# 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 effort depending on factors such as project type and tools used. Refer to APM Chapter 2 for level of effort information.

Some analysis performance measures are required. For example, state highway project v/c ratios are needed 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 APM 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 higher volume roadway affects more users than the lower 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 good potential for application for a range of studies are also discussed. TPAU can aid 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 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 APM 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 APM Chapter 18 for more information on transportation 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 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 such as an hour or a day. For additional detailed information on multimodal mobility-related performance measures refer to the HCM.

### 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 period under ideal conditions such as good weather, no incidents, no heavy vehicles, no geometric deficiencies.

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 period, such as vehicles per hour or day. 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 several variables including number of lanes, lane width, shoulder width, presence and type of control devices, free flow speed, and other features.

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 over-saturated conditions it is considered a demand to capacity ratio instead (see Section 9.2.5). 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.

<u>Specific performance measures using v/c</u>

- 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)

<u>Strengths of the performance measure</u>

- Simple to understand output, though not as straightforward as LOS
- V/C can be more consistently evaluated across tools and applications than other measures, such as per vehicle delay; this can support transportation analyses processes that depend on consistent results, including development review.
- Responsive to changes in volume as well as in capacity, so demand management, land use and multimodal policies are reflected
- Standardized calculation methodologies and tools available
- 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. 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).

<u>Limitations of the performance measure</u>

- Tends to not be representative of the complex balance of priorities.
- 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 a roadway's capacity. When demand exceeds capacity, a demand-to-capacity (d/c) ratio should be used.
- The v/c ratio is focused on a recurring peak period and does not address non-recurring congestion such as from incidents, weather, or special events.

Data needed for the performance measure
Data collection for this measure is a low to medium level of effort. To calculate v/c, several types of data are needed:

- **Geometric Data** (e.g., lane numbers and arrangements, cross-section elements, turn lane storage lengths) should be verified for consistency with previous work efforts, reviewed through aerial photography, and confirmed through a site visit. Available as-built data may also be used to verify existing roadway geometry. A full list of geometric data that is typically collected is provided in APM Section 3.3.1 (Geometric Data).
- **Operational Data** (such as signal timing plans, posted speeds, intersection control, parking, right-turn-on-red restriction) should be field verified and supplemented by available GIS data, aerials, and photos. A full list of data that is typically collected is provided in APM Section 3.3.2 (Operational Data).
- **Vehicle Volumes** based on collected counts and related factors (See APM Chapter 5 for existing conditions and APM Chapter 6 for or forecasted future volumes).

Analytical methods for this performance measure
The method to calculate the v/c ratio is described below. The methodology is specified in depth in the Highway Capacity Manual.

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 APM Chapter 13 and 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 $i$

Threshold considerations for the performance measure

Many local agencies in Oregon have used v/c ratio as a performance standard. Thresholds often are set for different roadway classifications and land use contexts. The v/c ratio is the only standard currently used by ODOT as described in the 1999 Oregon Highway Plan (OHP). For example, the OHP Policy 1F Table 7 (for the Portland Metro area only) currently includes targets for v/c ratio ranging from 0.99 to 1.1, depending on the facility and time of day. In addition to thresholds set based on facility type and geography, example evaluation criteria can also include:

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

Mitigations for the performance measure

When applying this measure as a standard, potential mitigations could include:

- Signal retiming, at individual intersections or for a corridor
- Added turn lanes or through lanes
- Travel demand management

Outcomes for the performance measure

- Increased vehicular efficiency, reliability, and mobility
- Increased safety risks for pedestrians and bicyclists
- Increased reliance on the automobile

### 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**

| 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<br><br>(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, 7, 17 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.

**Household-Based Vehicle-Miles of Travel (HH-based VMT per capita)**

Household-based vehicle miles per capita is a specific form of the more generalized VMT performance measure as described in the section after this. The form used in Oregon aligns with the definition in OAR 660-012-0005(63) that corresponds to the statewide greenhouse rules contained with OAR 660-044. The household-based VMT per capita was developed as a performance measure in part because of its alignment with the output from VisionEval, the model-based scenario planning used in Oregon. This measure applies to cities that are within Metropolitan Planning Organizations (MPO).

HH-based VMT per capita, when used within the Oregon context for the purpose of measuring the performance of a TSP (and other uses, as applied) is the number of miles traveled by household-based light vehicles for a specific jurisdictional area, regardless of where the miles occur, divided by the jurisdiction's population. This accounts for all travel generated by a household, regardless of trip purpose (e.g., travel from work to a store would be included).

This measure can be applied at the regional, jurisdiction, subarea or transportation analysis zone (TAZ) levels with the travel demand model. The Transportation Planning Rules (TPR) calls for household-based VMT per capita to be measured at the jurisdictional (city or county) level for the respective population within the Urban Growth Boundary.

<u>Strength of the performance measure</u>

- Demonstrates how project study area residents' vehicle travel levels vary based on land use mixes, densities, and based on the availability of travel options.
- Aligns with the OAR definition of VMT per capita which allows for comparison across Oregon jurisdictions
- Meets the requirements of the TPR for TSP, scenario planning, and other areas of compliance required by OAR 660-012 and 660-044.

<u>Limitations of the performance measure</u>

- Useful as a target or to identify land use and transportation actions that help decrease local residents' household VMT/capita at the jurisdictional scale per OAR 660-012-0160.
- Population growth and zoning allocation are outside the purview of some transportation agencies, including ODOT, therefore changes in this measure may not be solely attributed to actions implemented by the agency.

<u>Data needed for the performance measure</u>

Data collection for this measure is a low to medium level of effort, and requires output from a travel demand model in Oregon following the procedures described in APM Appendix 17B.

<u>Analytical methods for this performance measure</u>

The methods of calculating household-based VMT/capita are discussed in the APM Appendix 17B. The measure is an output from the travel demand model. VMT per capita is calculated as the VMT from trips generated by households residing within the study area TAZs (within a jurisdiction) divided by the total population in the study area. This calculation excludes trips that pass through the jurisdiction (external-external) and trips that start outside the jurisdiction and end within the jurisdiction (external-internal). This calculation includes non-home-based trips made by people residing within the jurisdiction, even if those trips occur outside the jurisdiction. As of January 2026, the method does not include the miles that would occur outside the boundaries of the regional travel demand model, though future work involving SWIM plans to address this gap.

<u>Threshold considerations for this performance measure</u>

For application of the VMT per capita performance measure at the jurisdictional level in a TSP per OAR 660-012-0160, the threshold is defined in the TPR as no increase in per capita VMT in the horizon year relative to the base year. Use of different definitions of VMT per capita is theoretically possible, though the use of any method that is not adopted in the APM creates a risk of noncompliance with the OARs and possible legal challenges.

A threshold for a standard could show a VMT per capita reduction with a land use or plan amendment. Application of VMT per capita to site development projects in the Oregon planning context may be difficult given the aggregation level required to measure change in VMT per capita.

<u>Mitigations for the performance measure</u>

- Increased pricing for parking and/or tolling
- Increased frequency of transit
- Expanded transit coverage, or improved walking access to transit stops
- New connections for modes, such as a pedestrian overcrossing or new roadway
- Increased mixed-used development with key destinations, employment, and transit hubs located in closer proximity to residential nodes

<u>Outcomes for the performance measure</u>

- Increased multimodal mobility and network connectivity
- Decreased reliance on the automobile and reduced climate pollution

**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. This can also be known as "on-road VMT" to differentiate it from the previously mentioned household-based version. 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 analyses in environmental documents and studies (see Chapter 16 for more information).

<u>Performance measure</u>

- Vehicle-miles of travel on segment or facility

<u>Example evaluation criteria</u>

- 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 (link-level, statewide, state-owned facilities only), or from a travel demand model (average weekday, 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 an 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.

**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:

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

Performance measure
- Person-miles of travel

Example evaluation criteria
- 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 such as 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 more difficult as occupancy factors may not be available or not enough bicycle/pedestrian counts may be available. Small urban models assume a static value for auto occupancy by trip purpose. MPO models and the statewide integrated model (SWIM), 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.

Throughput

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

Performance measure

- 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 (see Chapter 15 for more information). 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.

**Vehicle Hours of Travel (VHT)**

The hours traveled by all vehicles in a specific area during a specified period. Note that a variation of this measure (vehicle hours traveled per capita) considers population. VHT is typically calculated for an area or system-wide view.

Strength of the performance measure

- Effective for evaluating projects that involve changes in trip lengths.
- Can be aggregated to the regional level.
- Can be used to understand time required to complete a full trip, rather than evaluate delay at a given intersection.
- VHT may resonate with the public and decision makers as people tend to think about their travel times, rather than their travel distances.
- If using real world measurements, this metric is not dependent on a traffic model or assumptions about traffic characteristics (like arrival rate) to calculate existing conditions.
- If using a travel demand model, the metric can be output by most, if not all, modeling software packages.

Limitations of the performance measure

- Accuracy of VHT is highly dependent on the penetration rate of probe vehicles or other data used to estimate travel speed. A CalTrans report[2] estimated that a penetration rate of seven percent is enough to obtain reliable and accurate estimates of VHT.
- VHT is also dependent on estimating daily volume and volume profiles throughout the system.

Data needed for the performance measure

Data collection for this measure is a low to medium level of effort. To calculate Vehicle Hours Traveled using data observations, two data points are needed:

- Hourly volumes
- Hourly speeds

Vehicle Hours Traveled may also be calculated using a traffic demand model or a micro-simulation model.

Analytical methods for this performance measure

USDOT's Volpe Center calculates vehicle hours traveled using the method summarized below:

1. Allocate daily car and truck travel on each segment, by hour of the day and direction.
2. Calculate hourly speeds for each segment, using probe data.
3. Calculate VHT for cars and trucks during each hour of the day, by dividing the hourly vehicle miles traveled by the hourly average speed

Volumes for segments should be assessed in alignment with the APM Section 3.4 (Vehicle Count Surveys) section. In general, the following are found:

- State highways have readily available AADT and hourly volumes through ODOT.
- Arterials and major collectors may have estimated daily volumes available through local transportation plans or count programs.

Where hourly volumes are not available, a volume profile needs to be developed to disaggregate the daily volume to segments by direction and hour of the day. When developing a volume profile for the region or corridor, consider characteristics that may impact some segments differently than others. For example, consider directional commuting patterns, differences in weekend traffic in recreational areas, or different functional classifications.
Hourly speeds should be assessed in alignment with APM Section 3.5.2 (Speed) section. This section describes several methods to assess speed.

