recurring periods of congestion, such as an AM period and a PM period. Refer to APM Chapter 8 for procedures. Duration of congestion may be visualized with exhibits such as contour diagrams or heat maps, see example in Exhibit 9-2.

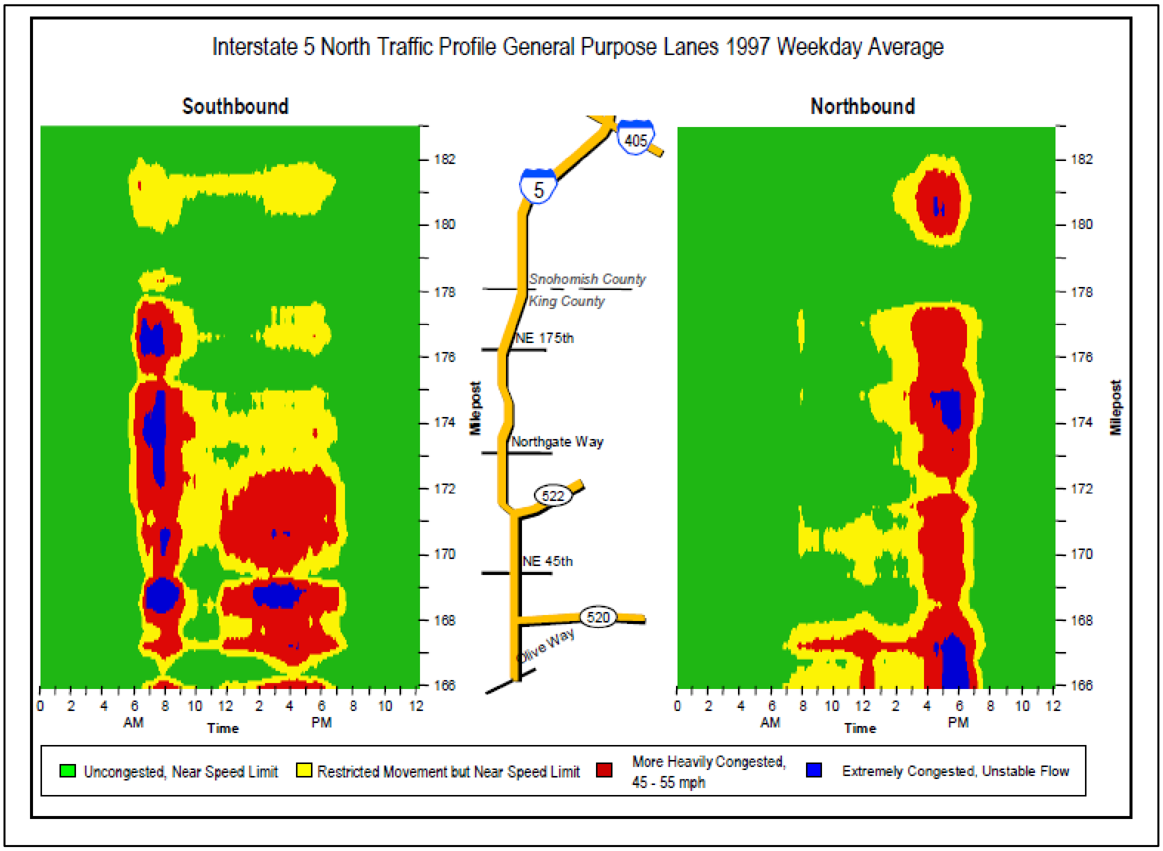
Performance measure

- d/c ratio above 1.0
- Speed below an agreed-upon threshold
- Excess/unserved demand
- Queue on uninterrupted flow facility
- Average Daily Traffic to Capacity Ratio (ADT/C)

Example evaluation criteria

- Number of hours facility exceeds capacity, v/c ratio > 1.0
- Number of hours the facility is rated at LOS F
- Number of hours that speed is below a designated threshold

Exhibit 9-2: Sample Heat Map



Source: Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation, FHWA, 2005

For analysis purposes non-recurring congestion is typically assumed to start when the demand in the analysis time period exceeds capacity. The congested period ends when there is no longer excess or unserved demand in the analysis time period. Other threshold definitions of congestion are sometimes used for other purposes such as for performance monitoring or investment decisions, such as using a speed threshold and speeds obtained from a travel demand model.

Travel speeds from a travel demand model are approximate and should only be used on a relative basis to compare alternatives/scenarios.

Average Daily Traffic to Capacity Ratio (ADT/C)

The ADT to C ratio (ADT/C) is the average daily traffic divided by the peak hour capacity. ADT/C has been used by ODOT as a rough indicator of the level of congestion. The ADT/C methodology was developed as part of studies prepared for FHWA [2] and has been used by ODOT as part of the statewide congestion management system. It is a way to estimate peak spreading on a road system. It is a higher planning level rating of the level of congestion as compared to duration of congestion or queueing. ADT/C can be used for segments or intersection approach analysis for planning estimates of congestion. For segments ADT/C should be reported out by direction. For intersections sum the sum the lane group capacities for each approach. The highest approach ADT/C is reported for the intersection.

Performance measure

- ADT/C

Example evaluation criteria

- Model links with ADT/C ratio exceeding threshold
- Alternative change in ADT/C ratio

Model capacities can be coded as a segment capacity or as a lane capacity depending on the model platform. The per lane capacity must be multiplied by the number of lanes before calculating the ADT/C ratio.

ADT/C thresholds are offered (from) as shown in Exhibit 9-3 below:

Exhibit 9-3 ADT/C Congestion Level Thresholds

Level	Condition	Description	Lower ADT/C	Upper ADT/C
1	Uncongested	No decrease in speeds during the peak hour.	0.00	6.75
2	Uncongested to Moderately		6.75	8.25
3	Moderately Congested	Speeds decrease slightly during portions of the peak hour.	8.25	9.25
4	Moderately to Congested		9.25	9.75
5	Congested	Speeds decrease significantly during portions of the peak hour.	9.75	10.75
6	Congested to Very		10.75	12.25
7	Very Congested	Speeds decrease substantially for substantial portions of the peak hour.	12.25	13.75
8	Very to Extremely		13.75	15.25
9	Extremely Congested	Speeds decrease substantially for more than the peak hour.	15.25	24.00

Queue Length

Motor vehicle queue length is typically a peak period performance measure. Queues occur in both under and over-saturated conditions. Undersaturated queues occur on interrupted flow facilities at traffic control locations. Both segments and intersections will experience oversaturated queuing when demand exceeds capacity. Oversaturated queue lengths measure the spatial extent of congestion in length (typically feet). Normally free-flow segments can experience queues when oversaturated.

Performance measures

- 95^{th} percentile queue length

Example evaluation criteria

- 95^{th} percentile queue length by approach (refer to APM v1 Chapter 7 and v2 Chapter 8)
- Queue blocking of turn or through lane
- Intersection queue blocking percentage exceeding 5% of peak hour
    - Queue spillback to railroad crossing
    - Queue spillback to functional area of intersection
    - Queue on exit ramp extending to deceleration area or mainline as calculated using design speed
    - Queue occurring in area with insufficient sight distance

Undersaturated queueing at a signalized intersection approach tends to build and dissipate with every green phase, with a maximum value reached during the peak period. Undersaturated queueing at a stop controlled intersection approach tends to gradually build to a maximum value during the peak period and then dissipate.

A queue blockage or spillback condition should be reported when the duration exceeds five percent of the peak hour. See Chapters 12 and 13 of APM. Queue spillbacks need to be evaluated with other contextual information to determine the extent and nature of the problem. Spillback queues can reduce both safety and capacity. Spillback occurs when a queue at one intersection extends into a second signalized intersection. This is typically reported as the total length of oversaturated queue beginning from bottleneck where the queue started.

Queuing is usually reported as the number of vehicles or length of vehicles in queue at the 95^{th} percentile. 95^{th} percentile queues are typically used to identify the extent of queuing problems and to evaluate alternatives that reduce queue lengths.

95^{th} percentile queues are calculated using deterministic tools following HCM methods, or by microsimulation. Depending on the solutions being evaluated, microsimulation is typically needed for final design in congested conditions. Methods of calculation vary by facility type and level of analysis detail. Refer to APM Chapter 12 and 13 for deterministic queue calculation procedures. Queuing is provided by microsimulation models where v/c ratios are high or conditions are congested (refer to APM Chapter 15).

Demand to Capacity Ratio

When the estimated v/c ratio exceeds 1.0, it is referred to as a demand to capacity (d/c) ratio. Travel demand models generate demand which can be used to calculate d/c ratios.

> *Typically a travel demand model run would be a constrained run. An unconstrained (infinite capacity) run can be requested that will show the full desired demand on a facility.*

This means that for a given time period, there are more vehicles desiring to use a facility than it can accommodate. This is also known as oversaturation. The actual volume will never exceed the capacity of the facility. Instead, the excess demand (unserved trips) may do one or more of the following: divert to other routes; change the time of the trip; distribute to other destinations; change the travel mode; or queue up to be served in following time periods (incurring additional delay).

Performance measure

- d/c ratio

Example evaluation criteria

- Travel demand model links with directional link peak hour d/c ratio exceeding 1.0
- Number of locations on state highways with a d/c ratio of 0.90 or higher
- Number of urban area lane-miles over 1.0 d/c ratio

Travel demand model d/c ratios are link-based and can only be relatively compared on a large-scale basis such as below, at, or over capacity. They cannot be compared with the Oregon Highway Plan or Highway Design Manual volume-to-capacity ratios as these require that volumes are based on the 30th highest hour from actual ground counts, while raw (not post-processed) model volumes typically only represent an average weekday condition and have been calibrated to the facility level. Also, model capacities are generically estimated based on functional class and speed rather than using HCM methods. Model d/c ratios represent a full 60-minute period rather than the peak 15-minute period. Model d/c ratios provide a planning level indication of the extent of demand on segments, including the level of potential congestion, without pinpointing specific intersection bottlenecks. For preliminary screening purposes model d/c ratios may be reported as below, near, or over capacity rather than reporting specific values.

- Over capacity: d/c > 1.10
- At capacity: d/c between .90 and 1.10
- Near capacity: d/c between .80 and .89
- Below capacity: d/c < 0.80

The d/c ratio can be used to evaluate and rank or prioritize oversaturated links, and to evaluate alternatives that reduce demand or increase capacity.

Travel Time

Travel time is a measure of the length of time a segment, facility or route can be traversed in a given time period. It is most often reported for a given direction during the peak period and expressed as the average travel time of all vehicles. Influences include design speed (encompassing facility geometrics), free flow speed, control delay, traffic volume, and travel distance.

Performance measures

- Average travel time during peak period
- Freight travel time
- Emergency services response time

Example evaluation criteria

Average peak period travel time is the sum of travel times for all trips on the segment over a given time period, divided by the traffic volume, typically expressed as minutes or seconds.

$$Travel\ Time = \frac{Distance}{Speed}$$

Speed is based on segment running speed or field or archived speed data between representative locations such as intermodal facilities, employment centers, CBDs, medical centers, park and ride lots, or transit centers.

> *As an input to noise analysis, speed is calculated as the speed at LOS C, except is reported as the posted speed if volumes are less than volumes at LOS C.*

Field or archived speed data such as from private sector probe data may be used as a measure of existing travel times as well as for reasonability checking of modeled speeds. Differences in methodologies need to be taken into account when comparing existing speeds from different sources and modeled speeds.

Total vehicle travel time is the average travel time per vehicle multiplied by the vehicle volume over the analysis period. At a very basic level:

$$Average\ Travel\ Time = \frac{Segment\ Length}{Average\ Travel\ Speed} \times 60$$

Where

Travel Time = Average travel time of all vehicles traversing segment (min)
Travel Speed = Average travel speed of vehicles (mi/hr)
Segment Length = Length of section (mi)

Travel time may be developed from travel demand models, based on zone to zone travel for an origin-destination (O-D) matrix or by summing link travel times between major intersections. MPO model travel times may be produced for a variety of modes such as SOV, HOV, freight, and transit. Travel times for all modes are used as inputs into measures of accessibility. Model based travel time travel time information can also be classified by trip type (i.e., work-based trips). Travel times from a travel demand model are approximate and should only be used on a relative basis to compare alternatives/scenarios.

For corridor or facility level analysis travel time may be developed from operational models such as HERS and HCM methods.

Travel time can be used on a relative basis to evaluate emergency services by making assumptions about faster speeds for an emergency vehicle to travel a given O-D path under emergency conditions. Contributing factors include the ability of the emergency vehicle to move through congestion and traffic control devices and the provision of emergency pre-emption.

Average Delay

Performance measures

- Average delay per vehicle (sec/veh)

Example evaluation criteria

- Average delay for intersection
- Average delay for lane group

Delay is the additional vehicle travel time beyond the free-flow travel time for a given facility. Free-flow travel time is defined differently depending on the tools used. For reliability it could be based on empirically determined speeds, or posted speeds can be used in some HCM deterministic procedures. The analysis period is typically the peak 15-minute period of the design hour. In some instances free-flow conditions may be replaced by a designated acceptable target travel time or speed. Delay is typically calculated using HCM procedures, which also include Level of Service thresholds based on delay for many facility types.

Delay is also calculated by travel demand models and microsimulation methods. These delay outputs must be post-processed in order to compare with HCM delay values.

$$Delay = [Actual\ Travel\ Time - Threshold\ Travel\ Time] \times \frac{1\ hour}{60\ min}$$

Where

Delay = Delay for all vehicles the segment over the study period (hours)

Actual Travel time = (minutes)

For uninterrupted flow facilities, threshold travel time may be defined in different ways; free-flow travel time, travel time at posted speed limit, or a policy definition of congested speed (minutes). For interrupted flow, delay is computed by HCM methodologies and is the sum of segment delay and control delay. Control delay is delay occurring due to traffic control devices such as signalized intersections, roundabouts, or stop signs. Delay per vehicle does not account for the total number of vehicles being delayed which can result in underestimation of the impact, as compared to using vehicle hours of delay, which is generally a better performance measure.

Total Delay (Vehicle Hours of Delay)

Vehicle hours of delay is the delay per vehicle for a given segment, multiplied by the total number of vehicles in the study period, typically daily or annual. The delay per vehicle is based on the travel time minus the free-flow or threshold travel time. Unlike delay per vehicle, vehicle-hours of delay evaluates the total number of vehicles that are delayed.

Performance measures

- Daily vehicle hours of delay (veh-hr/day)
- Annual vehicle hours of delay (veh-hr/yr)

Example evaluation criteria

- Peak period vehicle hours of delay for segment
- Annual hours of delay per 1000 VMT

$$Vehicle\ Hours\ of\ Delay = \frac{[Average\ travel\ time - threshold\ travel\ time] \times traffic\ volume}{\frac{60min}{hour}}$$

Where

Delay = vehicle-hours of delay per given time period for the study segment

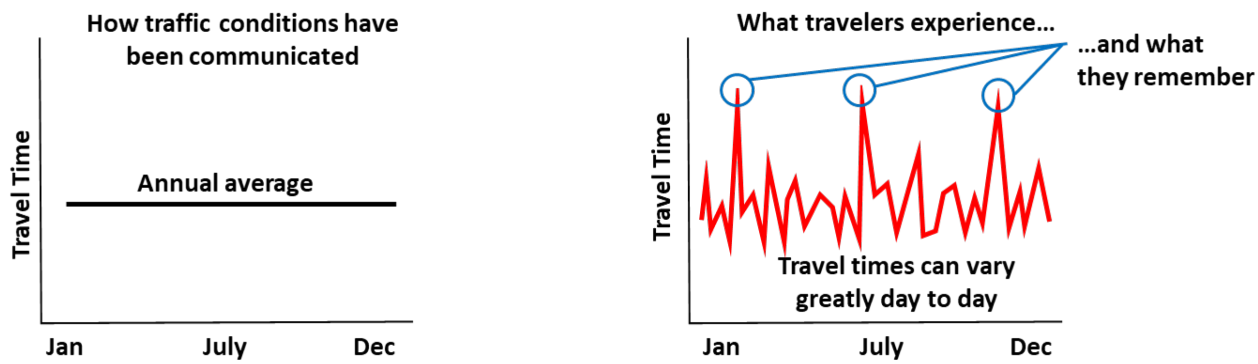
The threshold travel time is typically based on a threshold or target speed which could be free-flow speed, posted speed, or some other policy speed determined to be the minimum desirable operating speed. Several methods are available for estimating vehicle hours of delay, including the HCM, PPEAG, HERS-ST, and microsimulation. Facility VHD is obtained as the sum of the VHD of the individual segments. VHD is useful for evaluating an entire study area across multiple segments and is useful in sketch-level cost estimation.

In-vehicle person-hours of delay is VHD multiplied by the average vehicle occupancy.

9.3 Travel Time Reliability

Travel time reliability considers (1) the range of potential travel times roadway users may experience, (2) the consistency of travel times, and (3) the ability of a roadway to provide a desired travel time. Traditional measures of roadway operations, such as volume-to-capacity ratios or average travel speeds, reflect conditions during a design or analysis hour, such as the 30th-highest volume hour of the year. However, demand variation is just one of a number of factors that affect roadway operations. The effects of severe weather, incidents (e.g., stalls, debris), crashes, construction and maintenance activities, and special events (e.g., festivals, college football games) can all contribute to roadway operations that are different (and generally worse) than the average condition, as illustrated in Exhibit 9-4.

Exhibit 9-4 Difference Between Traditionally Reported and Actual Roadway Operations



Source: Derived from FHWA Travel Time Reliability website,
https://ops.fhwa.dot.gov/publications/tt_reliability/brochure/index.htm

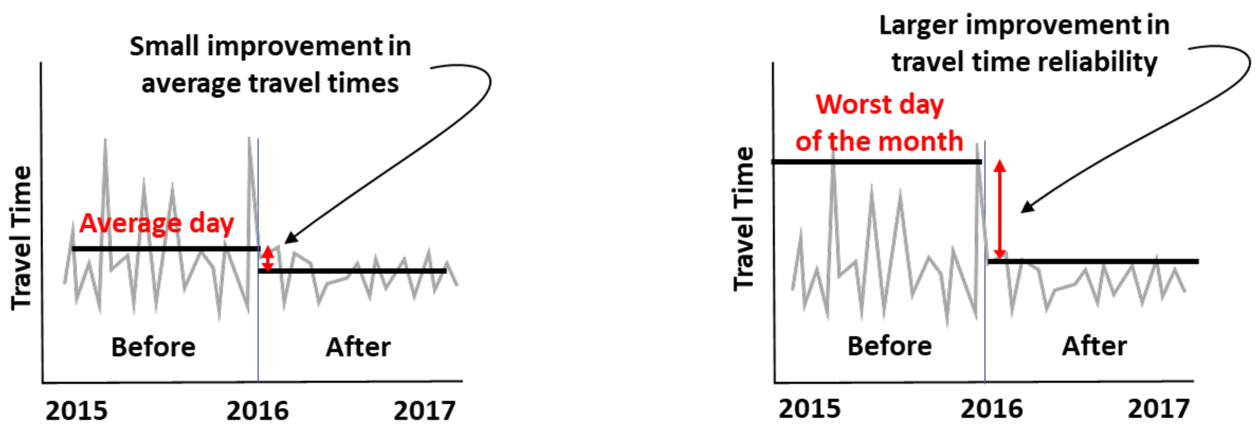
Measures of travel time reliability incorporate all of the factors influencing roadway capacity and free-flow speed to describe the variability of travel times along a particular roadway section or facility, or for a given trip. This variability affects roadway users in important ways, including:

- **Commuters,** who must plan extra time into their commute trip to avoid arriving late at work, even though they may not need that extra time most days;
- **Freight shippers,** who incur extra costs when shipments take longer to reach their destination, as well as their customers, whose supply chains may be disrupted by late deliveries; and
- **Transit operators,** who may need to add buses and drivers (at a significant added cost) to ensure frequent, reliable bus schedules that attract and retain customers.

Evaluating travel time reliability can also help roadway agencies better evaluate the effects of traffic operations strategies, such as ramp metering, dynamic part time shoulder use, and freeway service patrols. As illustrated in Exhibit 9-5, these strategies may produce relatively small effects on roadway capacity and average travel speed under normal conditions, but can have much greater effects on travel time reliability. For example, ramp metering may delay the onset of freeway breakdowns, or even reduce the number of days when freeway operations break down.

Traffic management centers and service patrols can help roadway agencies more quickly identify, respond to, and clear incidents, minimizing the effects of the incident both spatially and temporally.

Exhibit 9-5 Difference Between Traditionally Reported and Actual Roadway Operations



Source: Derived from FHWA Travel Time Reliability website, https://ops.fhwa.dot.gov/publications/tt_reliability/brochure/index.htm

The remainder of this section uses the term *reliability* as shorthand for travel time reliability. This section introduces methods of evaluating reliability, describes potential applications for a reliability analysis, and presents data sources and analysis tools currently available for evaluating and forecasting reliability. Methods for evaluating reliability on freeways and other uninterrupted-flow facilities are presented in APM Section 11.5.

9.3.1 Applications

Travel time reliability analysis has a number of potential applications, including:

- Performance reporting,
- Project planning, and
- Traffic management planning.

Performance Reporting

The federal MAP-21 and FAST Act transportation funding legislation requires states and metropolitan planning organizations (MPOs) to measure roadway performance. The FHWA's final rule implementing this legislation defines four reliability-related system performance measures as part of the set of National Performance Management Measures (*Federal Register*, Vol. 82, No. 11, January 18, 2017, 23 CFR Part 490). These performance measures can be evaluated using travel time data contained in the National Performance Management Research Data Set (NPMRDS) maintained by FHWA and made available to states and DOTs, or can be evaluated using an equivalent travel time dataset acceptable to FHWA.

Although performance management is outside the scope of this chapter, one potential analysis application is to forecast the contribution of project alternatives toward meeting roadway system performance targets. Furthermore, because the most difficult part of conducting a travel time reliability analysis is assembling a travel time dataset, the work that ODOT and MPOs invest in calculating FHWA's required performance measures can readily be extended to other applications, such as those described next.

Project Planning

Typical planning applications include problem identification, project evaluation, and project prioritization. The first of these requires (desirably) actual travel time data, while the latter two require both a reliability analysis model and actual travel time data for use in calibrating the model. Sources of travel time data are discussed in APM Section 9.3.5, while descriptions of currently available analysis models are provided in APM Section 9.3.6.

<u>Problem Identification</u>

In a typical problem identification application, reliability performance measures are evaluated for a defined roadway network (e.g., all freeways in a metropolitan area, all Interstate highways in Oregon). Roadway sections where the performance measure exceeds a threshold value, or alternatively, the worst *X*% of all roadway sections, are then flagged for further analysis to identify the cause(s) of the unreliability and, subsequently, potential projects or operational strategies to improve reliability. Any of the four primary travel time data sources available to ODOT (described later in Section 9.3.5) can be used to assemble a travel time dataset. Once this dataset has been created, the full range of reliability performance measures can be calculated from it. In addition, as described later in Section 9.3.6, planning-level estimates of some reliability performance measures can be developed without having a travel time dataset available. These planning methods require estimates of a roadway section's free-flow speed, average travel speed, and volume-to-capacity ratio.

> *ODOT has not yet set any targets or thresholds for reliability performance measures; doing so will require additional investigation and experience using these measures. The FHWA's National Performance Management Measures and the HCM's reliability rating (described below) are examples of measures with built-in threshold values for unreliable travel.*

<u>Project Evaluation</u>

Individual projects can be evaluated by comparing the values of one or more reliability performance measures with and without the project, following this general process:

1. Evaluate reliability performance for existing conditions using actual travel time data.
2. Calibrate a reliability-capable analysis tool, such as those described in Section 9.3.7, to replicate existing conditions.
3. Adjust the model parameters to reflect the project aspects that influence reliability.
4. Re-run the model to forecast future reliability performance with the project.

The additional effort required for the application is the effort to code the roadway facility in the analysis tool and to then calibrate the analysis output to reasonably match existing conditions. Once the existing facility is coded, it is relatively quick to forecast the reliability performance of a potential project in software. Exhibit 9-6 lists a variety of potential roadway capacity, modernization, and operations projects, along the factors influencing reliability that these projects affect.

Exhibit 9-6 Reliability Factors Influenced by Roadway Infrastructure Projects and Operations Strategies

Project Type	Reliability Factors Influenced
Add general-purpose (GP) lane	Capacity, the timing and amount of demand
Modernization	Free-flow speed, capacity
Ramp metering	Capacity, demand
Traffic management center	Incident detection and response times
Road patrols	Incident response and clearance times
Speed harmonization	Free-flow speed
Managed lanes	Capacity, demand in GP and managed lanes; benefits reflected in lowered person delay
Bus-on-shoulder	No bus volume in GP lanes; benefits reflected in lowered person delay
Part-time shoulder use	Capacity, possibly incident clearance times
Traveler information	Timing and location of demand
Traffic demand management	Timing and amount of demand

The effects of many operational strategies have not yet been well-quantified; therefore, it may be desirable to test a range of values for how a given strategy may affect reliability, to determine the sensitivity of the result to the assumptions used. Appendix B of the *IDAS User's Manual* (Cambridge Systematics and ITT Industries 2000), no longer supported but available in the Technical Reference Library section of HCM Volume 4 (http://hcmvolume4.org), provides default values for the effects of a number of operational strategies, although the information is somewhat dated at this point.

Project Prioritization

Once the effects of a given project or strategy have been forecasted, this information can be incorporated into a prioritization process, for example by considering both the magnitude of the reliability improvement and the number of vehicles or people that would benefit.

Traffic Management Planning

Reliability can also be incorporated into the development of various types of traffic management plans, such as:

- **Incident management planning—**forecasting the relative benefits of different strategies under consideration
- **Work zone planning—**identifying suitable work zone start and end times and number of lanes closed

- **Special event planning—**evaluating different event schedules, evaluating special traffic operations strategies for freeway off-ramps (e.g., temporary lane controls, signal timing adjustments, traffic control officers)

Considerations for Performing a Reliability Analysis

Evaluating reliability is most useful when a roadway facility operates, or is forecast to operate, over capacity on a regular basis, leading to highly variable travel times. In these cases, even if it is not financially or physically feasible to provide extra capacity through road widening, the effects of incremental improvements can still be evaluated in terms of reducing worst-case travel times, providing more consistent travel times, and/or reducing overall person delay.

For future-year forecasting, the additional effort required to conduct a reliability analysis using default values is minimal, once the facility has been coded and calibrated in an analysis tool that implements the HCM freeway facilities method. In other words, if a project would require a facility analysis using the core freeway facility methodology anyway, there is little reason not to go ahead and generate a set of reliability performance measures at the same time.

When forecasting the effects of project alternatives on a roadway's reliability, it is desirable to incorporate local reliability-related input values to the extent that the alternatives affect those inputs. For example, if an intersection improvement would be expected to affect the intersection's crash rate, using a local existing-conditions crash rate in lieu of a national default value is desirable. Similarly, when comparing and prioritizing potential projects on different roadways, it is desirable to account for differences in local traffic demand patterns. If the projects are located in different parts of the state with different climates, then using local weather data would also be desirable. Developing local input data for reliability methods is discussed in APM Chapter 11, Appendix 11F.

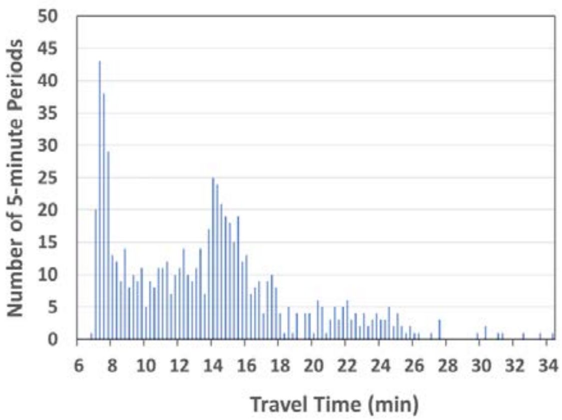
9.3.2 The Travel Time Distribution

A travel time distribution is a collection of travel time observations or forecasts for a defined roadway section (e.g., segment, facility) over a relatively long period of time (e.g., all nighttime time periods over the course of a year; all weekday time periods between 6:00 and 10:00 a.m.). Each observation represents the average travel time to traverse the road section during a defined time period, typically 5 or 15 minutes.

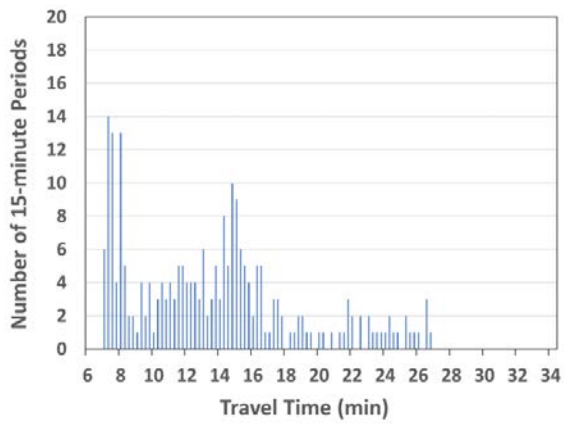
Once a travel time distribution has been created, nearly any reliability performance measure can be directly developed from it, except for certain measures where the measure's travel time reliability component is weighted by another variable (e.g., traffic volume, truck volume, person trips, regional population). The travel time distribution can be developed through direct observation of travel times (see Section 9.3.5) or by forecasting travel times using analysis tools (see Section 9.3.6).

Exhibit 9-7 illustrates travel time distributions developed for northbound I-5 in the Portland area between the Highway 217 and I-405 (south) interchanges, for all weekday a.m. peak (6:00 to 9:00 a.m.) time periods during February 2017. One distribution was developed using 5-minute data, while the other was developed using 15-minute data. The data were originally acquired for NCHRP Project 07-22 (*Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual*) from the PORTAL database maintained by Portland State University. Both of these graphs are frequency distributions: the *x*-axis represents travel times in 15-second bins, while the *y*-axis represents the number of travel time observations associated with each bin (i.e., the number of 5- or 15-minute time periods experiencing an average travel time within the 15-second range represented by the bin).