[2] Gan, Qijian, Gabriel Gomes, and Alexandre Bayen (2016). From LOS to VMT, VHT, and Beyond through Data Fusion: Application to Integrated Corridor Management. University of California Center for Economic Competitiveness in Transportation.

*INRIX link level speed data is the most effective method included in the APM for determining speed for use in calculating system level VHT. If VHT is being compared between time periods, for example if the agency is calculating VHT annually as a performance measure, ensure that similar segmentation and network is used for the analysis.*

The VHT metric can also be generated by a travel demand model.

Threshold considerations for this performance measure
Vehicle hours of delay under free flow conditions can be used as a baseline for threshold setting.

Mitigations for the performance measure

- Signal retiming, at individual intersections or for a corridor
- Added turn lanes or through lanes
- Increased network connectivity
- Congestion pricing
- Travel demand management

Outcomes for the performance measure

- Increased vehicular efficiency, reliability, and mobility
- Increased reliance on the automobile

**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.

**Hours of/Duration of Congestion**

The measures discussed in this section evaluate recurring congestion. See the 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. Duration of congestion can be applied at different scales, using different methods. Most often, it is calculated for uninterrupted highway segments though it is possible to measure hours of congestion on interrupted flow facilities such as arterial roadways.

Strength of the performance measure

- There is flexibility to define "congestion" in different ways (e.g., v/c or d/c above a specified threshold, travel speed below a threshold, ADT/C above a threshold, excess/unserved demand, presence/length queue on uninterrupted flow facility) depending on what the goal of the performance metric is.
- This metric can be forecast using a travel demand model, if a daily volume profile can be developed from the available data.

Limitations of the performance measure

- Measured or forecasted data must include multiple hours of the day.
- Accounting for peak spreading and multiple hours of analysis increases the complexity and time required for analysis.

Data needed for the performance measure

Data collection for this measure is a low to medium level of effort. The data needed to calculate HOC depends on how "congested" is defined. Likely data needs include:

- **Geometric Data** (lane numbers and arrangements, cross-section elements, turn lane storage lengths, etc.) should be verified for consistency with previous work efforts, reviewed through aerial imagery, and confirmed through a site visit. Available as-built data may also be used to verify existing roadway geometry. A full list of geometric data that is typically collected is provided in APM Section 3.3.1 (Geometric Data).
- **Operational Data** (such as posted speeds, intersection control, parking, right-turn on red) should be field verified and supplemented by available GIS data, aerials, and photos. A full list of data that is typically collected is provided in APM Section 3.3.2 (Operational Data).
- **Vehicle Volumes** based on collected counts and related factors (See APM Chapter 5) or forecasted volumes (see APM Chapter 6).

Analytical methods for this performance measure

The methods of calculating hours of congestion or duration of congestion are discussed in the APM Section 9.2.5 (Supplemental Vehicle Mobility Measures) and APM Chapter 8. APM Chapter 8 discusses how to forecast hours of congestion or duration of congestion, with consideration of peak spreading.

Threshold considerations for this performance measure

Thresholds will vary based on the existing conditions of the roadway system that is being analyzed. In general, agencies should be working to maintain a similar level of congestion as existing or as reasonably forecast for the future. Thresholds should consider roadway classifications, including whether an HOC threshold is useful (i.e. may not be appropriate to apply to local streets). For example, in Metro's 2023 Regional Transportation Plan (adopted by Metro Council on November 20, 2023), two HOC thresholds are set. For throughways with controlled access, the average speed shall not be below 35 mph for more than four hours per day. For throughways with traffic signals, the average speed shall not be below 20 mph for more than four hours per day. All other facilities do not have an HOC-based standard applied to them.

Example evaluation criteria for threshold setting

- 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

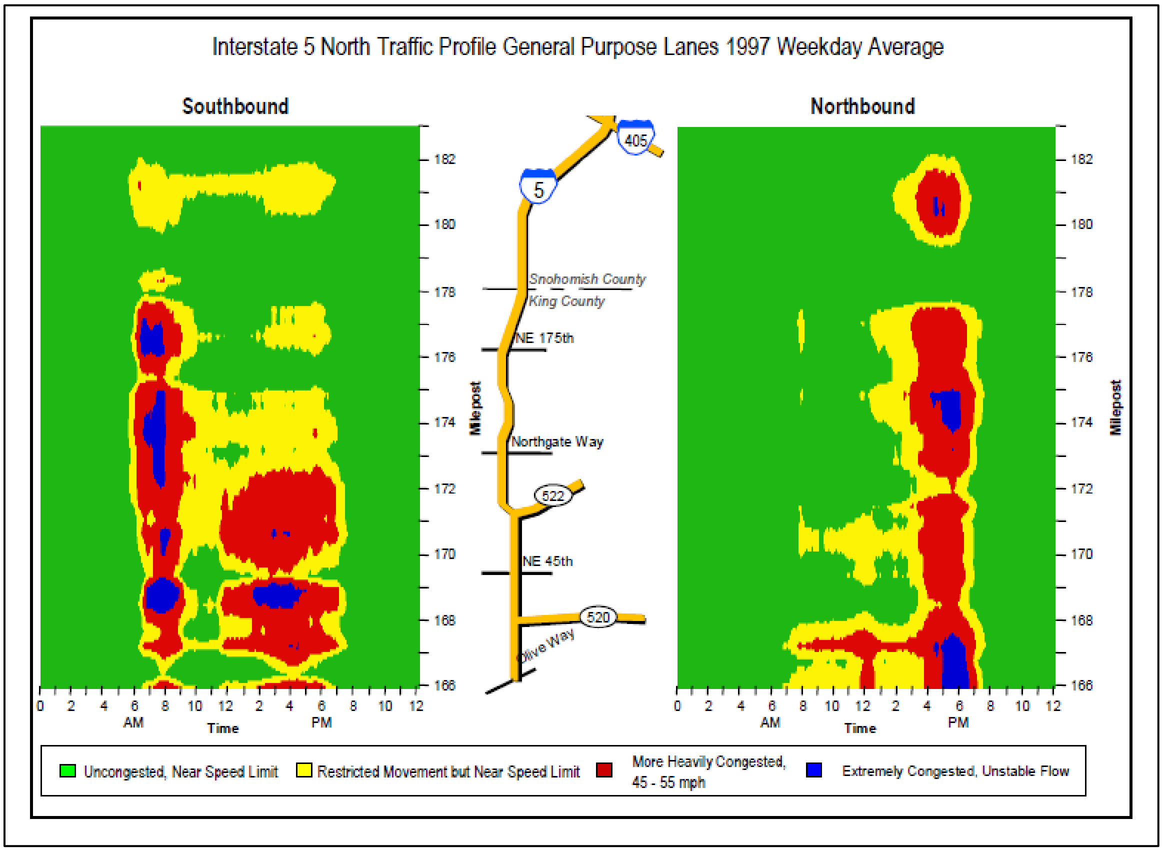
Mitigations for the performance measure

- Added through lanes
- Increased ramp metering
- Congestion pricing
- Travel demand management

Outcomes for the performance measure

- Increased vehicular efficiency, reliability, and mobility
- Increased reliance on the automobile

**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 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, and use will depend on how the regional travel model is segmented. 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.

Strength of the performance measure

- This metric can be forecast using a travel demand model or deterministic methods.
- Effective at measuring impacts of treatments to increase capacity or reduce demand (volume of traffic).

Limitations of the performance measure

- Model outputs can be used incorrectly if practitioners do not review whether they are based on total roadway trip estimates per direction or lane estimates per direction.
- This may not be the best indicator for areas that see high seasonal fluctuations, such as coastal or recreational destinations. For those locations, roadways may fall within an acceptable ADT/C during some months of the year, but real-life conditions during other portions of the year may experience congestion.

Data needed for the performance measure

Data collection for this measure is a low to medium level of effort. To calculate ADT/C two data points are needed: ADT and peak hour capacity.

**ADT:** Volumes for segments should be assessed in alignment with the APM Section 3.4 (Vehicle Count Surveys) section and computed as per APM Chapter 5 & 6. ADT may be calculated for different time periods depending on the agency requirements.

- ADT may be calculated over the course of a full year, effectively using Annual Average Daily Traffic (AADT), ADT may be calculated over a peak season, or another period may be used.
- State highways have readily available AADT and peak hourly volumes through ODOT.
- Arterials and major collectors may have estimated daily volumes available through local transportation plans or count programs.
- ADTs used should match the capacity assumption (i.e. mid-block, intersection approach or total intersection)

**Capacity:** Peak capacity is calculated according to HCM methods. This can be a segment/mid-block capacity, an intersection approach capacity, or a total intersection capacity depending on what element needs to be measured (e.g. segment, approach or intersection). The data input for these methods can include typically systemwide adjustment values based on seasonality or roadway characteristics

Analytical methods for this performance measure

The methods of calculating ADT/C are discussed in the APM Section 9.2.5 (Supplemental Vehicle Mobility Measures). As noted, this methodology was developed as part of studies prepared by FHWA and is the 24-hour volume divided by the peak one-hour capacity which could be based on existing measured conditions or forecast conditions

Capacity is assessed using HCM or other supported methods. The APM includes methods for calculating capacity for different facilities:

- APM Section 11.3 (Capacity-Related Inputs) – Freeways and Multilane Highways
- APM Section 11.4 Two-Lane Highways
- APM Section 12.3 Unsignalized Intersections
- APM Section 12.3.4 Roundabouts
- APM Section 13.4 Signalized Intersection Analysis

Threshold considerations for this performance measure

Exhibit 9-3 provides recommended ADT/C threshold levels, as shown below. Agencies can determine the appropriate congestion level for specific facilities or areas under their jurisdiction based on roadway classifications, land use, or other factors or transportation system goals. Suggested evaluation criteria for threshold setting can include: the number of model links with ADT/C ratio exceeding threshold or 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.*

Mitigations for the performance measure

- Signal retiming, at individual intersections or along a corridor
- Added turn lanes or through lanes
- Providing or increasing capacity on alternative routes
- Congestion pricing
- Travel demand management

Outcomes for the performance measure

- Increased vehicular efficiency, reliability, and mobility
- Increased safety risks for pedestrians and bicyclists
- Increased reliance on the automobile

**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 hour or 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.

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 APM Chapters 12 and 13). 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 location extends into an upstream location such as an intersection or an off-ramp merge point. This is typically reported as the total length of oversaturated queue beginning from the 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 Chapters 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).

Performance measures

- 95$^{th}$ percentile queue length
- 50$^{th}$ percentile queue length
- Maximum (extent) queue length

Strength of the performance measure

- Easily understood by the public.
- Able to be visually described on maps or in an animation
- Already used by most jurisdictions to evaluate turn lanes for concurrence with proposed developments and plan amendments.

Limitations of the performance measure

- Highly detailed. Often measured for only the peak hour (morning and afternoon) and therefore does not provide a good idea of overall system performance through a peak period or a day.
- In congested areas, the 95$^{th}$ percentile queue may need to be calculated using a calibrated microsimulation model to account for impacts of adjacent intersections. This increases the data requirements, complexity, and time required to implement the measure.

Data needed for the performance measure

Data collection for this measure is a low to medium level of effort. To calculate queuing, several types of data are needed.

- **Geometric Data** (e.g., lane assignments, cross-section elements, turn lane storage lengths) should be verified for consistency with previous work efforts, reviewed through aerial imagery, and confirmed through a site visit. Available as-built data may also be used to verify existing roadway geometry. A full list of geometric data that is typically collected is provided in APM Section 3.3.1 (Geometric Data).
- **Operational Data** (such as posted speeds, intersection control, parking, right-turn-on-red) should be field verified and supplemented by available GIS data, aerials, and photos. A full list of data that is typically collected is provided in APM Section 3.3.2 (Operational Data).
- **Vehicle Volumes** based on collected counts and related factors (see APM Chapter 5) or forecasted volumes (See APM Chapter 6).

Analytical methods for this performance measure

The use of queuing as a performance measure is discussed in the APM Section 9.2.5 (Supplemental Vehicle Mobility Measures). This section references several other sections in the APM for methods of calculating queue length. Methods described in the APM include:

- ODOT-developed queuing estimation methods (APM Section 12.5)
- Highway Capacity Manual (HCM) methods as implemented by software (APM Chapters 11-13)
- Non-HCM methods such as microsimulation (APM Chapter 15)

In addition to methodologies currently described in the APM, data sources of probe data may be used to estimate queue lengths. This approach is beneficial for estimating queue lengths across the system but may be less accurate depending on the sample size. Field observations of queuing may also be used at specific locations, and this can be especially valuable for model calibration.

Threshold considerations for this performance measure

When an agency is setting a threshold, consider several components of a threshold:

- The analysis period may be for a peak hour, a peak period, or full day.
- The criteria being measured may be the length of a certain percentile queue (such as the average or 95$^{th}$ percentile) or the number of cycles where the queue extends beyond a certain point (e.g., the available storage of a left-turn lane).
- For many thresholds, selecting the correct queuing percentile is critical. Typically, a 95$^{th}$ percentile queue is used, but in some cases, it may be appropriate to use the average or maximum queue length. 95$^{th}$ percentile queue length by approach (refer to APM Chapters 8, 12 and 13).
- 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

If the performance measure is intended to be applied at a scale other than a specific intersection approach, consider options for aggregating the measure. For example, an agency may choose to identify the number of intersections where at least one queue meets the threshold.

**Exhibit 9-4 Example Queuing Thresholds by Scale**

| Specific Location | Corridor | Region |
|---|---|---|
| $95^{th}$ percentile queue length (feet) for an intersection approach during the peak hour<br><br>Percentage of signal cycles during the peak hour where the queue length blocks the turn lane | Percentage of approaches at signals on a corridor that have a peak hour $95^{th}$ percentile queue that blocks a turn lane<br><br>Number of intersections blocked by peak hour $95^{th}$ percentile queues | Percentage of signals in the region that have an approach with a peak hour $95^{th}$ percentile queue that blocks a turn lane. |

<u>Mitigations for the performance measure</u>

- Signal retiming, at individual intersections or for a corridor
- Signal modification, such as protected left turn phasing or flashing yellow arrows
- Additional signal detection through “dump loops” to clear off-ramps
- Queue warning detection/signs on off-ramps/mainline
- Added turn lanes
- Lengthening available turn lane storage

<u>Outcomes for the performance measure</u>

- Increased vehicular efficiency, reliability, and mobility
- Increased safety risks for pedestrians and bicyclists
- Decreased safety risks for vehicles especially in high-speed locations
- Increased reliance on the automobile

**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 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 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 considered 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 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 HCM operational 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.

**Travel Speed**

Travel speed is a measure of the average or a percentile speed for a network segment or between origin-destination pairs, during a specific period. Travel speed is measured or calculated at the facility segment level but can be aggregated to a system-wide review.

Strengths of the performance measure

- Easily understood by the public.
- Can be measured through use of road tubes (on free-flow non-congested segments) or can be obtained from probe data.
- RITIS data is available statewide for many segments, through ODOT. RITIS data may be used to assess average speed for specific, predefined segments.

Limitations of the performance measure

- Increased vehicular speeds can have an impact of safety performance, especially on a multimodal corridor. There is a need to balance vehicular mobility and safety outcomes.
- Context is important when using travel speed as a performance measure. For example, small differences in travel speed in a long segment or corridor can indicate a large benefit; small differences in a short segment or corridor may reflect an amount of time saved that may not be apparent to system users.

Data needed for the performance measure

Data collection for this measure is a low to medium level of effort. To document and/or calculate travel speed, several types of data may be needed.

- Measured speeds from road tubes with vehicle classifying counters
- Probe data

Analytical methods for this performance measure

The methods of measuring or calculating travel speed are discussed in the APM Section 3.5.2 (Speed). As shown throughout the APM, travel speed can be used as a singular metric but can also be incorporated into other metrics, such as hours of congestion. Travel speed may also be calculated using travel demand models or simulation tools. If models are used to determine travel speed, calibration and post-processing may be required to acquire relevant results.

Threshold considerations for this performance measure

Thresholds will vary based on existing conditions and posted speed of the roadway system that is being analyzed. In general, agencies should be working to maintain a similar level of congestion as existing or as reasonably forecast for the future. Thresholds should consider roadway classifications, including whether a travel speed threshold is useful (i.e. may not be appropriate to apply to local streets). For example, in Metro’s 2023 Regional Transportation Plan (adopted by Metro Council on November 20, 2023), two travel speed thresholds are set. For throughways with controlled access, the average speed shall not be below 35 mph for more than four hours per day. For throughways with traffic signals, the average speed shall not be below 20 mph for more than four hours per day. All other facilities do not have a travel speed-based standard applied to them.

Agencies may also consider an upper limit threshold to inform the use of travel speed as a measure for monitoring safety conditions.

Mitigations for the performance measure

- Signal retiming, at individual intersections or for a corridor
- Added turn lanes or through lanes

When applying this measure as a standard, focused on managing speeds for safety considerations, potential mitigations could include speed management treatments like medians, curb extensions, and horizontal deflection.

Outcomes for the performance measure

- Increased vehicular efficiency, reliability, and mobility
- Increased safety risks for pedestrians and bicyclists
- Increased reliance on the automobile

**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 period for the study segment

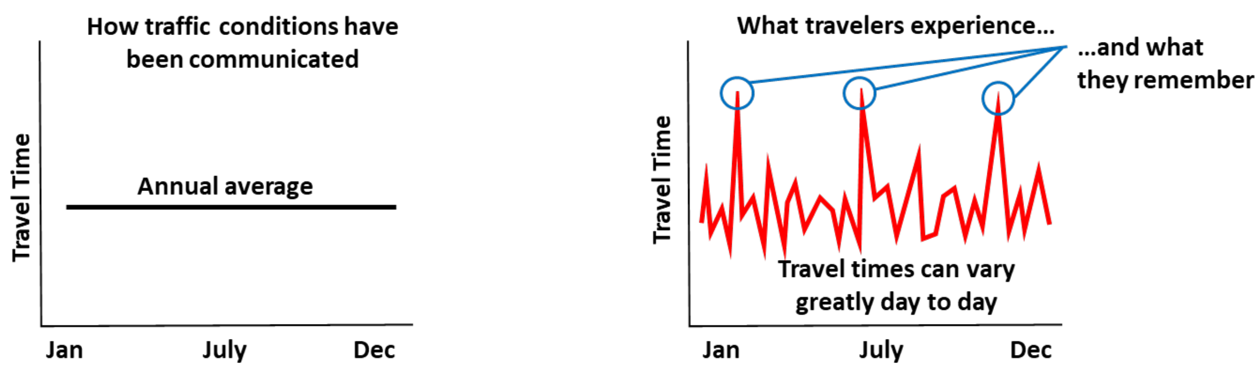
The threshold travel time is typically based on a threshold or target speed which could be free-flow speed, posted speed, or some other policy speed determined to be the minimum desirable operating speed. Several methods are available for estimating vehicle hours of delay, including the HCM, PPEAG, and 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 30$^{th}$-highest volume hour of the year. However, demand variation is just one of several 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 9-5.

**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*

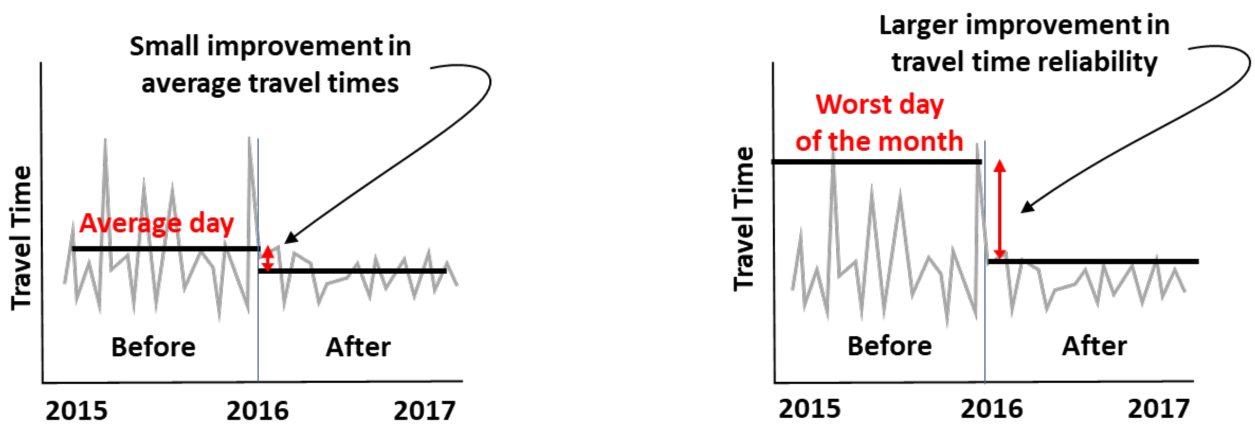
Measures of travel time reliability incorporate all of the factors influencing roadway capacity and free-flow speed to describe the variability of travel times along a particular roadway section or facility, or for a given trip. This variability affects roadway users in important ways, including:

- **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 9-6, 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 9-6 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.