Exhibit 9-7 Examples of Travel Time Distributions Developed from 5- and 15-Minute Data



(a) 5-minute Data



(b) 15-minute Data

Both distributions show a peak on the left side, corresponding to free-flow or nearly free-flow conditions. Both also show a secondary peak in the left-center area of the distribution, corresponding to typical peak-period traffic congestion. Finally, both distributions have a long tail to the right, corresponding to conditions during severe weather (e.g., freezing rain) and/or when incidents occur (e.g., crashes, stalls, water on the roadway). The 15-minute distribution is more compact than the 5-minute distribution, as the extremely low speeds reported during individual 5-minute periods occur less often over a longer 15-minute period.

Fifteen-minute data are generally adequate for performing reliability analyses and have the following advantages over 5-minute data:

- One-third the amount of data must be manipulated
- Reduced quality-control effort, due to fewer time periods with missing data or outlier travel times
- Compatible with FHWA requirements for National Performance Management System reporting
- Compatible with HCM analysis output

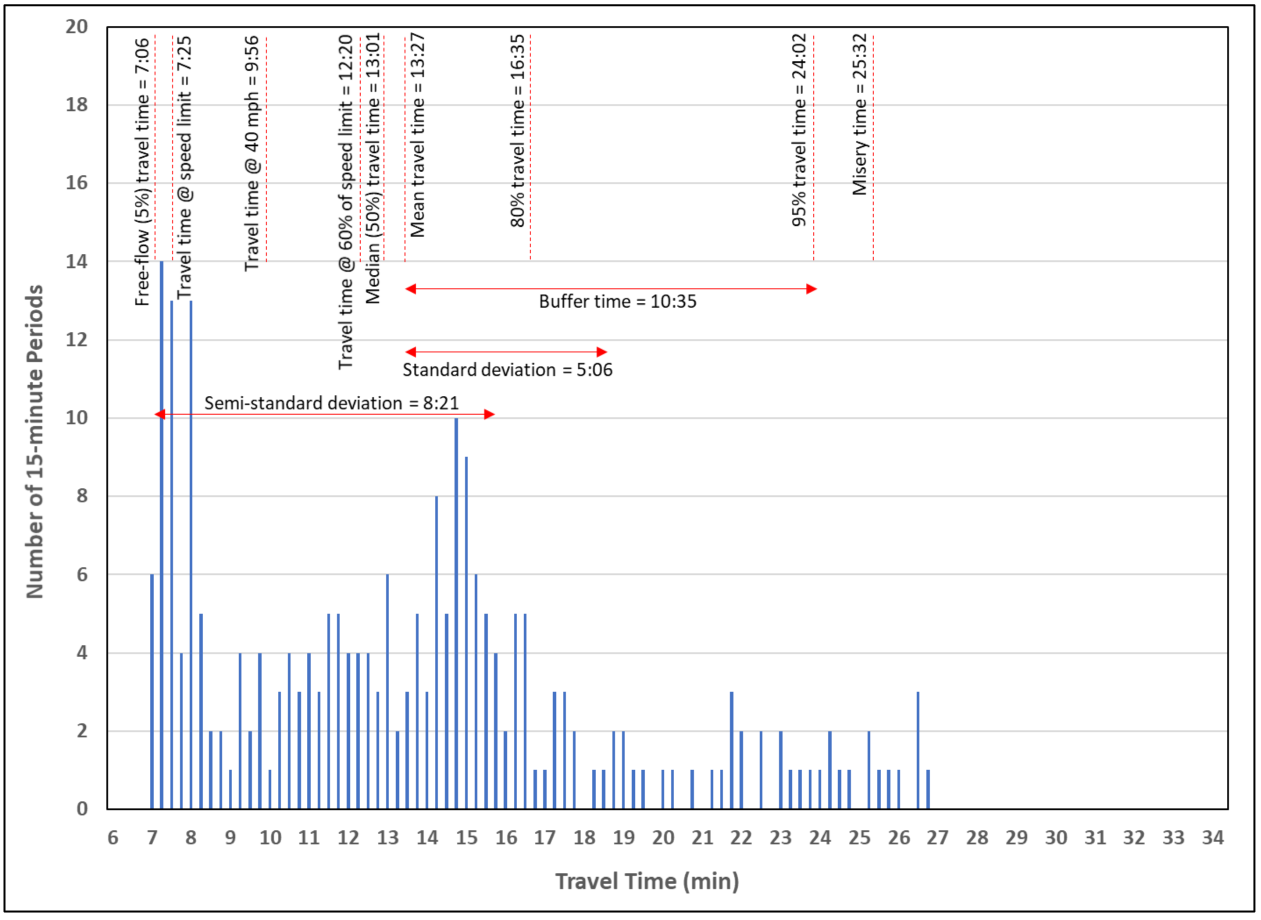
The greater detail provided by 5-minute data can be useful for diagnosing the causes of unreliability along a roadway. Diagnosing reliability problems is beyond the scope of this chapter, but is addressed in the HCM Planning Guide workshop material on performance management, available on HCM Volume 4, www.hcmvolume4.org.

9.3.3 Reliability Performance Measures

Identifying Key Travel Times from a Travel Time Distribution

The starting point for measuring reliability is identifying the travel times required to traverse a roadway section under specified conditions. These travel times can represent a fixed value (e.g., the travel time required to traverse the section at the posted speed limit), a percentile value (e.g., the 95th percentile highest travel time, a difference between two other travel times (e.g., the difference between the 50th and 95th percentile travel times), or statistical descriptors of the distribution such as the standard deviation. Exhibit 9-8 depicts common types of travel time values that can be obtained from the travel time distribution shown in Exhibit 9-7(b). These travel time values are described in the subsections that follow.

Exhibit 9-8 Examples of Travel Time Values Obtained from a Travel Time Distribution



Free-flow Travel Time

Free-flow travel time is the time required to travel a roadway section under low-volume conditions. It is preferably calculated as the average vehicle speed during low-volume periods (i.e., 500 pc/h/lane or less), with good weather and no work activity or incidents. Alternatively, when the study roadway is a freeway, multilane highway, or two-lane highway (i.e., uninterrupted flow without traffic signals), and the distribution clearly contains congestion-free periods, free-flow travel time can also be estimated as the 5th-percentile travel time, as shown in

Exhibit 9-8. Typically, free-flow travel time is not reported by itself, but is used instead to calculate other reliability measures, such as the *travel time index,* discussed later. *Highway Capacity Manual* (HCM) methods also calculate delay based on the difference between the actual travel time and the free-flow travel time.

Travel Time at the Speed Limit

The time required to travel a roadway section at the speed limit can be used as an alternative starting point for calculating delay, and as an input to reliability measures based on the percentage of time the roadway operates at or above a target percentage of the posted speed. This value can also be used as a check that the free-flow travel time estimate is accurate; the free-flow travel time will normally be slightly less (i.e., faster) than the travel time at the speed limit.

Target (Policy) Travel Time

This is the time required to travel a roadway section at a designated speed (e.g., free-flow speed, posted speed, speed producing maximum vehicle throughput, speed considered “congested”, speed at which greenhouse gas or particulate emissions significantly increase). It is typically not reported by itself, but is used in calculating other reliability measures, such as the policy travel time index and the percent of time or percent of travelers experiencing conditions where the target travel time is achieved.

> *ODOT uses the travel time at the posted speed limit rather than at the free-flow speed as the basis for calculating reliability performance measures for ODOT purposes. Different travel time targets may be required for FHWA reporting purposes.*

Average (Mean) Travel Time

This is the average time to travel a roadway section during a given time period. HCM segment and facility methods predict average 15-minute travel times for a particular set of conditions.

Percentile Travel Time

A percentile travel time is the travel time over a roadway section achievable a given percentage of the time. Percentile travel times may be reported by themselves, but are also often used in calculating other reliability measures. The most common percentile travel times are:

- **50^{th}-percentile (median) travel time—**this time typically will be slightly lower than the mean travel time, due to the influence of exceptionally long (outlier) travel times on the mean travel time;
- **80^{th}-percentile travel time**—the travel time achievable 80% of the time; research has shown that the 80^{th}-percentile time is more sensitive to roadway operational changes than the 95^{th}-percentile time, making it useful for evaluating project effects on reliability; and
- **95^{th}-percentile (planning) time—**for a segment or facility, the travel time achievable 95% of the time; for a trip, the travel time one would need to budget to ensure an on-time arrival 95% of the time (e.g., late to work approximately once a month when commuting).

Percentile Truck Travel Time

This measure, not depicted in Exhibit 9-8, is similar to *percentile travel time*, but is calculated from a distribution of truck travel times. These times may be different from overall vehicle travel times due to lower truck speed limits, severe roadway geometry (e.g., steep grades), presence of truck weigh stations, etc. FHWA's Freight Reliability performance reporting measure incorporates 50^{th}- and 95^{th}-percentile truck travel times.

Buffer Time

Buffer time is calculated as the 95^{th}-percentile travel time minus the average travel time. It represents the extra amount of time a traveler would need to budget for a trip to ensure an on-time arrival 95% of the time.

Misery Time

Misery time is the average of the highest 5% of travel time observations in the distribution, approximating a reasonable worst-case condition.

Standard Deviation of Travel Times

This is a statistical measure of how much travel times may vary from the average travel time. The larger the standard deviation, the greater the variability of travel times from day to day along the roadway.

Semi-Standard Deviation of Travel Times

This is a statistical measure of how much travel times may vary from the free-flow travel time. It is calculated from the set of travel time observations slower than the free-flow speed as follows:

$$SSD = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (FFTT - TT_i)^2}$$

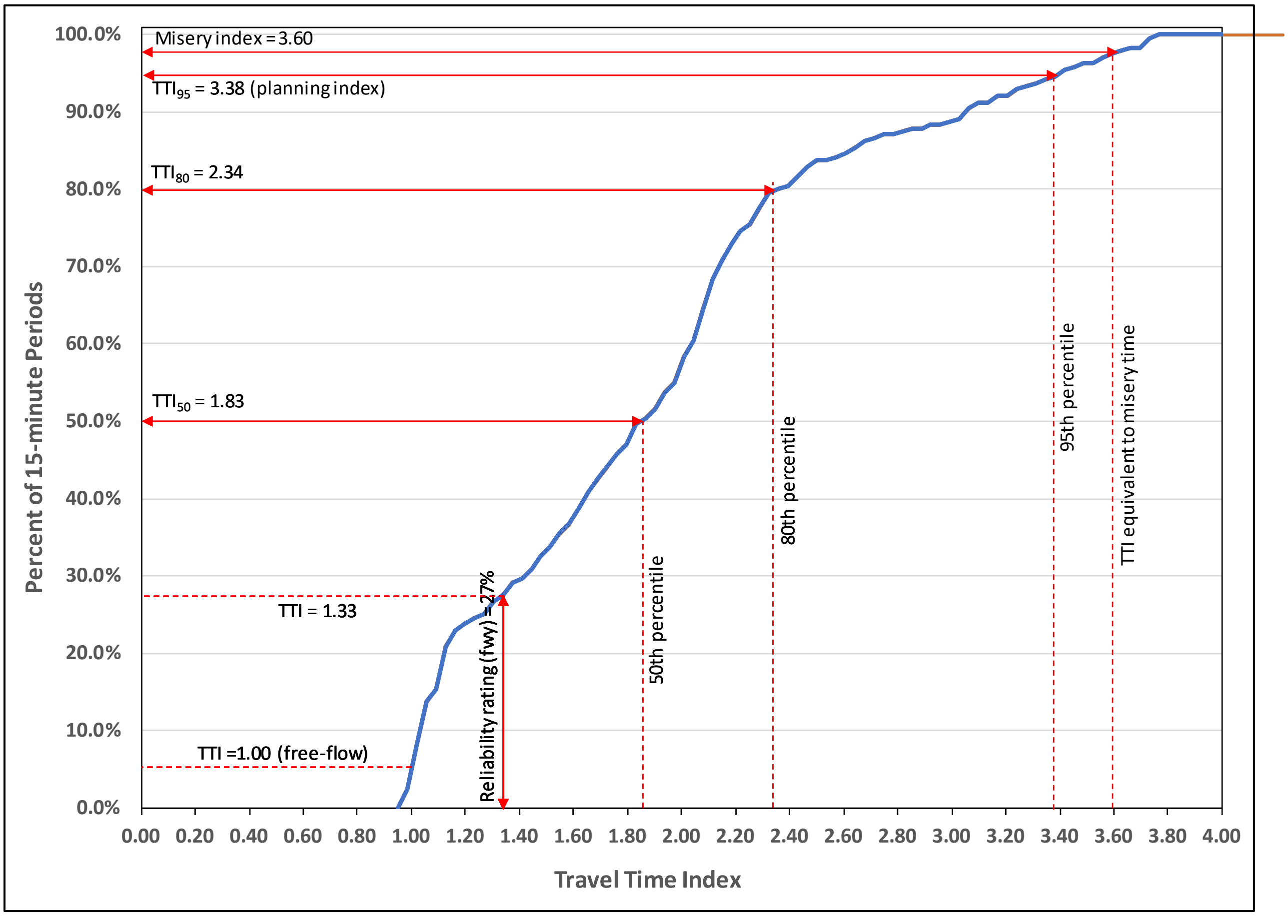
where

SSD = semi-standard deviation,
n = number of travel time observations slower than the free-flow speed,
$FFTT$ = free-flow travel time (s); and
TT_i = travel time observation i (s).

Ratio-Based Reliability Performance Measures

Travel time values are frequently used to create other measures of reliability. For example, one travel time value can be divided by another to create a ratio. When an observed travel time is divided by the free-flow travel time, the resulting ratio is known as a travel time index (TTI). The TTI indicates how much longer the observed travel time was, relative to the free-flow travel time. Exhibit 9-9 provides examples of ratio-based performance measures derived from the travel time distribution shown in Exhibit 9-7(b). The travel time distribution in Exhibit 9-9 is depicted as a cumulative distribution, with the *x*-axis containing TTI values and the *y*-axis showing the percentage of travel time observations occurring at or below a given TTI.

Exhibit 9-9 Examples of Ratio-Based Reliability Measures



Travel Time Index (TTI)

A TTI is calculated as a travel time divided by the free-flow travel time. A TTI value of 1.00 indicates travel at the free-flow speed, while a TTI value of 2.00 indicates travel that is twice as long, compared to free-flow conditions. Commonly reported TTIs include the 50th-percentile TTI (TTI_{50}, the 50th-percentile travel time divided by the free-flow travel time), the 80th-percentile TTI (TTI_{80}), the 95th-percentile TTI (TTI_{95}, also known as the planning index), and the mean (or average) TTI (TTI_{mean}, not pictured in Exhibit 9-9).

Policy Travel Time Index (TTI_P)

ODOT's policy TTI is calculated as a travel time divided by the travel time at the posted speed limit. A TTI_P value of 1.00 indicates travel at the posted speed, while a TTI_P value of 2.00 indicates travel that is twice as long as travel at the posted speed limit. Similar to the TTI, a variety of percentile values can be reported, including TTI_{P50} (the 50th-percentile travel time divided by the travel time at the posted speed limit), TTI_{P80}, and TTI_{P95}.

ODOT uses TTI_P instead of TTI for ODOT reporting purposes. Analysts should be aware that software packages may report TTI by default.

Level of Travel Time Reliability (LOTTR)

The LOTTR (not shown in Exhibit 9-9) is defined as the 80th-percentile travel time divided by the 50th-percentile travel time. The greater the LOTTR value, the longer travel times are on relatively poor (but not uncommon) travel days, compared to travel times on typical days. The FHWA incorporates LOTTR into its Interstate Travel Time Reliability measure, described below. The FHWA considers an LOTTR value less than 1.50 as indicating "reliable" conditions for reporting purposes.

Truck Travel Time Reliability (TTTR) Index

The TTTR Index (not shown in Exhibit 9-9) is defined as the 95th-percentile truck travel time divided by the 50th-percentile truck travel time. The FHWA uses this measure as the basis for the Freight Reliability component of its National Performance Management measures. For each roadway section, a TTTR Index is calculated for each of the following five reliability reporting periods:

1. All weekday a.m. peak periods (6 a.m. to 10 a.m.) during a calendar year
2. All weekday midday periods (10 a.m. to 4 p.m.) during a calendar year
3. All weekday p.m. peak periods (4 p.m. to 8 p.m.) during a calendar year
4. All weekend daytime periods (Saturday and Sunday, 6 a.m. to 8 p.m.) during a calendar year
5. All nighttime periods (Sunday through Saturday, 8 p.m. to 6 a.m.) during a calendar year

FHWA's Freight Reliability measure is calculated as the length-weighted average of the maximum of the five TTTR Index values for each Interstate roadway segment in the state.

Misery Index

The misery index indicates how much longer a reasonable-worst-case travel time is, relative to the free-flow travel time. It is computed as the misery time divided by the free-flow travel time.

Buffer Index

The buffer index (not shown in Exhibit 9-9) is the 95th-percentile travel time divided by the average travel time. Although this measure appears in the reliability literature, the HCM 6th Edition recommends against using it for tracking travel time trends "because it is linked to two factors that can change: average and 95th percentile travel times. If one factor changes more in relation to the other, counterintuitive results can appear." This same issue applies to other ratio-based measures incorporating the 50th-percentile or mean travel time, such as LOTTR and the TTTR Index.

Percentage-Based Reliability Measures

Percentage-based measures can indicate the percentage of time that a roadway operates at or better than a specified travel time or TTI. Percentage-based measures can also indicate the percent of people experiencing a specified condition (e.g., the percentage of people that were able to travel a roadway at 45 mph or faster).

On-time Percentage

The on-time percentage is the percentage of time periods when travel can occur at or above a specified target speed. *Failure rate* is a similar, but opposite, measure of the percentage of time periods when the target speed is not achieved. The target speed could be the posted speed, a percentage of the posted speed, the speed at capacity (i.e., the speed that maximizes throughput), or any other speed that makes sense for a particular analysis need. The *duration of congestion* (with "congestion" defined as travel slower than the target speed) is the study period length multiplied by the failure rate.

Reliability Rating

The HCM defines the reliability rating as the percentage of time periods where the TTI is no greater than a threshold value of 1.33 for freeways and 2.50 for urban streets. The threshold value represents the point at which facility operations typically break down; thus, the reliability rating approximates the percentage of time that a roadway operates below capacity.

Interstate Travel Time Reliability

The FHWA uses this measure, along with a companion National Highway System (NHS) Travel Time Reliability measure, as the reliability components of its System Performance measures for performance reporting. For each directional Interstate roadway section, a LOTTR is calculated for each of the following four reliability reporting periods:

1. All weekday a.m. peak periods (6 a.m. to 10 a.m.) during a calendar year
2. All weekday midday periods (10 a.m. to 4 p.m.) during a calendar year
3. All weekday p.m. peak periods (4 p.m. to 8 p.m.) during a calendar year
4. All weekend daytime periods (Saturday and Sunday, 6 a.m. to 8 p.m.) during a calendar year

Interstate Travel Time Reliability is then calculated as the length- and person trip–weighted percentage of Interstate roadway sections that have LOTTRs less than 1.50 during all four periods.

Delay-Based Reliability Measures

All measures of delay require defining a threshold where delay starts. Possible thresholds include:

- **Free-flow travel time—**the HCM uses free-flow travel time as the starting point for delay (i.e., any travel time slower than the free-flow travel time is considered to be delayed). This approach allows an apples-to-apples comparison of delay between roadways with different speed limits. However, this approach also allows delay to include travel times faster than the travel time at the posted speed, but less than the free-flow travel time, which may be inconsistent with both agency and traveler expectations.
- **Travel time at the posted speed—**any travel time slower than the travel time at the posted speed is considered to be delayed. This approach is probably the most consistent with traveler expectations for freeways and rural highways, but may not be particularly helpful in identifying or prioritizing problem areas, as higher-volume roadways with relatively high speeds will produce as much or more delay as lower-volume roadways

with lower speeds. ODOT uses the posted speed as the starting threshold for calculating delay.

- **Travel time at a target speed—**a minimum speed is specified as the target for satisfactory operations, and the portion of any travel time longer than the travel time at the target speed is considered to be delayed. For national performance reporting purposes, the FHWA defines a speed of 60% of the posted speed as the point where "excessive delay" begins.

Vehicle Hours of Delay

Delay is defined as the larger of (1) the actual travel time during a given time period minus the threshold travel time, or (2) zero. Vehicle hours of delay (VHD) is then:

$$VHD = \sum_i \frac{d_i \times V_i}{3{,}600}$$

where

VHD = vehicle hours of delay (veh-h),
d_i = delay during time period i (s),
V_i = volume during time period i (veh), and
3,600 = number of seconds in one hour (s/h).

Person Hours of Delay

Person hours of delay (PHD) is calculated similarly to VHD, but accounts for the vehicle occupancy of each mode using the roadway. Roadway operations strategies that reduce delay for higher-capacity modes (e.g., carpools, vanpools, transit) will show a greater percentage improvement in PHD than in VHD.

For roadways where all travel modes experience identical delays, PHD is calculated as:

$$PHD = \sum_i \frac{d_i \times V_i \times OF}{3{,}600}$$

where

PHD = person hours of delay (person-h),
OF = average vehicle occupancy (persons/veh), and
all other variables are as defined previously.

For roadways where different travel modes experience different delays (e.g., facilities with managed lanes or bus-on-shoulder operations), PHD is calculated as:

$$PHD = \sum_i \frac{\sum_m d_{i,m} \times V_{i,m} \times OF_m}{3{,}600}$$

where

$d_{i,m}$ = delay of mode *m* during time period *i*,
$V_{i,m}$ = volume of mode *m* during time period *i*,
OF_m = average vehicle occupancy of mode *m* (persons/veh), and
all other variables are as defined previously.

The Oregon default for average vehicle occupancy of private vehicles is 1.4 persons per vehicle, based on the 2009–2011 Oregon Household Activity Survey.

Recommended Reliability Performance Measures

The following performance measures provide a good starting point for evaluating reliability:

- **80th-percentile TTI_P—**this measure reports the upper limit of commonly occurring (e.g., once a week) travel conditions. This measure is more sensitive to roadway operations strategies such as ramp metering and road patrols than is the 95th-percentile TTI_P. This is because the longest travel times in the travel time distribution tend to be associated with major crashes and/or severe weather, both of which are less affected by operations strategies.
- **95th-percentile TTI_P—**this measure reports uncommonly poor, but not worst-case, conditions that roadway users would account for as part of their trip planning (e.g., a once-a-month occurrence on a commute trip). The planning time associated with this measure can be valued in terms of commuter time that could have been spent at home, extra freight shipment time that must be planned for, and longer transit trips that must be scheduled (possibly requiring additional vehicles and drivers). However, the use of an index rather than a pure travel time allows facilities with different lengths and different free-flow speeds to be compared on an apples-to-apples basis.

Additional reliability measures, such as TTI_{P50}, person delay, and reliability rating, can also be evaluated, depending on the specific needs of the analysis. For example, the FHWA national performance management measures would be forecasted if the purpose of the analysis was to investigate the potential contribution of different project alternatives toward meeting state or metropolitan system performance targets.

9.3.4 Reliability Reporting Periods

Reliability quantifies the uncertainty in travel times that a traveler might experience from day to day, across different times of day, over a period of time from a few months up to a year. Key reliability time periods are defined below.

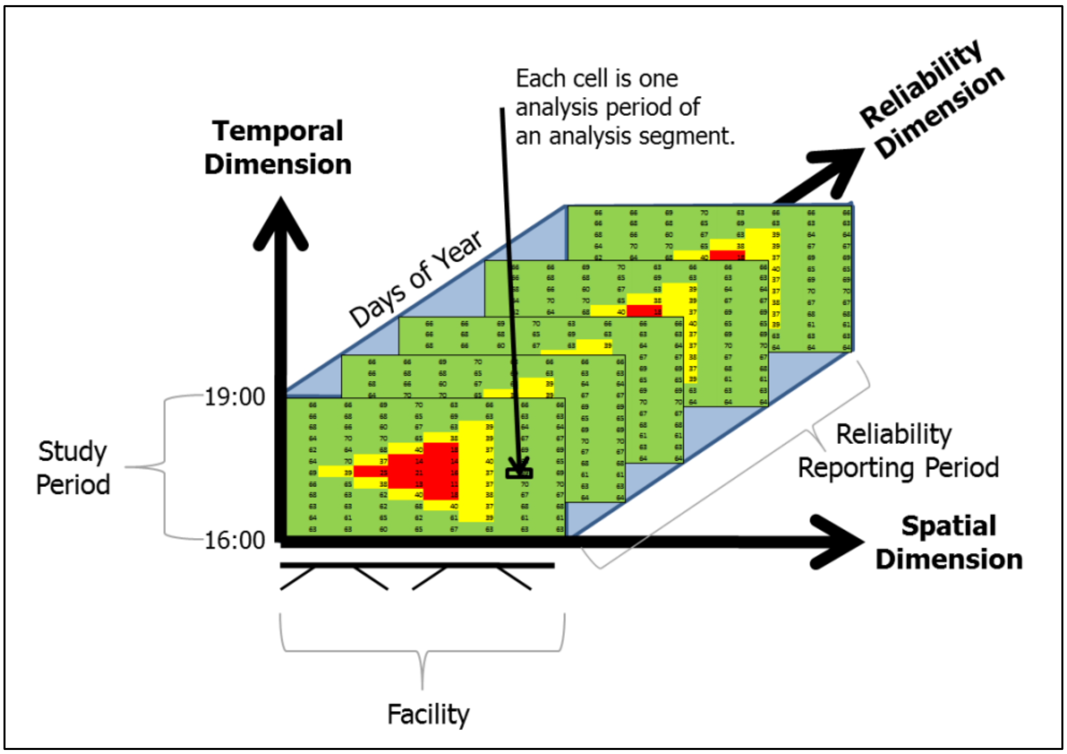
1. The *reliability analysis period* is the smallest time unit for which the analysis procedure is applied. In the case of freeway and urban street facility analysis, the analysis period is

typically 15 min, although it can be of greater or lesser duration, at the discretion of the analyst. Alternative tools may define different analysis period lengths.

2. The *study period* is the sum of the consecutive analysis periods for which the facility analysis procedure is applied (e.g., an a.m., midday, or p.m. peak period). The study period is defined by the analyst for each specific application. A study period of multiple hours is preferred, as a single congested peak hour could be very reliable but with poor travel times, while the shoulder hours could be much less reliable but with better travel times.
3. The *reliability reporting period* is the period over which reliability is to be estimated (e.g., the 250 non-holiday weekdays in a year). In essence, the reliability reporting period specifies the days within the year for which the reliability analysis is to be performed.

Exhibit 9-10 depicts these different time periods. The *y*-axis in the figure represents the time dimension on a given day, with each vertical cell representing one analysis period and the combination of all the individual analysis periods representing the length of the study period. The *x*-axis in the figure represents the facility's spatial dimension, with each horizontal cell representing one roadway section or HCM segment and the combination of all the individual sections or segments forming the length of the study facility.

Exhibit 9-10 Reliability Analysis Time−Space Domain



Source: HCM 6th Edition, Exhibit 11-1

The combination of the study period length and the facility length should be large enough to contain all analysis periods and segments where demand exceeds capacity (for example, the red and yellow areas shown in Exhibit 9-10). If congestion spills out of the study facility length and/or the study period length, the analysis results will understate the facility's operational performance and reliability.

The study period length should be carefully scoped when the analysis is not intended to cover a full day. Including numerous time periods that rarely, if ever, experience congestion will tend to lower reliability performance measure values, which in turn may mask problems on the facility or fail to show much benefit from operational treatments.

The *z*-axis in Exhibit 9-10 introduces the reliability dimension. The facility analysis is repeated for each day of the year represented in the reliability reporting period, each of which experiences, to a greater or lesser degree, a different set of conditions. The travel times required to travel the facility during each analysis period of each day in the reliability reporting period are then aggregated into a travel time distribution.

The days to include in the reliability reporting period will depend on the type of facility being analyzed and the purpose of the analysis. For example, a study of the reliability of a major commute route within a metropolitan area might define a reliability reporting period of all non-holiday weekdays during the year. In contrast, a study of the reliability of a highway leading from the Willamette Valley to the Oregon Coast might define a reliability reporting period consisting of Saturdays, Sundays, and holidays during the summer.

9.3.5 Travel Time Data Sources

Travel time data are most commonly obtained from online databases of probe-vehicle speed data. The data are generated from commercial vehicle fleets and users of cell phone–based navigation systems, with the probe devices recording speeds that are reported to a central database. Through post-processing, speeds are attributed to a reporting segment called a TMC (Traffic Message Channel). On freeways, a TMC is typically defined from ramp gore to ramp gore. The recorded speed data are then converted to travel times across the TMC and stored in online archival databases.

ODOT has access to four primary sources of travel time data:

- Iteris Performance Measurement System (iPeMS),
- HERE Traffic Analytics,
- National Performance Management Research Data Set (NPMRDS), and
- Portland, Oregon Regional Transportation Archive Listing (PORTAL).

ODOT is subscribed to the Iteris Performance Measurement System (iPeMS), which is a web-based database for speed, travel time, and other data for Oregon roadways. The iPeMS system collects, filters, processes, aggregates and visualizes speed and travel time data derived from the probe data collected by HERE. Access to the Oregon iPeMS database is available at https://odot.iteris-pems.com; TPAU approval is required for access by non-ODOT staff. ODOT also has access to raw HERE travel time data, which can be downloaded for automobiles only, trucks only, or both automobiles and trucks. APM Section 18.2.3 provides more information about iPeMS and HERE data.

The NPMRDS dataset is provided by FHWA to MPOs and state DOTs without charge. The NPMRDS dataset is accessed through the RITIS (Regional Integrated Transportation Information System) online data portal (www.ritis.org) and can be downloaded for a region or corridor of interest using the *Massive Data Downloader*. The download is in the form of a CSV (comma separated value) file containing 5-minute sample summary data for the selected TMCs over the time period of interest. The NPMRDS further contains separate records for passenger cars and freight traffic. Additional information on the NPRMDS is available in APM Section 18.2.3 and through FHWA at http://www.ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/vpds/npmrdsfaqs.htm. The NPMRDS dataset only covers the National Highway System.