Problem Identification

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.*

Project Evaluation

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 9-7 lists a variety of potential roadway capacity, modernization, and operations projects, along the factors influencing reliability that these projects affect.

**Exhibit 9-7 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

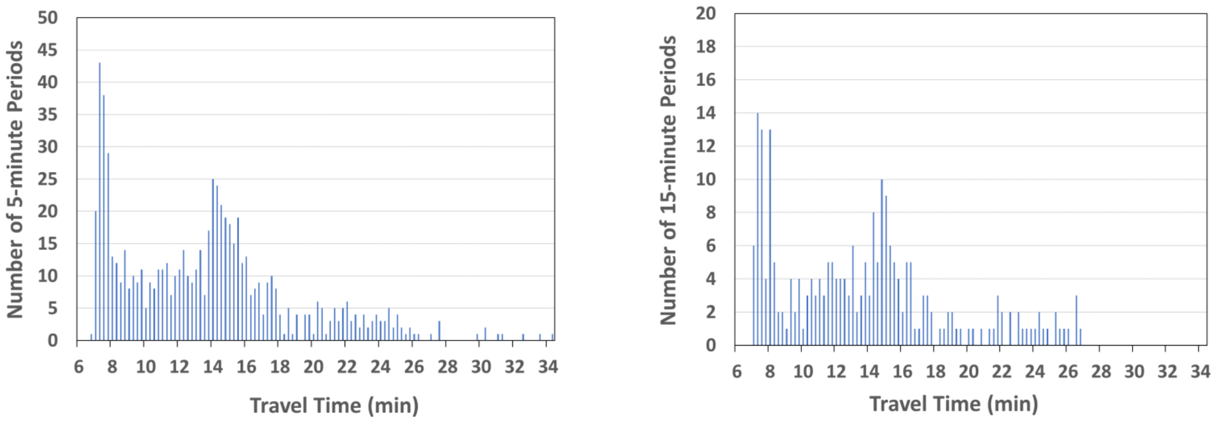
A travel time distribution is a collection of travel time observations or forecasts for a defined roadway section (e.g., segment, facility) over a relatively long period of time (e.g., all nighttime time periods over the course of a year; all weekday time periods between 6:00 and 10:00 a.m.). Each observation 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 9-8 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 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 9-8 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 five-minute distribution, as the extremely low speeds reported during individual five-minute periods occur less often over a longer 15-minute period.

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

- 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

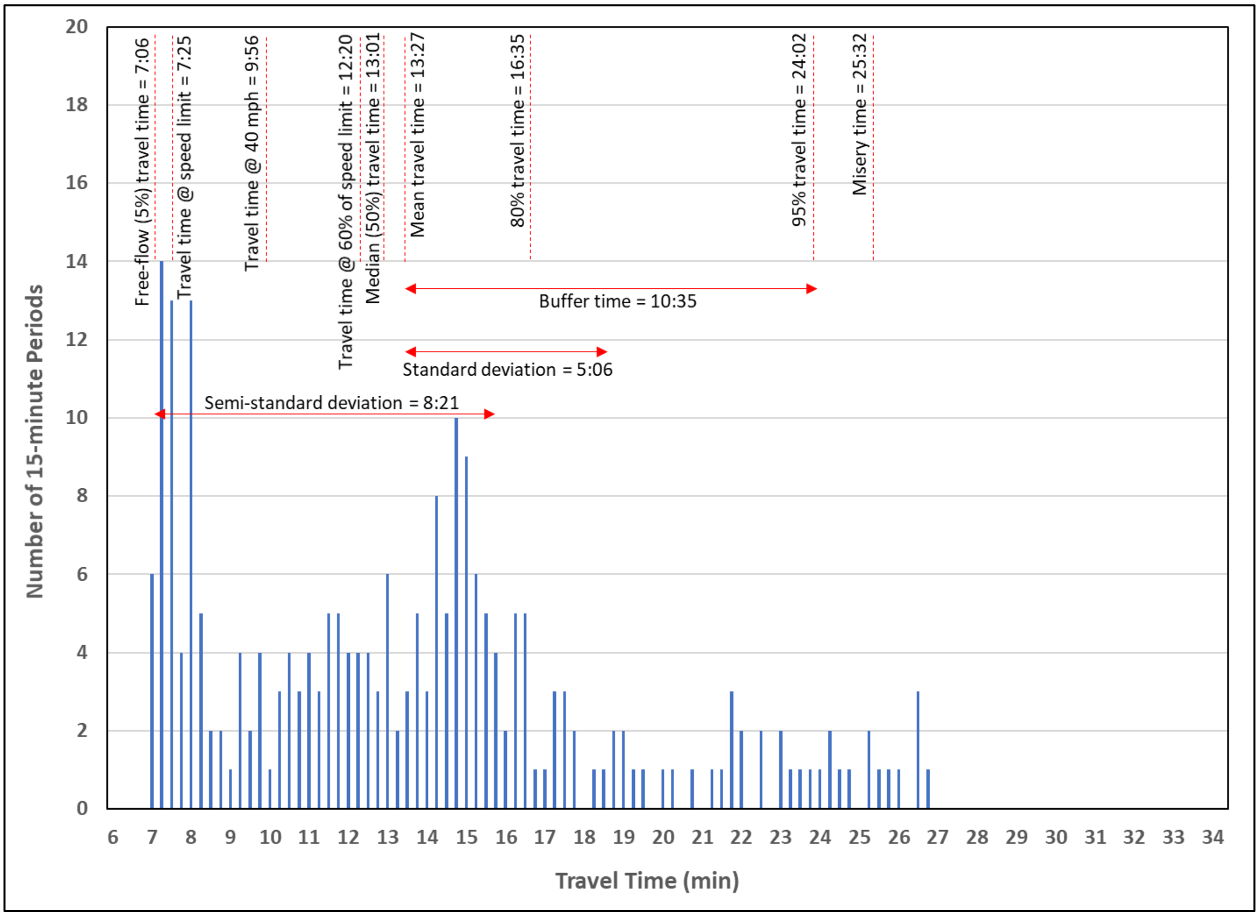
The greater detail provided by five-minute data can be useful for diagnosing the causes of unreliability along a roadway. Diagnosing reliability problems is beyond the scope of this chapter but is addressed in the HCM Planning Guide workshop material on performance management, available on HCM Volume 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 95$^{th}$ percentile highest travel time, a difference between two other travel times (e.g., the difference between the 50$^{th}$ and 95$^{th}$ percentile travel times), or statistical descriptors of the distribution such as the standard deviation. Exhibit 9-9 depicts common types of travel time values that can be obtained from the travel time distribution shown in Exhibit 9-8(b). These travel time values are described in the subsections that follow.

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




<u>Free-flow Travel Time</u>

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 5$^{th}$-percentile travel time, as shown in

Exhibit 9-9. 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.

<u>Travel Time at the Speed Limit</u>

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.

<u>Target (Policy) Travel Time</u>

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 percentage of time or 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.*

<u>Average (Mean) Travel Time</u>

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

<u>Percentile Travel Time</u>

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$^{\text{th}}$-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$^{\text{th}}$-percentile travel time**—the travel time achievable 80% of the time; research has shown that the 80$^{\text{th}}$-percentile time is more sensitive to roadway operational changes than the 95$^{\text{th}}$-percentile time, making it useful for evaluating project effects on reliability; and
- **95$^{\text{th}}$-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 9-9, 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:

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

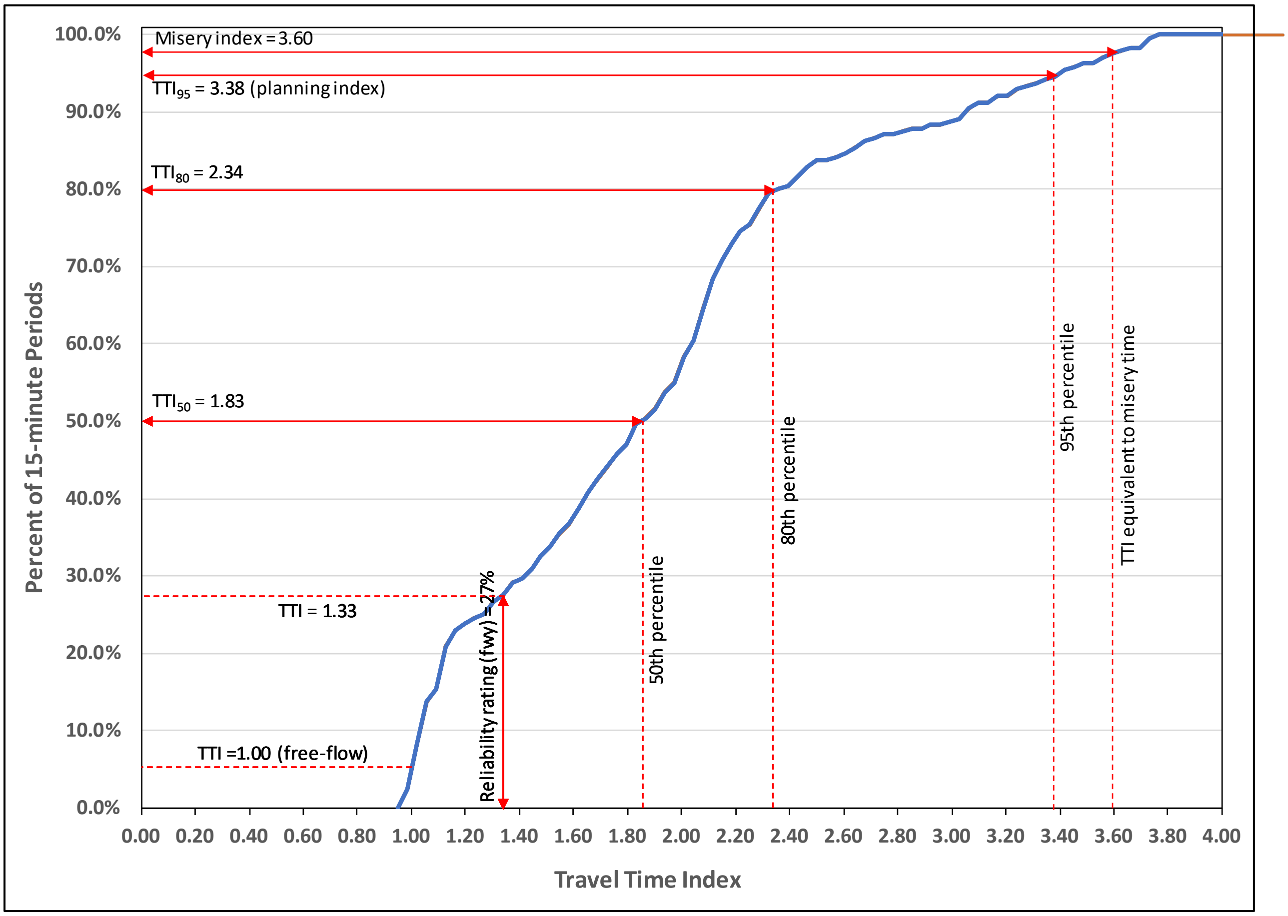
Where:

$SSD$ = 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 9-10 provides examples of ratio-based performance measures derived from the travel time distribution shown in Exhibit 9-8(b). The travel time distribution in Exhibit 9-10 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 9-10 Examples of Ratio-Based Reliability Measures**




<u>Travel Time Index (TTI)</u>

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 9-10).

<u>Policy Travel Time Index ($TTI_P$)</u>

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 9-10) is defined as the $80^{th}$-percentile travel time divided by the $50^{th}$-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 9-10) is defined as the $95^{th}$-percentile truck travel time divided by the $50^{th}$-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 9-10) is the $95^{th}$-percentile travel time divided by the average travel time. Although this measure appears in the reliability literature, the HCM recommends against using it for tracking travel time trends "because it is linked to two factors that can change: average and $95^{th}$ 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 $50^{th}$-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 proportion 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 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 from a few months up to a year. Key reliability time periods are defined below.

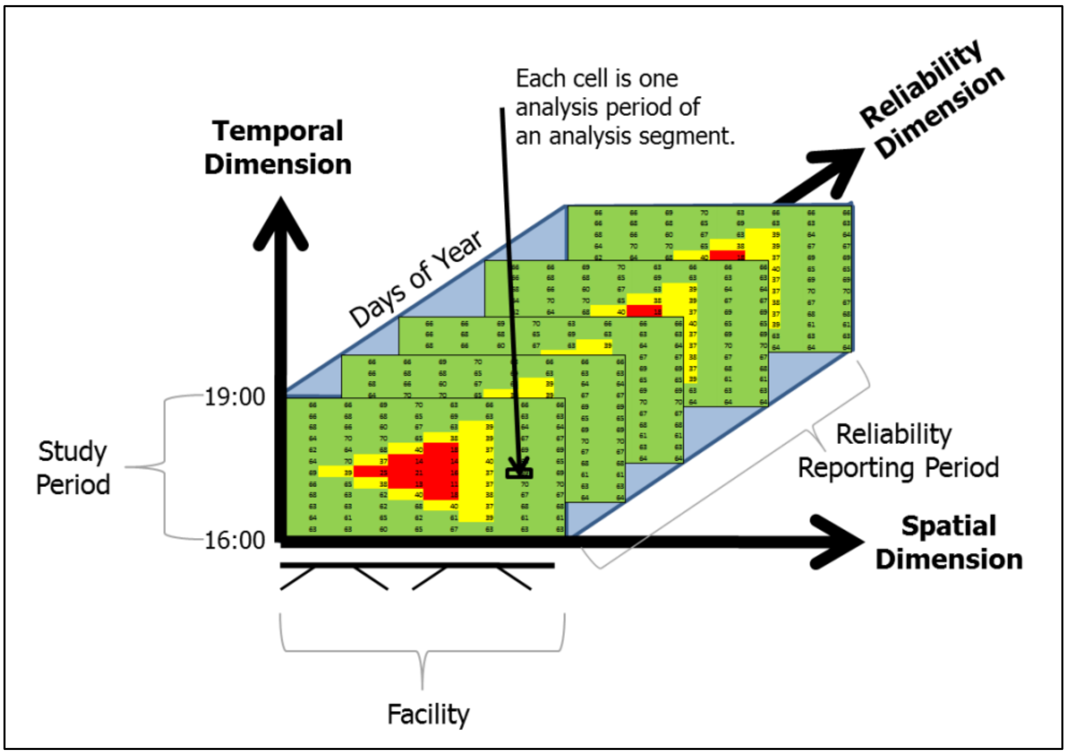
1. The *reliability analysis period* is the smallest time unit for which the analysis procedure is applied. In the case of freeway and urban street facility analysis, the analysis period is

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 9-11 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 9-11 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 9-11). 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 9-11 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 traverse 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 for 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 three primary sources of travel time data:

- Regional Integrated Transportation Information System (RITIS),
- National Performance Management Research Data Set (NPMRDS), and
- Portland, Oregon Regional Transportation Archive Listing (PORTAL).

ODOT is subscribed to the Regional Integrated Transportation Information System (RITIS). See https://www.oregon.gov/odot/Data/Pages/RITIS.aspx for account requests, log-in information, training resources and system documentation. RITIS is a web-based system for analyzing and visualizing speed, travel time, and other data for Oregon roadways through a variety of dashboards and tools based on INRIX probe data. Data is available from 2016 to the present. Free access to RITIS is available to all ODOT employees, State of Oregon public agencies and consultants or university staff performing work for a public agency withing Oregon.

The NPMRDS dataset is provided by FHWA to MPOs and state DOTs without charge. The NPMRDS dataset is accessed through the RITIS online data portal 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 five-minute sample summary data for the selected TMCs over the 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. 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 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 period (e.g., one 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 9-5.

When reporting travel time reliability, most 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, most 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 two main groups: (1) sketch-planning methods developed through the SHRP 2 program, and (2) the detailed HCM freeway and the urban streets reliability 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 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 eight or nine 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.

<u>SHRP 2 Project C11 Method</u>

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 can forecast 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)
- 95th-percentile TTI
- 80th-percentile TTI
- 50th-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.

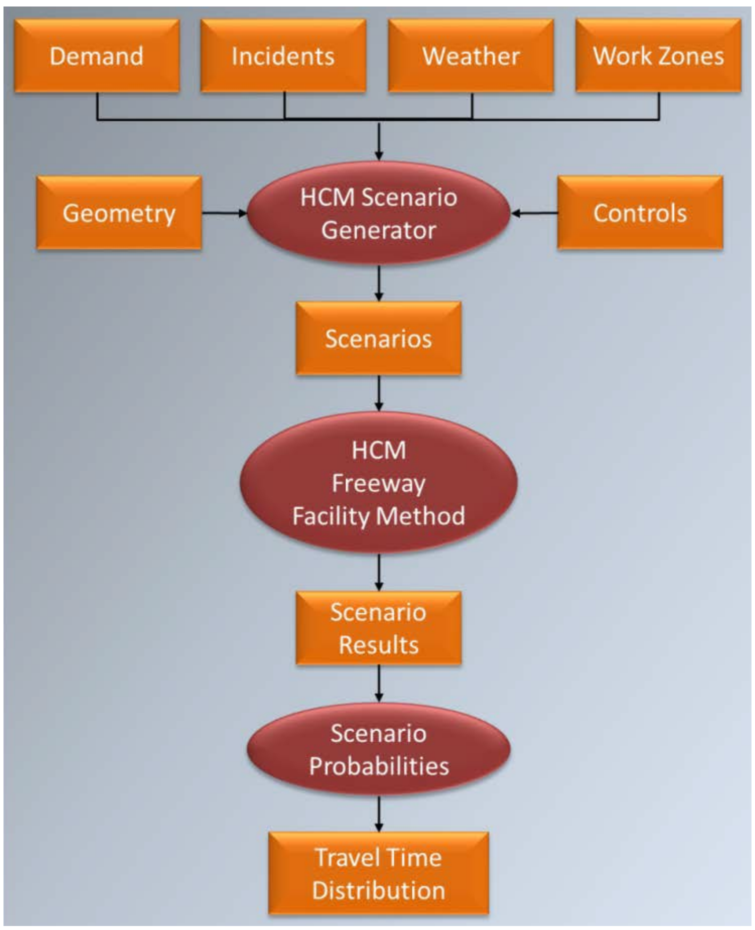
The method predicts the same performance measures described above for the SHRP 2 C11 method. The reliability reporting period is also the same: one or more weekday analysis hours over an entire year.

**HCM Freeway Reliability Method**

The HCM freeway reliability analysis methods are described in Chapters 11 and 25 of the HCM. 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 9-12 illustrates the method's flow from scenario generation through outputting a distribution of travel times.

**Exhibit 9-12. 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 the methods have tools available to assist in applying the method. Exhibit 9-13 compares the capabilities of the different methods.

**Exhibit 9-13. Comparison of Travel Time Reliability Analysis Methods**

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

Notes: NA = not applicable, FFS = free-flow speed, v/c = volume-to-capacity ratio.
*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 eight or nine 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.

For the HCM method, 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 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 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 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 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.

**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.

**SHRP 2 C11 Spreadsheet Tool**

The C11 reliability spreadsheet tool is an Excel spreadsheet that calculates all 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" available at https://www.oregon.gov/odot/Planning/Documents/Value_of_Travel_Time_Estimates.pdf APM Section 10.6.8 provides more information about economic analysis.

**Tool Comparison**

Exhibit 9-14 summarizes key features of software tools that implement the HCM's reliability method.

Exhibit 9-15 provides similar information for tools that are based on the planning-level SHRP 2 C11 reliability equations.

**Exhibit 9-14 HCM-Implementing Tool Comparison**

| Overview | HCS | FREEVAL |
|---|---|---|
| Source | McTrans | hcmvolume4.org |
| Cost | License Fee | Free |
| Operating system | Windows | Windows/Mac |
| Installation required | Yes | No (need Java) |
| Widespread use | High | Medium |
| Learning curve | Medium | Medium |
| Complexity | Medium | Medium |
| Training available | ● | ◐ |
| User guide | ● | ● |
| Instructional videos | ○ | ● |
| Technical support | ● | ◐ |
| Copy/paste | ○ | ◐ |
| Load/save | ● | ● |
| Import/export | ● | ● |
| Auto-fill | ◐ | ● |
| 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 9-15 SHRP 2 C11 Implementing Tool Comparison**

| Overview | SHRP 2 C11 Reliability Tool | PPEAG Tool |
|---|---|---|
| Source | tpics.us/tools | hcmvolume4.org |
| Cost | Free | Free |
| Operating system | Windows/Mac | Windows/Mac |
| Installation required | No (need Excel) | No (need Excel) |
| Widespread use | Low | Low |
| Data source for reliability inputs | Defaults or another tool | Calculated |
| Reliability calculations | Automated | Manual or separate spreadsheet |
| Learning curve | Low | Low |
| Complexity | Low | Medium |
| Training available | ○ | ○ |
| User guide | ● | ◐ |
| Instructional videos | ○ | ○ |
| Technical support | ○ | ○ |
| 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. LOS can be applied at different scales, using different methods. Most often, LOS is calculated for intersections or highway segments.