PORTAL is the data archive for the Portland metropolitan region, which has been a collaborative effort between ODOT and Portland State University's Intelligent Transportation Systems (ITS) Laboratory, with additional data supplied by WSDOT, PBOT, TriMet, and Clark County, among others. PORTAL archives speed and count data from approximately 500 inductive loop detectors in the Portland metropolitan region dating back to July 2004. PORTAL has a web-based interface that provides performance metrics designed to assist practitioners and researchers. More information on the PORTAL system can be found on the Portland State University website at http://portal.its.pdx.edu and in APM Section 18.2.4.

In addition to these online databases, travel time reliability data can be obtained from other devices that allow longitudinal measurements of speeds and travel times. For example, Bluetooth or Wi-Fi readers can be used to monitor individual vehicle travel times over extended periods of time. These raw travel time data can be aggregated to derive a travel time reliability distribution.

9.3.6 Methods for Forecasting Reliability

Differences Between Reporting Existing Reliability and Forecasting Future Reliability

Existing travel time reliability is normally determined from actual travel time data from one of the sources described in the previous section. Reliability performance measures derived from these travel time distributions thus *report* the actual conditions that occurred during the period of time covered by the data.

In the absence of travel time data, it is also possible to *forecast* various measures of travel time reliability using one of the analytical methods described in this section. Analytical methods will tend to predict somewhat worse reliability performance than would typically occur in any given time period (e.g., 1 year). This is because analytical methods account for very rare events (e.g., unusually severe weather) that have very large travel time impacts. These events may not occur in any given reporting year, and therefore are not necessarily used in planning decisions, but nevertheless are the events that "travelers remember," as was highlighted in Exhibit 9-4.

When reporting travel time reliability, the majority of the effort involves manipulating the travel time data and (potentially) matching the data to information from other databases, such as traffic volumes. Some travel time data sources provide an analysis tool that performs this data manipulation and analysis, while other sources provide only the raw travel time data, which analysts must manipulate themselves.

When performing a detailed forecast of travel time reliability, the majority of the effort involves coding and calibrating the facility in the analysis tool. The analysis tool then takes care of creating various reliability scenarios, generating the travel time database, and reporting reliability performance.

Categories of Reliability Forecasting Methods

Reliability forecasting methods can be divided into three main groups: (1) sketch-planning methods developed through the SHRP 2 program, (2) the detailed HCM freeway and urban streets reliability methods, and (3) Oregon's implementation of HERS-ST, which incorporates elements of the other two methods.

Although in theory microsimulation can also be used to estimate reliability, it is not currently practical to do so in a way that addresses the multitude of potential scenarios the way the HCM or HERS-ST can, because of the time required to develop, code, run, and analyze the many different reliability scenarios that would be required to accurately estimate reliability. For example, the HCM method allows random variation in the location, severity, and time of day of incidents; severity and start time of severe weather events; and so on. HCM-implementing software can evaluate hundreds of scenarios for a facility covering up to 24 hours a day for an entire year in a matter of seconds. In contrast, FHWA's pilot tests of evaluating reliability using simulation used only 8 or 9 scenarios (combinations of demand and incidents) in two cities to represent relatively common peak-period conditions, and without consideration of weather effects. Such an approach may be sufficient to demonstrate some benefit from traffic management strategies, but not to forecast future reliability.

SHRP 2 Sketch-Planning Methods

The SHRP 2 program developed planning-level methods for estimating selected travel time reliability measures. Unlike reporting methods and the detailed HCM method, these methods do not assemble a travel time distribution. Instead, they use equations to estimate what a roadway's reliability performance would be, using a minimum number of inputs: free-flow speed, volume-to-capacity ratio, and number of lanes. These equations were developed from research into the reliability performance of a variety of roadways in different parts of the U.S.

SHRP 2 Project C11 Method

This method estimates delay due to recurring and nonrecurring congestion using just two inputs: volume-to-capacity ratio and facility type (freeway, arterial, collector, ramp, local road). Facility type is used as a proxy for free-flow speed. Predictive equations are then used to estimate common reliability performance measures. The method is capable of forecasting reliability impacts and costs for individual projects, and can be applied to any roadway type.

Roadway segments are the basic unit of analysis. Segments can be of any length, but it is recommended that they not be so long that their characteristics change dramatically along their length. Reasonable segment lengths would be:

- Freeways: between interchanges;
- Signalized highways: between signals; and
- Rural highways (non-freeways): 2–5 miles.

The method first estimates the mean TTI. The mean TTI then becomes an input to other predictive equations for estimating:

- Recurring delay (hours)
- Incident delay (hours)
- Total delay (hours)
- 95^{th}-percentile TTI
- 80^{th}-percentile TTI
- 50^{th}-percentile TTI
- Percent of trips < 45 mph
- Percent of trips < 30 mph
- Cost of recurring delay
- Cost of unreliability
- Total congestion cost

The reported reliability values apply to a single weekday analysis hour (the hour used in calculating the volume-to-capacity ratio supplied to the method) over the course of a year. The results from multiple calculations can be combined and weighted to produce reliability values for longer weekday study periods.

HCM Planning Guide Method

The *Planning and Preliminary Engineering Applications Guide (PPEAG) to the HCM* presents a method for estimating freeway reliability. It is based on the SHRP 2 C11 method, but allows specific roadway characteristics to be used to estimate the free-flow speed, and it simplifies the calculation of incident-related delay. Because the HCM does not currently provide reliability methods for multilane and two-lane highways, the PPEAG limits itself to forecasting freeway reliability. However, because the underlying SHRP 2 C11 equations can be applied to any facility type, the PPEAG method can also be applied to any facility type.

Required inputs to the method are:

- **Free-flow speed:** Estimated using Appendix 11A of APM Chapter 11.
- **Analysis-hour speed:** Estimated using the screening method in APM Section 11.3.5 (for freeways and multilane highways) or from the appropriate PPEAG method for other roadway types.
- **Number of directional lanes:** 2 to 4 (if less than 2 lanes, use 2; if more than 4 lanes, use 4)
- **Volume-to-capacity ratio:** Estimated using APM Chapter 11 screening-level methods.

The method predicts the same performance measures described above for the SHRP 2 C11 method. The reliability reporting period is also the same: one or more weekday analysis hours over an entire year.

<u>Oregon HERS-ST Method</u>

The HERS-ST software does not directly calculate reliability performance measures. However, ODOT has used HERS-ST to generate the inputs required for the SHRP 2 C-11 mean TTI equation, namely: free-flow speed, recurring delay rate, and incident delay rate. Once the mean TTI has been determined, all of the other performance measures described above for the SHRP 2 C11 method can also be predicted.

ODOT has also demonstrated the application of HERS-ST for developing reliability scenarios combining a variety of severe weather, incident, and work zone events. Appropriate demand and capacity, and free-flow speed adjustments for a given scenario are made in HERS-ST before re-running the model. The individual scenario results are then weighted by their probability of occurrence when calculating an overall performance measure result. Because HERS-ST results apply to individual roadway sections, they may not fully reflect the delay associated with queue spillback from one section into other upstream sections.

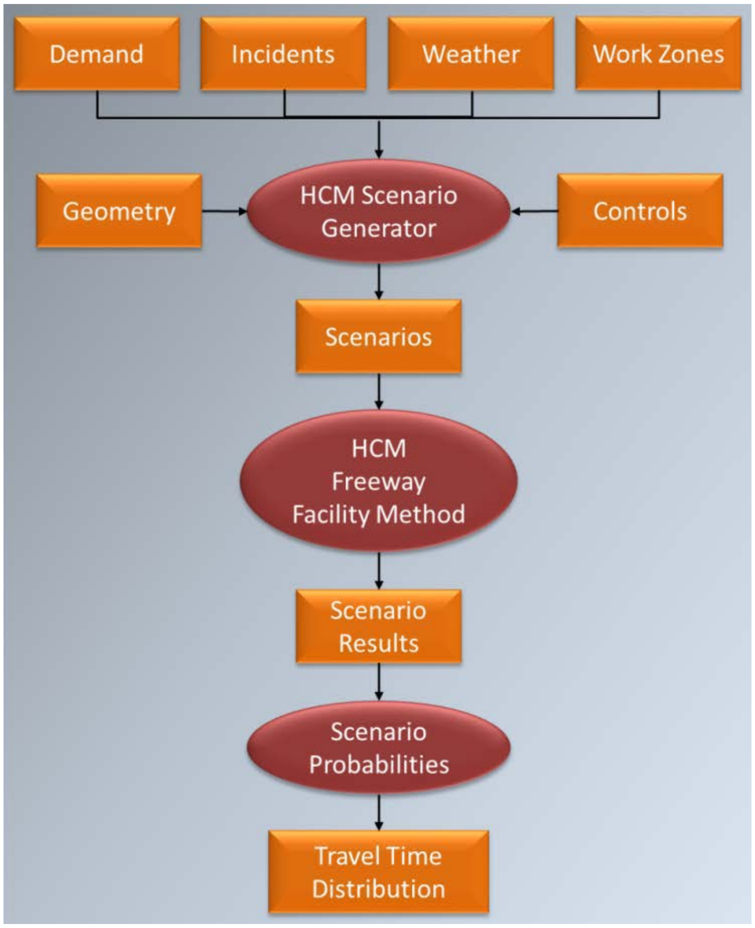
The HERS-ST method can be applied to any roadway type, for a reliability reporting period consisting of the weekday peak hour over an entire year.

HCM Freeway Reliability Method

The HCM freeway reliability analysis methods are described in Chapters 11 and 25 of the HCM 6th Edition. A reliability analysis starts by coding a base scenario for the facility, consisting of all the data normally entered for an HCM operations analysis using the HCM's core freeway facility methodology (described in APM Chapter 11). The HCM reliability method then creates a series of scenarios representing various combinations of demand, severe weather, incidents, work zones, and special events, along with a probability of occurrence for each scenario. Each reliability scenario adjusts the base scenario's demand, capacity, and/or free-flow speed in some way, resulting in a different set of performance results (e.g., travel times) for each scenario. Finally, a travel-time distribution is generated based on the weighted probability of each scenario occurring.

Exhibit 9-11 illustrates the method's flow from scenario generation through outputting a distribution of travel times.

Exhibit 9-11. Flowchart of the HCM Freeway Reliability Analysis Method



The HCM provides national default values for incident probabilities and durations by incident severity, and demand variations by day of week and month of year. It also provides probabilities of 10 categories severe weather by month for the 101 largest metropolitan areas around the U.S. (Portland is the only Oregon metropolitan area represented in the HCM's default weather data) The analyst can choose to replace any or all of the default values with local values, and can also optionally provide data regarding long-term work zones and special events that significantly alter traffic demand and/or traffic operations strategies.

The analyst must supply the following: the day of year represented by the base scenario's traffic volume (so that each scenario's demand adjustment can be applied relative to that day), the study period length coded in the base scenario (e.g., 6–10 a.m.), and the days to include in the reliability reporting period.

The HCM does not provide much guidance on time periods to include in a reliability analysis, other than to state that reliability reporting periods spanning one year are most common and that the study period length should be long enough to allow queues to dissipate by the end of the study period. The choice of days to include in the reliability reporting period will depend in part on the use of the facility—a commuter route might analyze weekdays, while a recreational route might analyze weekends. For national reporting purposes, the FHWA defines four study periods for the Interstate Travel Time Reliability measure (weekday a.m. peak, weekday midday, weekday p.m. peak, weekend daytime) and five for the Truck Travel Time Reliability Index (the four listed above, plus nighttime periods).

Method Comparison

The reliability forecasting methods discussed above vary in the following respects:

- Input data requirements
- Ability to be adapted to local conditions
- Number of scenarios used to model travel time variability
- Facility types covered
- Types of events modeled that influence reliability

All of the methods have tools available to assist in applying the method. Exhibit 9-12 compares the capabilities of the different methods.

Exhibit 9-12. Comparison of Travel Time Reliability Analysis Methods

	SHRP 2 C11	PPEAG	Oregon HERS-ST	Simulation	HCM
Scenarios used	1	1	1/100s*	≤10	100s to 1,000s
Scenario generation process	NA	NA	NA/Manual*	Manual	Automated
Facility types covered	All	Freeways (extendable to all)	All	All	Freeways, urban streets
Required inputs	FFS, v/c, # lanes	FFS, v/c, # lanes, average speed	Obtained from HPMS	All required by simulation tool	All required for freeway facility analysis
Local adjustment capability	No	Values used to generate input data	Scenario generation	Inputs, scenario generation	Inputs, scenario generation
Reliability measures output	Most common	Most common	Most common/ any*	Any	Any
Creates travel time distribution	No	No	No/Yes*	Creates sub-distributions for each scenario	Yes
Reliability reporting period	Single analysis hour for all weekdays in one year**	1–24 analysis hours for all weekdays in one year	Weekday peak hour for one year	Typically, 1+ analysis hours for all weekdays in one year	Any, up to one year
Models weather impacts	No	No	No/Yes*	No	Yes
Models incident impacts	Indirectly	Indirectly	Indirectly/Yes*	If included as scenarios	Yes
Models work zone impacts	No	No	No/Yes*	If included as scenarios	Yes

Notes: NA = not applicable, FFS = free-flow speed, v/c = volume-to-capacity ratio.
*In a batch-processing application using multiple scenarios.
**Calculations can be repeated for additional weekday analysis hours if desired.

The number of scenarios used by a method affects (1) the variety of conditions analyzed that can impact roadway operations and (2) the ability to incorporate local conditions into the analysis.

Sketch-planning methods produce a single estimate of reliability, based on regression equations developed from nationally representative travel time datasets. These methods do not account for the effects of local weather conditions, differences in incident frequencies or detection and clearance times, or other local factors. The base SHRP 2 C11 method is also insensitive to differences in roadway characteristics that would affect the roadway's FFS or capacity and thus the reliability result. In contrast, the PPEAG method can account for these differences.

As the number of reliability scenarios increases, the greater the analyst's ability to account for the various factors affecting reliability, but also the greater the effort required—either up front or for each analysis—to develop the scenarios. Even the method using the greatest number of scenarios, the HCM, places constraints on the types of situations considered in order to reduce analysis complexity. (For example, the HCM limits consideration of weather to weather events that decrease capacity by at least 4%.) Similarly, FHWA's pilot tests of simulation used just 8 or 9 scenarios, because of the effort required to develop individual simulation models for each scenario, along with determining the probability of each scenario. Although multiple simulation runs can be performed for each scenario and the results compiled into a travel time distribution, what the analyst ends up with is a single mean travel time for each scenario, each with its own distribution around the scenario mean. This collection of sub-distributions does not match the full spectrum of travel time observations that would be measured in the field.

HERS-ST offers the option of producing a single estimate of travel time reliability, using the SHRP 2 C11 equations, or using its batch-processing feature to generate a true travel time distribution from a series of reliability scenarios. For example, an analysis of a section of US 97 between Sunriver and LaPine incorporated 8 demand levels and 89 capacity-reducing events (combinations of severe weather, incidents, and/or work zones) were included, for a total of 712 reliability scenarios. Capacity reductions for each event were derived from the default values given in the HCM 6th Edition. The probabilities of each demand level and capacity-reducing event occurring were also determined and used to weight the scenario's resulting travel time.