### 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 substantial and demand may exceed capacity. This condition is typically evident in long queues and delays.

Performance measure

- Level of Service letter grade A-F

Strength of the performance measure

- Simple to understand output.

- Easy to communicate to the public because it is a measure of the user's experience based on average per-vehicle delay, measured in seconds.

Limitations of the performance measure

- Tends to not be representative of the complex balance of modal and other priorities, such as safety or accessibility.
- In very congested conditions, this measure loses granularity. When an intersection is already at LOS "F", worsening congestion does not get assigned a lower grade to indicate further degradation of the intersection.

Data needed for the performance measure

Data collection for this measure is a low to medium level of effort. To calculate LOS, several types of data are needed.

- **Geometric Data** (e.g., lane assignments, cross-section elements, turn lane storage lengths) should be verified for consistency with previous work efforts, reviewed through aerial imagery, and confirmed through a site visit. Available as-built data may also be used to verify existing roadway geometry. A full list of geometric data that is typically collected is provided in APM Section 3.3.1 (Geometric Data).
- **Operational Data** (such as posted speeds, intersection control, parking, right-turn on red) should be field verified and supplemented by available GIS data, aerials, and photos. A full list of data that is typically collected is provided in APM Section 3.3.2 (Operational Data).
- **Vehicle Volumes** based on collected counts and related factors (see APM Chapter 5) or forecasted volumes (see APM Chapter 6).

Analytical Methods

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 Section 11.4 and 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)

Threshold considerations for this performance measure

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 for specific calculations and LOS thresholds for each facility type:

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

<u>Example evaluation criteria for threshold setting</u>

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

<u>Mitigations for the performance measure</u>

- Signal retiming, at individual intersections or for a corridor
- Added turn lanes or through lanes

<u>Outcomes for the performance measure:</u>

- Increased vehicular efficiency, reliability, and mobility
- Increased safety risks for pedestrians and bicyclists
- Increased reliance on the automobile

### 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.

### 9.4.3 Pedestrian and Bicycle Level of Service

*The APM methodologies to calculate segment-level Pedestrian and Bicycle LOS are simplified re-estimated versions of the HCM Pedestrian and Bicycle LOS. Refer to APM Chapter 14 for detailed procedures.*

The segment-level 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. The intersection-level procedures are index scores based on the presence or absence of elements (e.g. curb ramps, bike facility types, turn conflicts).

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 (Shared path) LOS
- Signalized intersection pedestrian or bike LOS
- Unsignalized intersection pedestrian or bike LOS (In development)

Performance ratings for bicyclists are provided for roadways with and without bike facilities, separated/shared paths, and intersections. Bike facilities evaluated include shared lanes, bike lanes, buffered bike lanes, and separated bike lanes, and shared paths. 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 LOS evaluates number of through traffic lanes, traffic volume, posted speed, and sidewalk width.

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 and excessive data needs.

### 9.4.4 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.

Performance measures

- Segment Transit LOS letter grade A-F

Example evaluation criteria

- 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.

### 9.4.5 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.

Performance measure

- Truck LOS on highway facility

Example evaluation criteria

- 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 owners 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 can also be measured to key destinations as defined in OAR 660-012-0360. 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 measured at different scales and 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, which includes accessibility to employment or to key destinations

Strengths of the performance measure

- Can effectively compare the transportation system between modes

Limitations of the performance measure

- Identifying key destinations or getting an accurate and complete list of employment locations may be subjective or require extensive manual effort or public outreach.
- Developing a complete and usable network can be time consuming.
- Assessing the transit network using scheduling and routing data may be cumbersome.
- Transit service frequency and span of operations should be considered with respect to transit accessibility.

Data needs for the performance measure

- Data collection for this measure is a medium to high level of effort, although it is lower if there is a travel demand model available. To calculate accessibility to key destinations, several data sets are needed.
- Employment data should be available from the Oregon Employment Department, local sources, or through census data.
- Transportation network data should be developed such that a network analysis can be completed in GIS or a similar geospatial program. This involves confirming that roadway segments are connected, incorporate pedestrian and bicycle facilities and include attributes that may impede travel such as one way links. Transit network and scheduling data can be collected for many agencies using the General Transit Feed Specification (GTFS).
- Traveler behavior may inform the development of thresholds. For example, if data is available that indicate that people in the community are willing to walk ½ mile to reach a transit stop or other destinations, that may be an effective threshold to determine a pedestrian walkshed. If travel behavior data is not available for a specific community, using default values may be a good alternative.

Threshold setting considerations for the performance measure

- Thresholds may vary greatly based on the existing conditions of the area that is being analyzed. In general, agencies should seek to support increasing accessibility to employment or key destinations so that they are able to be reached within a certain time or distance as the transportation system evolves.
- Common travel times used as thresholds for accessibility are often 20 to 30 minutes, for all modes. Common distances used as thresholds to define walking and bicycling are one mile and five miles, respectively.
- Accessibility to key destinations from a particularly important origin. For example, assessing the number of key destinations that can be reached within a 20-minute bicycle ride from a dense residential area, and then setting a relevant target for the future.
- Travelshed from key destinations. For example, assessing the portion of households that are within a 30-minute transit trip of a specific destination, such as a library, or within a

30-minute transit trip from any key destination, and then setting a relevant target.

Mitigations for the performance measure

- Added connections for pedestrians and bicyclists, such as accessways between cul-de-sacs, filling sidewalks gaps, and installing new bicycle lanes
- Signal retiming
- Increased frequency of transit
- Expanded transit coverage
- Increased mixed-use development with key destinations, employment, and transit hubs located in closer proximity to residential nodes.

Outcomes for the performance measure

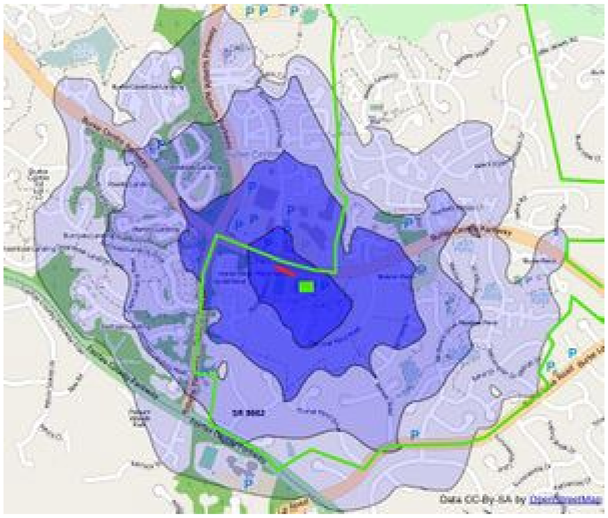
- Increased multimodal mobility and network connectivity
- Improved safety for pedestrians and bicyclists
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

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 9-16 below for an example of an isochrone map.

**Exhibit 9-16 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.

### 9.5.2 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 consider 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.

### 9.5.3 Accessibility for Transit Riders

Accessibility for transit riders measures the proximity of transit service available. It can be defined by the number or percent of a population (e.g., weighting households by size), jobs, or households living within a defined distance or travel time from a transit stop. The specific definition or combination of these items (population, jobs or households) may be selected and applied. Transit stops should be considered for all transit modes including bus, bus rapid transit, commuter rail, streetcar, and light rail. 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

Scale of the performance measure

- This measure can be applied at a variety of scales. Typically, the measure is used to evaluate proposed impacts of projects on travel from an area's transit stop network. For example, the number of jobs within ¼ mile from a sub-area's transit stop network might be compared between existing conditions and the addition of a bridge across a freeway or set of network improvements.

Strengths of the performance measure

- Can compare transit system alternatives.

Limitations of the performance measure

- Developing a complete and usable network can be time consuming.
- Assessing the transit network using scheduling and routing data may be cumbersome.
- Transit service frequency and span of operations should be considered with respect to transit accessibility.

Data needs for the performance measure

- Data collection for this measure is a medium to high level of effort, although it is lower if a travel demand model or other routable inventoried street network (e.g., GIS) is available. To calculate accessibility to transit, several data sets are needed.
- Transportation network data should be developed such that a network analysis can be completed in GIS or a similar geospatial program. This involves confirming that roadway segments are connected, incorporate pedestrian and bicycle facilities and include attributes that may impede travel such as one way links. Transit network and scheduling data can be collected for many agencies using the General Transit Feed Specification (GTFS).
- Traveler behavior may inform the development of thresholds. For example, if data is available that indicate that people in the community are willing to walk ½ mile to reach a transit stop or other destinations, that may be an effective threshold to determine a pedestrian walkshed. If travel behavior data is not available for a specific community, using default values may be a good alternative.

Threshold setting considerations for the performance measure

- Thresholds will vary greatly based on the existing conditions of the area that is being analyzed. In general, agencies should be working to increase accessibility with more housing and employment able to be reached within a certain time or distance of transit stops as the transportation system evolves.
- Common travel times used as the analysis factors are often in increments of 15 minutes, for all modes of transit.
- Common distances used as analysis factors for walking and bicycling to/from transit stops are ¼ mile and 1 mile, respectively. Depending on the region of application and the transit network that is provided, consideration may be given to high-capacity transit versus other service levels.

Mitigations for the performance measure

- Added connections for pedestrians and bicyclists, such as accessways between cul-de-

sacs, filling sidewalks gaps, and installing new bicycle lanes
- Signal retiming
- Increased frequency of transit
- Expanded transit coverage
- Increased mixed-use development with key destinations, employment, and transit hubs located in closer proximity to residential nodes.

Outcomes for the performance measure
- Increased multimodal mobility and network connectivity
- Improved safety for pedestrians and bicyclists
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

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 disaggregate 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 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.

Performance measure

- 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

Example evaluation criteria

- Segment crash rate exceeding average for similar facility type from Oregon State Highway Crash Rate Tables
- Intersection crash rate exceeding published 90$^{th}$ 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 the reference population(s)

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 3 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(s).

### 9.6.5 Expected or Predicted Crash Frequency

Expected or predicted crash frequency is an HSM predictive measure of long-term crash frequency and severity. 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 regression to the mean 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 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 or prioritizing and comparing alternatives. Refer to APM Section 4.4 Predictive Methods for details.

Strength of the performance measure

- The required data is likely already available.
- Easily understood by the public.

Limitations of the performance measure

- Predictive methods are detailed and more time-intensive than reporting existing crashes.
- Crashes for some future situations cannot be predicted with the same level of accuracy due to gaps in research and data

Data needs for the performance measure

Data collection may rely on existing databases, although data collection needs will likely vary depending on the type of facility or crash type being analyzed. As discussed in the APM Section 4.4 (Predictive Methods), the following data types are needed to calculate predicted total crashes:

- Crash frequency by severity, collision type, and pedestrian and bicyclist involvement (if using the Empirical Bayes Method)
- AADT traffic volumes for major and minor roads
- Pedestrian and bicyclist volumes or estimates
- Traffic control information

- Geometric design and roadway details
- Data requirements vary by predictive model and are discussed in APM Section 4.4.6. Complete Highway Safety Manual (HSM) Part C data requirements can be found in HSM Part C, Sections 10.4, 11.4, and 12.4
- Per APM Section 4.4 (Predictive Methods), "Predictive methods do not require observed crash data to derive quantitative safety evaluations, and therefore can be used with future scenarios or design alternatives that do not yet exist."

<u>Analytical methods for this performance measure</u>
Reported crash documentation does not require a methodology for calculation.

The methods of calculating predicted total crashes are discussed in the APM Section 4.4 (Predictive Methods). As noted, this methodology is based on the HSM.

In addition to APM Section 4.4 (Predictive Methods), predicted total crashes are also discussed in APM Section 9.6.5 (Expected or Predicted Crash Frequency).

<u>Threshold considerations for this performance measure</u>
For this measure, many jurisdictions have a target to reach near or towards zero fatalities/serious injuries on the transportation system. A threshold could be based on decreasing the predicted total crashes relative to the existing total crashes for a facility or area. Potential thresholds could be related to:

- Excess Expected Crash Frequency using Empirical Bayes (EB) Adjustments

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 exists and the analysis period being used for the predictive method.

- Net Change in Expected or Predicted Crashes

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

<u>Mitigations for the performance measure</u>
- Reduced posted speed limit
- Reduced vehicular travel lanes
- New or improved pedestrian crossings

- Intersection control modifications
- Signal retiming
- New or updated signage, striping, or markings
- See ODOT's ARTS crash reduction factor (CRF) list for other potential mitigations and associated crash reduction factors that can be used for analysis
- Additionally, the CRF Clearinghouse includes a range of crash modification factors that can be used for analysis

Outcomes for the performance measure

- Increased multimodal reliability
- Improved safety for all modes

### 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.

Example performance measures

- 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 Bicycle Crash Risk

Bicycle crash risk is a risk score for a roadway section based on bicyclist behavior, roadway features, and other contextual factors such as land use. Bicycle crash risk is calculated at the facility level but can be aggregated to a system-wide review. For example, ODOT has calculated bicycle crash risk for all highways and then divided the highway segments into quintiles to identify the top 20 percent with the highest bicycle crash risks for both urban and rural contexts. See the Vulnerable Road User Assessment from November 2023 for more information.

Strengths of the performance measure

- The needed data is likely already available, or, if not, assumptions can be used to fill gaps.
- As of 2020, ODOT has calculated the bicycle crash risks for all state highways.

Limitations of the performance measure

- Risk factors include land use factors that may increase bicycle activity but may result in conflation with increasing crash risk. For example, proximity to schools or to transit stops may increase bicycle activity level, which could lead to more frequent crashes, though the increase to the risk of crashes may not be directly affected (or decrease).

Data needs for the performance measure

Data collection for this measure is a medium to high level of effort, dependent on what inventory data is available. For ODOT's statewide systemic safety analysis completed in 2020, the bicycle risk factors used included.

- Principal arterial
- Minor arterials
- Number of lanes (>= 4 Lanes)
- Posted speed (>=35mph)
- No presence of a bicycle lane
- High-access density
- Mixed use zoning
- Proximity to schools (one mile)
- Proximity to transit stops (1/4 mile)
- High population over the age of 64 (threshold was set to 16.8 percent).

While vehicle volume is not explicitly identified in the analysis referenced above, it remains a risk factor regarding bicyclist safety. See ODOT Report SPR 779: Risk Factors for Pedestrian and Bicycle Crashes.

Analytical methods for this performance measure

As part of the Oregon Pedestrian and Bicycle Safety Implementation Plan, ODOT implemented the NCHRP Research Report 893 methodology in 2020. This methodology uses risk factors to complete a systemic safety analysis aimed at identifying high risk locations for pedestrian and bicycle crashes along the state highway system. Systemic safety, as opposed to the traditional review of crash history, allows practitioners to proactively identify high risk sites for potential safety improvements based on risk factors that often correlate to locations with a low frequency of bicycle crashes, though the crashes that do occur tend to cause severe injuries or fatalities. Crash risk is a measure used by ODOT to assess bicycle and pedestrian safety.

To calculate bicycle crash risks, apply the following steps:

1. Collect data for the chosen analysis roadway segments. If data is not available, apply reasonable assumptions to fill data gaps. For example, if posted speed data is not readily available in a geospatial format, posted speed could be assumed based on roadway classification (e.g., 25 mph for local roadways, 30 mph for collectors). Analysis segments should be broken every time a risk factor characteristic changes for the facility (e.g., when the posted speed changes from less than 35 mph to more than 35 mph).
2. Determine for each analysis segment whether a specific bicycle risk factor is present.
3. Add the risk factor weightings together for each analysis segment (weightings shown below are based on either urban or rural contexts). If a risk factor is present, the risk factor weight is added. If a risk factor is not present, then the risk factor weight is 0. If the risk factor is not applicable (i.e. shown as "- "in Exhibit 9-17, then do not include that risk factor in the analysis.

Exhibit 9-17 Bicycle Risk Factor Screenings Weights

**RISK FACTOR SCREENING WEIGHTS: BICYCLISTS**

| | Risk Factor Weights | |
|---|---|---|
| **Risk Factor** | **Urban** | **Rural** |
| Principal Arterial | 1.13 | 1.39 |
| Minor Arterials | 1.07 | — |
| Number of Lanes (>= 4 Lanes) | 1.08 | — |
| Posted Speed (>=35 mph) | 1.11 | 1.09 |
| No Bike Lane | 1.06 | — |
| High-Access Density | 1.02 | — |
| Mixed Use Zoning | 1.00 | — |
| Proximity to Schools (1 Mile) | 1.01 | 1.00 |
| Proximity to Transit Stops (1/4 Mile) | 1.03 | 1.03 |
| High Population over the Age of 64 | 1.00 | 1.00 |

Source: Oregon Pedestrian and Bicycle Safety Implementation Plan

Threshold considerations for this performance measure

For this performance measure, the target should be set such that a reduced bicycle risk factor is achieved. A threshold could be based on maintaining or decreasing the risk factor of a facility. A jurisdiction could also base a threshold off of existing conditions. If the risk factors of all facilities or of facilities of a specific roadway classification or higher are calculated, the risk factor value that separates the top 20 percent from the top 40 percent, or a similar binning process, could be used to determine when a safety-based action is triggered.

Mitigations for the performance measure

- Added facilities for bicyclists
- Reduced posted speed limit
- Reduced vehicular travel lanes
- Access management to reduce high-access density

Additional strategies to mitigate high crash risks but that don't impact the calculated crash risk include driver and bicyclist safety courses and signage among many other strategies that may be identified in a Transportation Safety Action Plan.

Outcomes for the performance measure

- Increased multimodal reliability
- Improved safety for bicyclists
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing safety in areas with underserved populations

### 9.6.8 Pedestrian Crash Risk

Pedestrian crash risk score for a roadway section based on pedestrian behavior, roadway features, and other contextual factors such as land use. Pedestrian crash risk is calculated at the facility level but can be aggregated to a system-wide review. For example, ODOT has calculated pedestrian crash risk for all highways and then divided the highway segments into quintiles to identify the top 20 percent with the highest pedestrian crash risks based on both urban and rural contexts. See the Oregon Bicycle & Pedestrian Safety Implementation Plan from November 2020 for more information.

<u>Strength of the performance measure</u>

- The data needed is likely already available or can use assumptions to fill gaps.
- In 2020, ODOT calculated the pedestrian crash risks for all state highways.

<u>Limitations of the performance measure</u>

- Risk factors include land use factors that may increase pedestrian activity but may result in conflation with increasing crash risk. For example, proximity to schools or to transit stops may increase pedestrian activity level, which could lead to more frequent crashes, though the increase to the risk of crashes may not be directly affected (or decrease).

<u>Data needs for the performance measure</u>

Data collection for this measure is a medium to high level of effort, dependent on what inventory data is available. For ODOT's statewide systemic safety analysis completed in 2020, the pedestrian risk factors used included.

- Principal arterial
- Number of lanes (>= four lanes)
- High-access density
- No sidewalks (or only one side)
- Posted speed (>= 35 mph)
- Mixed use zoning
- Other zoning[3]
- Proximity to schools (one mile)
- Proximity to transit stops (1/4 mile)
- High population over the age of 64 (threshold of 16.8 percentt).

While vehicle volume is not explicitly identified in the analysis referenced above, it remains a risk factor regarding pedestrian safety. See ODOT Report SPR 779: Risk Factors for Pedestrian and Bicycle Crashes.

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[3] "Other" zoning includes all zoning classifications within the Oregon Spatial Data Library (OSDL) except for residential, commercial, industrial, mixed-use, and farm-use zoning. Examples of "Other" zoning including forest/federal lands, coastline, parks, and rangeland

Analytical methods for this performance measure

As part of the Oregon Pedestrian and Bicycle Safety Implementation Plan, ODOT implemented the NCHRP Research Report 893 methodology in 2020. This methodology uses risk factors to complete a systemic safety analysis aimed at identifying high risk locations for pedestrian and bicycle crashes along the state highway system. Systemic safety, opposed to the traditional review of crash history, allows practitioners to proactively identify high risk sites for potential safety improvements based on risk factors that often correlate to locations with low frequency but high severity crashes. Crash risk is a measure used by ODOT to assess bicycle and pedestrian safety.