The scenario-generation approach taken by the HCM is different than that used by simulation or HERS-ST. Rather than rely on the analyst to define scenarios and decide which ones to include or exclude, the analyst provides information on demand variability by day of week and month of year, the probabilities of various types of severe weather by month, and probabilities of various types of incidents. This information can come from the HCM's national defaults, from a one-time effort to create local or regional defaults, or from location-specific data. The analyst also specifies the number of replications of each day–month demand combination; the HCM suggests 4 for a reliability reporting period spanning one year, corresponding to each day being modeled approximately four times in a given month. If a shorter reliability reporting period is used, the HCM recommends increasing the number of replications so the total number of scenarios (replications × months × days) generated is at least 240. The HCM method then randomly assigns weather and incident events (or non-events) to each scenario, along with random start times for each event and (for incidents) random locations. This process recognizes, for example, that heavy rain that occurs in the middle of the night will have a different impact on roadway operations than a downpour in the middle of rush hour. The process also allows rarer events to be considered as part of the overall analysis, without needing to arbitrarily decide which events to include or exclude—it may not snow in Portland every winter, but ODOT prepares for the possibility of snow anyway because of its severe impacts on roadway operations.

9.3.7 Tools for Forecasting Reliability

This section introduces software tools available to predict travel time reliability for freeways and uninterrupted flow facilities. Three of the tools implement the HCM 6th Edition method, while the other three implement versions of the SHRP 2 C11 planning-level equations.

FREEVAL

FREEVAL is the official computational engine of the HCM 6th Edition freeway facilities and freeway reliability chapters. It can be downloaded for free on the HCM Volume 4 website (http://www.HCMVolume4.org). A FREEVAL reliability analysis builds on a calibrated and completed freeway facilities analysis (described in APM Chapter 11), and then adds the reliability dimension. FREEVAL applies user input or national defaults for incident distributions and day-of-week and month-of-year demand variability, along with historical weather data and user-specified work zone inputs. FREEVAL further integrates the HCM 6th Edition method on Active Travel and Demand Management (ATDM) with methods for evaluating impacts of traffic system management and operations strategies such as ramp metering, part-time shoulder use, and managed lanes.

Highway Capacity Software (HCS)

HCS is commercial software for the Windows operating system that is developed, distributed, and supported by the McTrans Center at the University of Florida. Similar to the process used by FREEVAL, HCS builds from a calibrated freeway facilities analysis by adding the HCM's reliability method and (optionally) the HCM's ATDM method. Users can apply the national default values for demand variability, weather patterns, and incidents, or supply their own local values. Users supply facility-specific work zone information.

TTR/ATDM

TTR/ATDM is a reliability analysis tool based on the HCM 6th Edition developed by SwashWare and the University of Florida Research Foundation. The tool is an extension of the HCM Calc tool for freeway facility analysis (described in APM Section 11.2.5). TTR/ATDM implements the HCM reliability and ATDM methodologies, similar to what was described for FREEVAL above. The tool can be downloaded for free through the Microsoft store.

PPEAG

The PPEAG's freeway computational engine, available on HCM Volume 4, can be used to estimate a freeway segment or facility's volume-to-capacity ratio and average speed, given a user-provided free-flow speed and number of directional lanes. These results can then be used with the PPEAG reliability equations (either manually or by setting up a simple spreadsheet) to estimate any of the reliability performance measures supported by the SHRP 2 C11 method.

HERS-ST

HERS-ST can estimate any roadway section's free-flow speed directly, while HERS-ST output can be used to develop the section's recurring delay rate and incident delay rate. These results can then be used to estimate (either manually or by setting up a simple spreadsheet) any of the reliability performance measures supported by the SHRP 2 C11 method. ODOT has demonstrated the ability to model weather and work zone scenarios with HERS-ST to develop estimates of travel time reliability for non-freeway roadways and corridors containing a mix of facility types. See APM Section 7.3 for more information about HERS-ST.

SHRP 2 C11 Spreadsheet Tool

The C11 reliability spreadsheet tool is an Excel spreadsheet that calculates all of the reliability measures supported by the C11 method. The spreadsheet also calculates the value of reliability improvements based on the following assumptions, which can be changed within the spreadsheet:

1. For passenger travel, it assumes a $19.86/hour average value of time multiplied by a 0.8 reliability ratio (i.e., hours of delay are multiplied by 0.8 when calculating the value of changes in reliability),
2. For commercial travel, it assumes a $36.05/hour average value of time multiplied by a 1.1 reliability ratio.

For ODOT projects, values of travel time should be consistent with the most recent version of "The Value of Travel Time: Estimates of the Hourly Value of Time for Vehicles in Oregon," available at https://www.oregon.gov/ODOT/Data/Pages/Economic-Reports.aspx. APM Section 10.6.8 provides more information about economic analysis.

Tool Comparison

Exhibit 9-13 summarizes key features of software tools that implement the HCM's reliability method. Exhibit 9-14 provides similar information for tools that are based on the planning-level SHRP 2 C11 reliability equations.

Exhibit 9-13 HCM-Implementing Tool Comparison

Overview	HCS	FREEVAL	TTR/ATDM
		Tool Overview	
Source	McTrans	hcmvolume4.org	University of Florida
Cost	License Fee	Free	Free
Operating system	Windows	Windows/Mac	Windows 10
Installation required	Yes	No (need Java)	Yes
Widespread use	High	Medium	Low
		Staff and Support Needs	
Learning curve	Medium	Medium	Medium
Complexity	Medium	Medium	Medium
Training available	●	◐	○
User guide	●	●	●
Instructional videos	○	●	○
Technical support	●	◐	◐
		User Experience	
Copy/paste	○	◐	◐
Load/save	●	●	●
Import/export	●	●	○
Auto-fill	◐	●	○
		Specialized Features	
Charts/visualizations (reliability)	●	●	●
Charts/visualizations (ATDM)	○	●	○
Automated report generation	●	○	◐
Built-in scenario comparison	○	●	○
Calibration (adjustment factors)	●	●	●
Built-in weather adjustments	●	●	◐
Incident scenario analysis	●	◐	◐
Work zone scenario analysis	●	◐	◐
ATDM method	○	●	○
Ramp metering	○	◐	○

Notes: ● = fully supported, ◐ = partially supported, ○ = not supported.

Exhibit 9-14 SHRP 2 C11 Implementing Tool Comparison

Overview	SHRP 2 C11 Reliability Tool	PPEAG Tool	ODOT HERS-ST
Tool Overview			
Source	tpics.us/tools	hcmvolume4.org	ODOT
Cost	Free	Free	Free
Operating system	Windows/Mac	Windows/Mac	Windows
Installation required	No (need Excel)	No (need Excel)	Yes
Widespread use	Low	Low	Low
Data source for reliability inputs	Defaults or another tool	Calculated	Imported from HPMS
Reliability calculations	Automated	Manual or separate spreadsheet	Manual or separate spreadsheet
Staff and Support Needs			
Learning curve	Low	Low	Medium
Complexity	Low	Medium	Medium
Training available	○	○	
User guide	●	◐	
Instructional videos	○	○	○
Technical support	○	○	
Specialized Features			
Congestion cost estimates	●	○	○

Notes: ● = fully supported, ◐ = partially supported, ○ = not supported.

9.4 Level of Service (LOS)

Level of Service (LOS) and quality of service (QOS) are indicators that cannot be measured directly in the field and are a letter grade based on an underlying performance measure value.

9.4.1 Motorized Vehicle Level of Service

Motorized vehicle Level of Service is a commonly used performance measure computed following Highway Capacity Manual methodologies. It is a rating of the level of mobility (typically as a function of delay or density) of a facility, segment, intersection or approach on a scale of A-F. LOS A, B, and C indicate conditions where traffic moves without significant delays over periods of peak hour travel demand. LOS D and E are progressively worse operating conditions. LOS F represents conditions where average vehicle delay has become excessive and demand has exceeded capacity. This condition is typically evident in long queues and delays.

Performance measure

- Level of Service letter grade A-F

Example evaluation criteria

- Unsignalized intersection approach LOS compared to local jurisdiction LOS standard
- Freeway segment LOS

Motorized vehicle LOS is determined for the following facility types using the following quantitative measures (all specified in the HCM):

- Freeway segments, facilities, merge, diverge and weaving segments
  - Density – specifically, average number of vehicles per lane mile (pc/mi/ln). LOS F where demand exceeds the capacity of the segment.
- Two-lane highway segments
  - Density – specifically, follower density (veh/mi/ln) of directional segment (refer to APM v2 Addendum 11B).
- Intersections – signalized, unsignalized, by approach, lane group or intersection as a whole
  - Delay – specifically, average delay (sec/veh) (by approach, lane group or intersection as a whole).
- Urban Streets – segment or facility
  - Speed (mi/hr)

Many local jurisdictions have adopted LOS as a performance measure for facilities under their jurisdiction and have adopted LOS thresholds as standards. The analyst needs to evaluate LOS and compare to the adopted local standards when analyzing those facilities. Some jurisdictions have dual performance thresholds for both v/c ratio and LOS in general or by facility type. Reporting LOS for state highways is optional, although reporting LOS on state highways is best practice to obtain a complete picture of operations versus reporting v/c ratio alone. Facilities with low v/c ratio could still have high delays. Refer to the HCM 6th Edition for specific calculations and LOS thresholds for each facility type.

- Basic freeway segments – Chapter 12
- Two lane highways – Chapter 15
- Signalized intersections – Chapter 19
- Unsignalized intersections – Chapters 20-22

9.4.2 Multimodal Level of Service (MMLOS)

MMLOS is a Quality of Service (QOS) measure. QOS measures the perceived level of comfort by the user, which could be a pedestrian, a bicyclist, or a transit rider. While vehicular LOS includes factors for the effects of pedestrians on vehicular mobility, pedestrian/bicycle/transit LOS reflects the point of view of the pedestrian, bicyclist or transit rider. The methodology creates a score which is equated to a Level of Service rating. Refer to APM Chapter 14 for procedures.

A qualitative multimodal methodology is also available as an alternative to the full HCM MMLOS method. It uses the same data categories as the HCM method, but is a qualitative assessment which can be used where HCM methods do not apply or where data are not available.

Pedestrian and Bicycle Level of Service

The APM methodologies to calculate Pedestrian and Bicycle LOS are simplified versions of the HCM Pedestrian and Bicycle LOS. Refer to APM Chapter 14 for detailed procedures.

The APM Pedestrian and Bicycle LOS are based on user perception scores of the level of comfort a user would experience on a given facility. Performance ratings for pedestrians are provided for roadways with and without sidewalks and multi-use paths. PLOS evaluates sidewalk width, posted speed, number of through traffic lanes and vehicle traffic volume. Additional performance measure methods are under development for midblock crossings, signalized intersections and unsignalized intersections.

Performance measure

- Level of Service letter grade A-F
- Qualitative MMLOS (good/fair/poor)

Example evaluation criteria

- Pedestrian facility LOS
- Bicycle facility LOS
- Multi-use facility LOS
- Signalized intersection ped or bike LOS (TBD)
- Unsignalized intersection LOS (TBD)

Performance ratings for bicyclists are provided for roadways with and without bike facilities, separated paths, and intersections. Bike facilities evaluated include shared lanes, bike lanes, buffered bike lanes, protected bikeways, and bike signals. Bicycle LOS evaluates the number of through travel lanes, presence of bike lane or paved shoulder, posted speed and number of unsignalized intersections and driveways.

Pedestrian and bicycle LOS can be used to evaluate walk and bike networks such as for a TSP to identify needs, as well as to evaluate alternatives affecting sidewalk width, bike facility type, volumes, lanes, posted speeds, and driveways.

Capacity-based HCM pedestrian performance measures evaluate the utilization of available space. These measures are generally not used in Oregon due to the lack of pedestrian density.

Transit Level of Service

> *The APM methodology to calculate Transit LOS is a streamlined version of the HCM Transit LOS. Refer to APM Chapter 14 for detailed procedures.*

The APM Transit LOS is based on user perception scores of transit service on a segment. Transit LOS relates to passengers' perception of walking to a transit stop on the street, waiting for the transit vehicle, and riding on the transit vehicle. The method applies to buses, street cars, and other types of transit vehicles operating with mixed traffic on the roadway. The measure does not apply to transit operating in separated right-of-way. Transit LOS is a function of transit schedule speed, transit frequency and pedestrian LOS. Transit LOS can be used to evaluate alternatives that affect route speed, frequency, and pedestrian LOS.

<u>Performance measures</u>

- Segment Transit LOS letter grade A-F

<u>Example evaluation criteria</u>

- Transit LOS letter grades by segments along a transit route

Transit LOS is not an indicator of ridership, which may involve several contributing factors such as land use density, transit frequency, reliability, wait time, walk time, transfers, fares, bus stop amenities, and parking availability and cost.

9.4.3 Truck Level of Service Index

Truck Level of Service is a recently developed measure of the quality of service provided by a facility for truck hauling of freight, as perceived by shippers and carriers. Truck LOS was developed as part of NCFRP Report 31 [(3)]. It is a composite index based on the percentage of ideal truck operating conditions achieved by a facility. Ideal conditions are defined as a facility usable by trucks with legal size and weight loads, with no at-grade railroad crossings, that provide reliable truck travel at truck free-flow speeds, at low costs (i.e., no tolls). Truck Level of Service (TLOS) Index is the ratio of the actual utility to the utility for ideal conditions (free-flow speed and no tolls). Methodology details are found in the HCM Planning & Preliminary Engineering Applications Guide (PPEAG) to the HCM 6th Edition.

<u>Performance measure</u>

- Truck LOS on highway facility

<u>Example evaluation criteria</u>

- Relative difference in facility Truck LOS letter grade

Truck Level of Service Index

$$\%TLOS = \frac{1}{(1 + 0.10e^{-200U(x)})}$$

Where

%TLOS = truck LOS index as a percentage of ideal conditions (decimal),

U(x) = truck utility function, and

e = exponential function.

Truck Utility Function

$$U(x) = A \times (POTA - 1) + B \times (TTTI - 1) + C \times (Toll\ mi) + D \times (TFI - 1)$$

Where

U(x) = utility of facility for truck shipments,

A = weighting parameter for reliability, sensitive to shipping distance = 5 / ASL, for Oregon = 0.025

B = weighting parameter for shipment time, sensitive to free-flow speed = -0.32 / FFS, FFS = free-flow speed,

C = weighting parameter for shipment cost = -0.01,

D = weighting parameter for the facility's truck friendliness = 0.03,

POTA = probability of on-time arrival = 1 if the mixed flow (autos and trucks) travel time index is ≤1.33 (freeways and highways) or ≤3.33 (urban streets),

TTTI = truck travel time index for the study period, the ratio of truck free-flow speed to actual truck speed,

Toll/mi = truck toll rate (dollars per mile), a truck volume–weighted average for all truck types, and

TFI = truck friendliness index, where 1.00 = no constraints or obstacles to legal truck load and vehicle usage of facility and 0.00 = no trucks can use the facility.

The truck utility function is based on several parameters including the probability of on-time arrival for the truck shipment, the travel time index for trucks, tolls paid by trucks, and the truck friendliness index.

The Truck LOS index is focused on the heavier long-haul trucks that travel intercity (externals in travel demand models), rather than commercial vehicles that are typically lighter (can be pickups and panel vans) and are used to distribute goods within an urban area. The response of these two groups can be significantly different. For example, long haul trucks have more potential to be shifted to rail. Commercial vehicles are often fleets of vehicles whose owner can be influenced by local policies, e.g., availability of CNG fueling stations or EV charging infrastructure, or simply levels of local congestion.

Level of Service thresholds are based on %TLOS and class of freight facility. Three classes of freight facility are defined. Truck LOS can be used to evaluate facilities of a uniform freight class, and alternatives that affect travel time reliability, weight or dimensional restrictions, or tolls.

For oversize/overweight vehicles, the ORS 366.215 approval process must be followed if considering alternatives that reduce roadway widths on certain freight routes. For more information refer to [ORS 366.215 Implementation Guidance](#)

(4)

9.5 Accessibility

Accessibility is a point, zonal, district or area-wide measure of the availability of a range of opportunities such as employment, schools, shopping, medical, recreation, etc, by mode. Accessibility measures typically include travel distance, travel time, population and employment data. Other factors such as level of congestion, parking availability/cost, tolls, and safety may be included directly or indirectly. A destination may be physically close by but if obstructed by a freeway or river or other restrictions, it may not be very accessible. No single accessibility measure captures all possible factors. Accessibility is typically an area or point measure and requires a network. However, the Place Types land use methodology (see Chapter 7) produces a rough accessibility measure of jobs within five miles on a straight line basis. As such, it does not require a network, and is a rough measure of centrality of the location.

Accessibility is important for the bike, walk and transit modes as a travel option and equity measure. The automobile mode generally has good accessibility in most areas. Bike, walk and transit often do not have good accessibility due to incomplete networks or services. Maximizing travel options is more likely to focus on those modes.

9.5.1 Accessibility for Motorized Vehicles, Pedestrians and Bicyclists

JEMnR (MPO-level) travel demand models include accessibility utilities. Accessibility can be analyzed by mode, trip purpose or time of day. OSUM (non-MPO) models can produce accessibility information by trip purpose only. Zone to zone demand and travel time is available from trip matrices, which can also be mapped. Accessibility from travel demand models identifies the potential level of interaction between zones. Applications include evaluating a zone's potential for development. Thematic or heat maps may be produced identifying the most likely locations for development or transit for example. Accessibility can also be used for equity analysis, based on household income, race, limited English proficiency and other socio-economic factors.

Performance measure

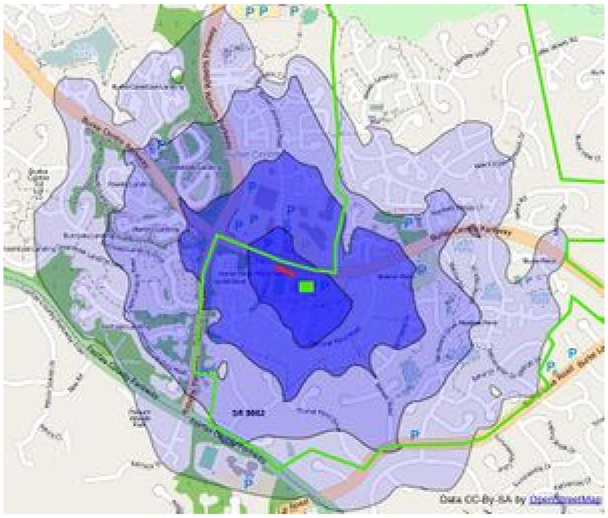
- Area that can be accessed within a given travel time, by mode of travel

Example evaluation criteria

- Percent change in regional accessibility (to jobs or shopping) in each TAZ stratified by walk, transit and auto (JEMnR models)
- Number of essential destinations within a buffer travel time such as 20-minutes by any mode. Essential destinations are defined as hospitals, grocery stores, parks, schools, major retail, etc.
- Number of essential destinations or daily needs accessible within a certain travel time by all modes to low-income, people of color, or limited English proficiency households
- Number of households within a market area such as a travel time radius of a commercial or shopping zone, by mode. Percent of jobs or households within walking or bicycling distance or travel time.
- Number of jobs within certain travel times for all modes accessible to low income, people of color, and limited English proficiency households
- Percent of households/population located with ¼ mile of a bikeway or transit stop.
- Percent of population with X minutes between work and home
- Percent of population located within a mixed use or transit oriented development
- An index of the ratio of direct travel distances to actual travel distances. Well connected streets result in a high index. Less connected streets with large blocks result in a lower index.

The area or distance that can be accessed within a given travel time can be shown using isochrone lines or by shading of TAZs to reflect numbers or percent changes in accessibility variables. Isochrones are contour lines which show the spatial extent of the area or network that can be accessed from a given location given different travel time thresholds, such as 5 minutes, 10 minutes or 20 minutes. Travel demand models and GIS tools are typically used to produce isochrones lines for motorized vehicle travel, whereas GIS tools are typically used to measure bicycle and pedestrian accessibility. It is critical to measure actual network travel time and distance, not “as the crow flies”, especially for pedestrian and bicycle accessibility. Pedestrian network analysis which codes each side of a street separately and which includes improved crossings is superior to street centerline-based analysis, since lack of improved street crossings can be a major barrier to safe pedestrian travel. See Exhibit 9-15 below for an example of an isochrone map.

Exhibit 9-15 Isochrones



Source: Wikipedia

Accessibility may be used to evaluate land use scenarios/changes, such as those that increase density and diversity, for example Transit Oriented Developments (TODs). Travel demand models can evaluate these changes as well as RSPM for use in scenario planning (refer to Chapter 7).

> *When evaluating pedestrian or bicycle accessibility, any unofficial routes such as trails or unofficial crossing locations should be noted as they indicate actual usage and shortcuts which have potential to be improved as official walkways, bikeways or crossings. For example, Strava's heat map can be used to find non-traditional bicycle pathways.*

Accessibility for pedestrians and bikes may be used to compare alternatives or scenarios that affect densification of land use or walk or bike connections, such as completing paths, adding new paths, or improving crossings. Accessibility does not typically address facility adequacy. Accessibility is one of many contributing factors that affect the amount of walking or biking trips. Other contributing factors include level of comfort, completeness, and safety on the facilities being traveled. Pedestrian and bike travel typically works best for travel distances under one mile for pedestrians or five miles for bicyclists. Refer to Chapter 14 for multimodal considerations.

Bike, Walk and Transit Scores

Bike score, walk score, and transit score are types of accessibility ratings, by mode of travel, of locations based on the number and variety of nearby activities/amenities and the travel time to access them. For example, for a given point (origin), what is the area that can be accessed within a walking distance of ¼ mile, and what amenities are available within that area. A highly accessible location for a given mode of travel would be one with a variety of amenities available within a reasonable travel time for that mode. A less accessible area would be one that has limited or no amenities located within a reasonable travel time. These types of scores typically do not take into account the comfort, safety or quality of the travel facilities or services being used. The scoring method can be expressed in terms of accessibility to important destinations such as schools, shopping areas, parks, medical facilities and transit facilities.

Such scoring methods may be identified using GIS, or using commercial products such as Walk Score, an application used in evaluating the accessibility of candidate residential properties. Commercial tools may create a combined measure or index that accounts for factors other than just travel time. For example, a more complete bicycle score might include consideration of topography. Other non-travel time based measures or indices may be included as well, such as crime statistics, or hilliness of an area. Scoring methods may be aggregated into a rating for an entire city, region or neighborhood, or can be localized to individual properties by address. Heat maps may be created to visualize variations in accessibility throughout an area.

Accessibility scores may be useful in a sketch planning level analysis, but may be limited to existing conditions only. Network-based accessibility measures can show improvements in accessibility when certain links or crossings are added to the network. Commercial software is generally used, as GIS analysis effort can be high, although there may be a cost associated with obtaining the data. Commercial software may not share the complete algorithm or data sources the score is based upon. ODOT has no proposed way to calculate these scores.

9.5.2 Accessibility for Transit Riders

Accessibility for transit riders measures the proximity of transit service available. It is used to evaluate areas with or considering transit service. It may be used to evaluate or prioritize alternatives that affect land use proximity via transit, such as land use densification, adding new routes, or increasing frequency or span of service.

Performance measures

- Proximity of households/population to transit stops
- Proximity of households/population to destinations via transit

Example evaluation criteria

- Percent of population living within "X" miles or "Y" minutes that can access fixed route transit.
- Percent of jobs or households within ¼ mile walking distance of transit stops.
- Percent of households in environmental justice (EJ) communities within half mile of high capacity transit or quarter mile of frequent bus service. As used in equity analysis, such as for environmental projects or TSPs, for identification of affected populations such as minorities, income level, age, etc.

Some general rules of thumb for transit corridors to be potentially viable are those with the following characteristics

- Walk distance to/from transit stops less than or equal to ¼ mile, or ½ mile to high capacity transit stations
- Residential density greater than 4-5 dwelling units/acre for local bus service (1 bus per hour)
- No more than one transfer required

MPO travel demand models include transit lines, fares, and transit stops, and assign transit trips to routes. These models can calculate accessibility to potential transit stops. Small urban area models do not model transit. Metro's model is more sophisticated with the ability to estimate transit loadings at stops. Activity-based models promise a more dis-aggregate treatment of transit, which is likely to be significantly more detailed and accurate, leading to more flexibility in terms of transit performance measures.

Other transit accessibility measures include the use of isochrones to visualize how far a transit rider can get from a given starting point within 15, 30, 45, and 60 minutes of travel using only transit and walking. These illustrate the extent of activities that can be reached from points on transit at different times. For information on other transit tools see the ODOT Public Transit tools webpage.

Transit accessibility is just one of many contributing factors that may affect potential transit ridership. Other factors include land use density, transit coverage, span, frequency, total travel time, pedestrian level of stress/comfort, transit stop amenities, safety, transit fare, transfers required, accommodation of bicycles, and bus occupancy.

Accessibility to frequent transit service may address equity by measuring the ease of access to transit by specific groups such as lower income households. It may be part of the environmental analysis process or may also be performed in some planning studies. GIS databases are able to provide distance information. Factors include travel distance, level of comfort, safety, traveler demographics, and frequency of service.

9.6 Safety

Safety performance measures evaluate historical or are predictors of future potential of crashes on networks and facilities, including crash type and severity. Crashes or crash rates can be displayed using GIS or other mapping tools to identify hot spots for network screening. Detailed procedures are provided in APM Chapter 4.

9.6.1 Crash Rate

Crash rates are a commonly used safety performance measure for a wide range of planning and project analysis studies as part of identifying safety improvement needs. Crash rates are easy to calculate and require little data. Crashes should be based on the official data published by

ODOT's Crash Analysis and Reporting (CAR) Unit. AADTs are required for segments and Total Entering Volume (TEV) AADTs are required for intersections. See APM Chapters 3 and 4 for detailed information.

<u>Performance measure</u>

- Intersection crashes per million entering vehicles (MEV)
- Segment crashes per million vehicle-miles traveled (MVMT)
- Fatal and Severe Injury crashes
- Fatal and Severe Injury crash rates per 100 million vehicle miles traveled

<u>Example evaluation criteria</u>

- Segment crash rate exceeding average for similar facility type from Oregon State Highway Crash Rate Tables
- Intersection crash rate exceeding published 90th percentile intersection crash rate for similar intersection type (APM Exhibit 4-1)
- Crash rate exceeding site critical crash rate based on reference population of similar sites
- Pedestrian and/or bicycle involved fatal and severe injury crashes

The critical crash rate is a Highway Safety Manual screening method of the likelihood that a site crash rate is high as compared to a reference population of similar site types. Critical crash rate is used to flag and prioritize high crash rate locations for further study. See APM Section 4.3.4.

Requirements/Limitations

- Segment crash rates can be heavily influenced by the length of the segment.
- Lack of crashes inhibits usefulness of the measure for evaluating pedestrian and bicycle safety
- Does not account for regression to the mean (RTM) (See Chapter 4 for definition)
- Critical rate requires sufficient number of sites in reference population

Crash Severity – indicator of need and priority based on the level of injury of crashes, the highest priority being the reduction of fatal and severe injury crashes.

- Does not account for regression to the mean
- Requires AADT volumes
- Does not address future safety performance or alternatives

9.6.2 Safety Priority Index System (SPIS)

SPIS is a screening method developed by ODOT that computes a safety index based on crash and volume history on segments. The SPIS index is a function of crash frequency, rate and severity. The Traffic-Roadway Section (TRS) calculates SPIS numbers annually for the entire public road system in Oregon. SPIS sites exceeding threshold scores based on the top 5% or 10% percentile are identified and flagged for further safety investigation. SPIS site maps are available including on TransGIS. The annual SPIS index is calculated based on the last 3 years of reported crash history. Refer to APM Chapter 4 for more detailed information.

Example evaluation criteria

- Top five and ten percent SPIS locations

9.6.3 Change in Crash Frequency Using Crash Modification Factors (CMFs) or Crash Reduction Factors (CRFs)

CMFs and CRFs are typically used to evaluate candidate countermeasures for safety solutions. The initial source for countermeasures should be the ODOT-approved set of proven countermeasures and associated CRFs that are used for the All Roads Transportation Safety (ARTS) Program. See Chapter 4 for detailed procedures.

Example performance measures

- Reduction or percent change in average annual crash frequency, type and/or severity by application of a countermeasure, as calculated using CRFs or CMFs

9.6.4 Excess Proportions of Specific Crash Types

Excess proportion of specific crash types is an HSM screening measure of the extent that a crash type (for example, fatal and serious injury, or pedestrian or bicycle crashes) at a site is overrepresented. Crash sites can be intersections or segments. This is based on a comparison to a reference population of similar sites. Excess proportion of crash types is an indicator of the likelihood that a site will benefit from a countermeasure targeted at the collision type under consideration.

Example evaluation criteria

- Target crash type or severity exceeding threshold

Excess proportion is most frequently used in large area studies such as TSPs. Refer to APM Section 4.3.5 for procedures.

The method does not account for regression to the mean. It does not require traffic volumes. It does not address future safety performance or alternatives. It requires a sufficient number of sites of a similar type in the reference population.

9.6.5 Expected or Predicted Crash Frequency

Expected or predicted crash frequency is an HSM predictive measure of long term crash frequency. This is based on Safety Performance Functions (SPFs) which factor in geometrics, traffic control, volumes, and operations. The Empirical Bayes adjustment methodology factors in crash history. These methods account for RTM error, the natural fluctuation of crashes that occurs over the long-term independent of the contributing factors the analysis is trying to review. Predictive crash analysis is used most often for detailed analysis of alternatives. Expected or predicted fatal and serious injury crash frequency should always be reported as a sub-category of total crashes. Crash frequency can also be reported out by crash type such as bicycle or pedestrian crashes if sufficient data exist. The method predicts reported crashes. There are no established thresholds but the measure may be used for ranking/prioritizing and for comparing alternatives. Refer to APM Section 4.4 Predictive Methods for details.

<u>Example performance measures</u>

- Excess Expected Crash Frequency using Empirical Bayes (EB) Adjustments
- Net Change in Expected or Predicted Crashes

Excess Expected Crash Frequency using Empirical Bayes (EB) Adjustments is used to evaluate the extent that a site's long term average crash frequency differs from that of similar sites.

Excess Expected Average Crash Frequency = Expected Crashes – Predicted Crashes

The EB method requires a calibrated prediction model (with overdispersion factor) and substantial similarity between the analysis period for which crash data exist and the analysis period being used for the predictive method.

Net Change in Expected or Predicted Crashes is used to compare alternatives. Expected crashes can be determined for alternatives if the only changes are in AADT. Otherwise, net change in predicted crashes is used.

Net Change in Expected/Predicted Average Crash Frequency = Expected/Predicted No Build Crash Frequency - Expected/Predicted No Build Crash Frequency

9.6.6 Conflicts

Conflicts are a measure of the number and type of locations where paths cross, merge or diverge at an intersection or junction. Bicycle, pedestrian and transit vehicle conflicts can also be reported as multimodal safety performance measures. Conflict points are potential crash locations, although the number of conflict points does not indicate the probability of occurrence of a crash, which would depend on additional factors such as traffic volumes. Paths that cross are considered major conflicts while those that merge or diverge are considered minor conflicts. Refer to APM Section 4.8.3 for procedures.

<u>Example performance measures</u>

- Number of conflict points at an intersection, total or by type of conflict

Conflicts are typically reported when analyzing alternative intersection types, alignments or lane configurations.

9.6.7 Access Spacing

Access spacing is a measure of the distance between driveways and public street intersections along a roadway segment, or between interchanges along a freeway or expressway. ODOT access spacing standards are provided in Appendix C of the OHP. Local jurisdictions may have their own access spacing standards. A related measure is driveway density which is a factor in bicycle Level of Service. Refer to OAR 734-051 and APM Chapter 4 for procedures. Substandard access spacing can lead to safety and operational problems. Access density is a factor in bicycle LOS.

<u>Example performance measures</u>

- Number of accesses not in compliance with spacing standards
- Percent of roadway in compliance with spacing standards
- Percent deviation from spacing standard
- Number of deviations required

Access spacing is commonly evaluated in corridor plans or refinement plans such as IAMPs or AMPs, in approach permitting, and in projects considering new or modified accesses or roadway connections.

Functional Area

The functional area of an intersection is a measure of the adequacy of spacing between intersections and/or access points to accommodate vehicle paths. Functional area inputs include speed, perception-reaction time, deceleration, lane changing, and queueing/storage lengths. Refer to APM Chapter 4 for detailed procedures.

<u>Performance measures</u>

- Access or junction within functional area of an intersection

<u>Example evaluation criteria</u>

- Functional area of a new connection to the roadway
- Extent of overlapping functional areas

9.7 Other Multimodal Performance Measures

9.7.1 Mode Share

Mode share, typically an area measure, is a function of many contributing factors. Factors include trip purpose, travel time, level of stress/comfort, Level of Service, directness of route, route completeness/connectivity, safety, accessibility, land use, travel costs, and household characteristics. Typical automobile cost factors include auto ownership, maintenance, fuel, parking, and tolls, and is highly influenced by the vehicle's fuel efficiency (e.g., electric vehicles can cost a fraction to fuel relative to internal combustion vehicles, with hybrids somewhere in-between, depending upon the share of miles driven with electricity). Typical transit cost factors include bus fares and subsidies. Bike mode share is also affected by topography, and increasingly bike-share programs (e.g., Portland and Rogue Valley) and their cost schedule.

Performance measure

- Mode share

Example performance measures

- SOV mode share
- Change in mode share
- Percent share of total trips by mode – pedestrian, bicycle, transit, auto
- Percent share of total VMT by drive alone mode (SOV)

Mode share would typically be evaluated for transportation system plan performance or scenarios or alternatives that may significantly change mode share. Examples include transit route changes, transit subsidies, or parking availability/cost.

Mode share is typically obtained from a travel demand model as an estimate that may not represent observed data and is not calibrated. In Oregon there are two levels of travel demand models. In small urban models mode share is assumed from the household survey used to build it (observed travel behavior). It is static and does not react to land use and transportation policies / projects. MPO models have a mode choice model that does react to policies and projects and is an important measure to be aware of and should be requested for all MPO-level model runs.

9.7.2 Transit Service Miles per Capita

Transit Service Miles per Capita is a measure of transit service coverage. It is calculated as fixed route transit revenue service miles divided by area population. Data sources include the National Transit Database (NTD), local transit agency plans and the General Transit Feed Specification (GTFS). RSPM uses this measure and it is also an Oregon Statewide Transportation Strategy (STS) monitoring measure. It can be used as a screening or supplemental for RTPs and TSPs.

Performance measure

- Transit service miles per capita

For the base year, transit service is provided in units of bus-equivalent fixed route transit revenue miles (not counting miles for transit vehicles when not in service). The number of miles traveled while in service for each fixed route transit vehicle is summed over all transit vehicles, for a period of one year. The measure is reported in units of annual service miles per capita.

This measure allows comparisons between alternatives that involve changes in transit service in terms of routes or frequencies, including either expansions or reductions in service. The measure does not reflect ridership.

Transit revenue miles can typically be obtained directly or calculated from miles on various routes combined with hours of operation and headways from the local Transit Agency. This should only include fixed route service. The National Transit Database (NTD) also reports annual service miles by transit provider. Future transit service inputs are provided in units of growth of the region's bus-equivalent revenue miles per capita. It is also important to note that revenue miles are reported in bus-equivalent units.

9.7.3 Multimodal Mixed-Use Area (MMA)

A multimodal Mixed-Use Area (MMA) is an Oregon land use designation that may be adopted by a local government pursuant to the Transportation Planning Rule (TPR – OAR 660-012-0060-10)) to promote mixed-use, pedestrian-friendly, transit oriented, compact land use and transportation activity centers. In order to encourage these types of centers, an MMA designation allows plan or land use regulation amendments to be approved without applying performance standards related to motorized vehicle congestion levels, including volume to capacity ratio, delay or travel time.

Performance measures for evaluating proposed MMA designations within interchange areas are primarily safety related

- TPR requirements
  - Crash rates compared to statewide average for similar facilities
  - Top ten percent SPIS locations
  - 95th percentile queue lengths on freeway exit ramps
- Suggested supplementary measures
  - Critical crash rate
  - Excess proportion of specific crash types
  - Excess expected average crash frequency

For more information including definitions and maps of mixed use areas refer to the DLCD Place Types webpage.

9.8 Infrastructure

Infrastructure performance measures evaluate the supply of transportation networks or services.

9.8.1 Network Connectivity and System Completeness

Network Connectivity and System Completeness are measures of network completeness, redundancy, and availability of alternative routes, which could include streets, intersections, sidewalks and bicycle facilities. Connectivity and completeness is typically evaluated in system planning as well as when considering the potential for re-routing of trips such as for TSMO purposes. Inventories of network elements are prepared and displayed on maps, identifying gaps. Data sources include the FACS-STIP tool for state highways, Google maps and Google Earth, city or regional GIS databases, and Active Transportation Needs Inventories (ATNI) in Regions 1, 4 and 5.

Performance measure

- Network connectivity – extent that the network is inter-connected
- System completeness – percent of planned facility elements such as sidewalks, bike lanes, or improved pedestrian crossings that currently exist

Example evaluation criteria

- Percent local I-I versus regional external –internal or internal-external (E-I/I-E) versus external-external through trips (E-E) on highway – using select links relative to study area
- Percent completeness of bike and walk facilities within ¼ mile of transit stops or ½ mile of schools
- Percent of planned network with sidewalks and/or bicycle facilities
- Percent of network restricted to heavy vehicles
- Capacity available on parallel local facilities
- Ratio of shortest network path distance (driving, walking, or biking) to shortest straight-line distance (as shown in Exhibit 9-16). This is a theoretical minimum distance. Ratios closer to 1 are preferred.
- Number of roadway links divided by the number of roadway nodes or intersections (as shown in Exhibit 9-17).[2]

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[2] A higher index indicates that travelers have increased route choice, allowing more direct connections for access between any two locations. Links are the segments between intersections, nodes the intersections themselves. Cul-de-sac heads count the same as any other link end point. A higher index means that travelers have increased route choice, allowing more direct connections for access between any two locations. According to this index, a simple box is scored a 1.0. A four-square grid scores a 1.33 while a nine-square scores a 1.5. Dead-end and cul-de-sac streets reduce the index value. This sort of connectivity is particularly important for nonmotorized vehicle accessibility. A score of 1.4 is an example threshold for a 'walkable' community.

Exhibit 9-16 Shortest Network Path versus Straight-Line Distance

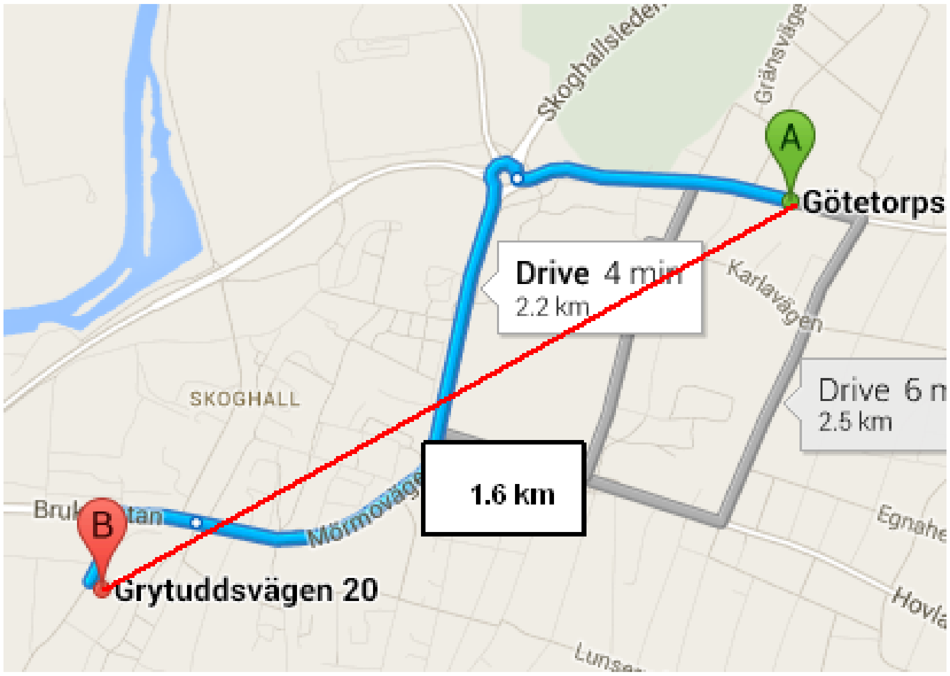
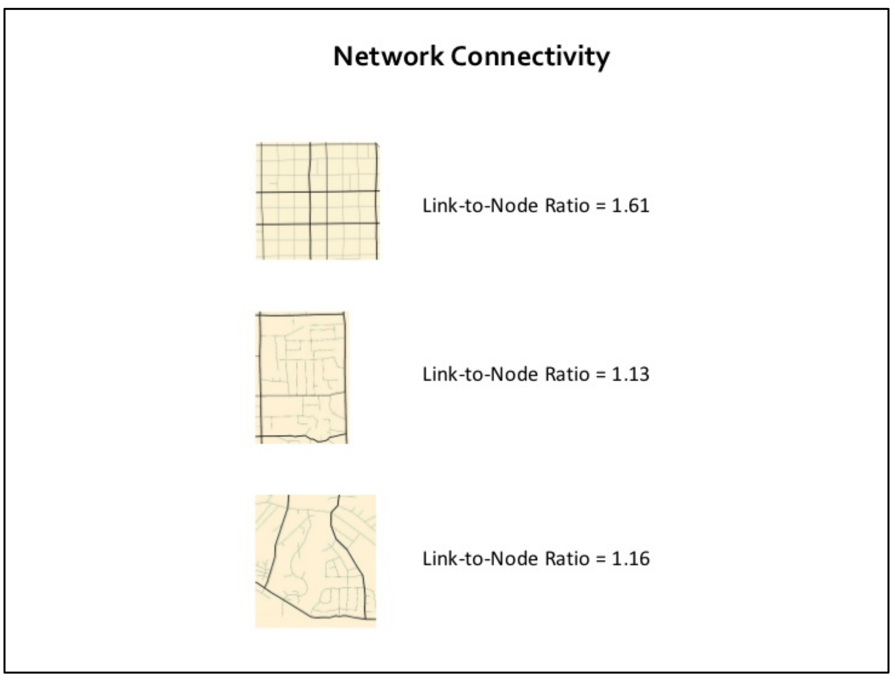


Exhibit 9-17 Links/Nodes Ratio



Out-of-direction Travel

Example performance measures

- Distance out-of-direction (mi or feet), by mode
- Additional VMT

This is the amount of additional travel time and/or distance for a trip or movement due to out-of-direction travel, as compared to a base case. In other words, this is a measure of circuitousness of a route as compared to a direct path. An example would be the out-of-direction travel for an indirect J-turn or at-grade jug handle alternative as compared to a direct left turn. Excess out-of-direction travel for motorized vehicles adds to travel time and VMT and may result in driver frustration which could lead to violations or safety problems. Excess out-of-direction travel for pedestrians (greater than approximately 0.10 mile) may deter use or lead to improper roadway crossings. Excess out-of-direction travel for bicyclists (greater than approximately 0.33 mile) is likely to deter use.

Intersection Density

Intersection density or multi-modal street density are not a common performance measure but are occasionally used as a potential indicator of urban form, i.e., network redundancy, connectivity, or pedestrian friendly paths in an area. Intersection density would be high value for a grid system and low for an area with cul-de-sacs or public street access control is used in JEMnR travel demand models used in many regions of the state. The similar street density is used in Place Types, utilizing block group level data.

Example performance measures

- Number of intersections per square mile within a region or area
- Density of pedestrian-oriented/local streets and/or multi-modal streets miles per square mile within a region or area.

9.8.2 Bicycle or Pedestrian Level of Traffic Stress (LTS)

Bicycle or pedestrian LTS is an ODOT APM Chapter 14 methodology that rates the level of comfort of bicyclists or pedestrians traveling along or crossing a roadway. Scores range from 1 to 4, with 1 being the most comfortable and 4 being the least comfortable. Factors for pedestrian LTS include sidewalk width, condition, and ADA ramps. Target scores are generally either 1 or 2, depending on nearby land uses and demographics such as schools, transit stops, downtown cores, medical facilities, etc. It is useful to display LTS on maps to identify connectivity islands and high stress locations such as major road crossings. Such locations create discontinuities which if fixed could improve the LTS of an entire route. Refer to APM Chapter 14 for procedures.

LTS is not by itself an indicator of the potential use of a walk or bike facility, which would need to take into account additional factors such as the proximity and size of land use origins and destinations, topography, and competition with other modes.

<u>Example performance measures</u>

- Pedestrian or bicycle LTS score on a roadway segment, intersection, approach, or crossing
- Project study area network locations not meeting LTS threshold

[**Appendix 9A – Applicability of Analysis Performance Measures by Plan or Project Type**]

[**Appendix 9B – Alternative Mobility Targets (Planning Business Line Team Operational Notice)**]

References

(1) Dowling, Richard. *Traffic Analysis Toolbox Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness.* No. FHWA-HOP-08-054. 2007.

(2) Estimating the Impacts of Urban Transportation Alternatives, Participant's Notebook, FHWA/NHI December, 1995.

(3) Dowling, R., G. List, B. Yang, E. Witzke, and A. Flannery. NCFRP Report 31: Incorporating Truck Analysis into the Highway Capacity Manual. Transportation Research Board of the National Academies, Washington, D.C., 2014.

(4) Guidance for Implementation of ORS 366.215 (No Reduction of Vehicle-Carrying Capacity), ODOT Transportation Development Division, April 17, 2015