To calculate pedestrian crash risks, apply the following steps:

1. Collect data for the chosen analysis roadway segments. If data is not available, apply assumptions to fill data gaps. For example, if posted speed data is not readily available in a geospatial format, posted speed could be assumed based on roadway classification (e.g., 25 mph for local roadways, 30 mph for collectors). Analysis segments should be broken every time a risk factor characteristic changes for the facility (e.g., when the posted speed changes from less than 35mph to more than 35 mph).
2. Determine for each analysis segment whether the pedestrian risk factor is present.
3. Add the risk factor weightings together for each analysis segment (weightings shown below based on urban or rural contexts). If a risk factor is present, the risk factor weight is added. If it is not present, then the risk factor weight is 0. If the risk factor is not applicable (e.g., shown as "- "in Exhibit 9-18, then do not include that risk factor in the analysis.

Exhibit 9-18 Pedestrian Risk Factor Screenings Weights

**RISK FACTOR SCREENING WEIGHTS: PEDESTRIANS**

| | Risk Factor Weights | |
|---|---|---|
| Risk Factor | Urban | Rural |
| Principal Arterial | 1.24 | 1.46 |
| Number of Lanes (>= 4 Lanes) | 1.55 | 1.73 |
| High-Access Density | 1.64 | — |
| No Sidewalks (or Only One Side) | 1.38 | — |
| Posted Speed (>=35 mph) | 1.83 | 1.63 |
| Mixed Use Zoning | 1.00 | — |
| Other Zoning | — | 1.45 |
| Proximity to Schools (1 Mile) | 1.03 | 1.17 |
| Proximity to Transit Stops (1/4 Mile) | 1.08 | 1.00 |
| High Population over the Age of 64 | 1.00 | — |

Source: Oregon Pedestrian and Bicycle Safety Implementation Plan

Threshold considerations for this performance measure
For this measure, the target is to reach a reduced risk factor. A threshold could be based on maintaining or decreasing the risk factor of a facility. A jurisdiction could also base a threshold off of existing conditions. If the risk factors of all facilities or of facilities of a specific roadway classification or higher are calculated, the risk factor value that separates the top 20 percent from the top 40 percent, or a similar binning process, could be used to determine when a safety-based action is triggered.

Mitigations for the performance measure
- Added facilities for pedestrians
- Reduced posted speed limit
- Reduced vehicular travel lanes
- Access management to reduce high-access density

Additional strategies to mitigate high crash risks but that don't impact the calculated crash risk include driver and pedestrian safety courses and signage among many other strategies that may be identified in a Transportation Safety Action Plan.

Outcomes for the performance measure
- Increased multimodal reliability
- Improved safety for pedestrians
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing safety in areas with underserved populations

### 9.6.9 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.

Example performance measures
- 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.

### 9.6.10 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.

Performance measures
- Access or junction within functional area of an intersection

Example evaluation criteria
- 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 are 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, percent of planned facilities that are built within a specified modal network, system redundancy, and availability of alternative routes, which could include streets, intersections, sidewalks and bicycle facilities. Connectivity and completeness are 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 Region's 1, 4 and 5.

Strengths of the performance measure
- Easily understood by the public.
- The planned system that is used as the basis for this measure will be highly dependent on the local agency. Their TSP needs to be up-to-date and have been vetted through a public engagement process.

Limitations of the performance measure
- While it may not be likely, the planned system could change whenever a TSP update or new plan document is created. Tracking progress over time could be impacted by these changes or show less progress depending on the changes

Data needs for the performance measure
Data collection for this measure is a medium to high level of effort, dependent on what inventory data is available. System completeness heavily relies on inventory data. Ideally, facility characteristics can be collected by block or roadway segment and stored as geospatial data accessible for review, calculation, and visualization in programs such as ArcGIS. The following facility characteristics are needed for different planned modal networks being assessed:

- Facility type
- Location
- Other characteristics determined for the complete system, such as number of roadway lanes, bicycle facility type, or connected pedestrian network

The planned future system must also be provided to create the comparison between what currently exists versus what is proposed. These planned networks would ideally be contained within a geospatial program such as ArcGIS.

<u>Analytical methods for this performance measure</u>
This method uses a simple percentage calculation based on planned and existing facility elements. The planned system will be determined by a local agency's transportation system plan, which must meet the requirements contained within several sections in OAR 660-012. System completeness is evaluated for each mode.

<u>Threshold considerations for this performance measure</u>
For system completeness, the target is to reach a 100 percent complete transportation network. But the reality of reaching that goal will vary greatly based on the existing conditions of the area that is being analyzed. In addition, the planned "complete" system may change over time, especially when Transportation System Plans (TSPs) or other planning documents are created or updated. A threshold could be based on maintaining or increasing the system completeness of an area. Options for threshold setting include:

- 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 9-19). 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 9-20. [4]

[4] 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.

Mitigations for the performance measure

- Added facilities for pedestrians and bicyclists
- Expanded transit coverage
- Added turn lanes and through lanes up to the planned system design standards
- New connections for all modes, such as new roadways, bicycle lanes, or multi-use paths

Outcomes for the performance measure

- Increased multimodal mobility and network connectivity
- Improved safety for pedestrians and bicyclists
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

**Exhibit 9-19 Shortest Network Path versus Straight-Line Distance**

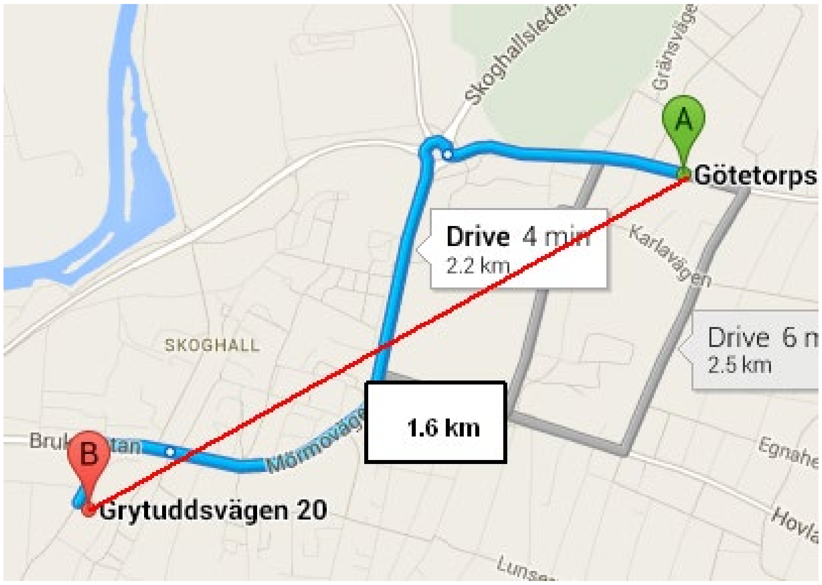
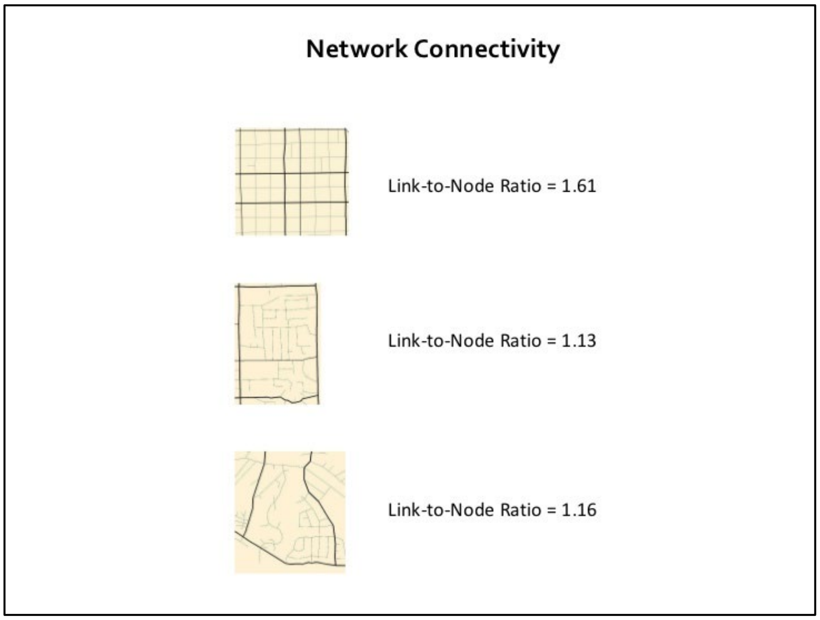


**Exhibit 9-20 Links/Nodes Ratio**




### 9.8.2 Out-of-direction Travel

<u>Example performance measures</u>

- 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.

### 9.8.3 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.

### 9.8.4 Bicycle Level of Traffic Stress (BLTS)

Bicycle LTS is an ODOT APM Chapter 14 methodology that rates the level of comfort of bicyclists traveling along or crossing a roadway. Scores range from 1 to 4, with 1 being the most comfortable and 4 being the least comfortable. 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 BLTS 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 BLTS of an entire route. Refer to APM Chapter 14 for procedures.

BLTS is not by itself an indicator of the potential use of a bicycle facility, which would need to consider additional factors such as the proximity and size of land use origins and destinations, topography, and competition with other modes. However, research indicates that most bicyclists prefer to bike on higher comfort facilities.

BLTS is well suited for high-level plans such as corridor and transportation system plans (TSP). This method can also be used in detailed refinement-level plans and projects as a screening or flagging tool.

Strengths of the performance measure

- Direct connection to roadway characteristics.
- Most data points tend to be readily available in local jurisdiction or statewide datasets for most roads.

Limitations of the performance measure

- Not sensitive to land use changes and changes to bicycle trip volumes.
- Data collection may require extensive manual review of aerial photos

Data needs for the performance measure

Traffic counts/daily volumes are not required except for higher-speed rural applications (APM 14.4).

- Bicycle facility: Bicycle facilities should distinguish between >= 7’ buffered bicycle lane, 5.5-7’ bicycle lane, 4-5.5’ bicycle lane, <4’ bicycle lane, frequent blockage of bicycle lane, shared lane, no facility, separated facility.
- Speed: Posted speed is typically available and can be used in this methodology. If there are identified areas where prevailing operating speed is known to be higher than posted speed, this could impact the results.
- Auto lanes per direction: The number of auto lanes per direction is typically available from ODOT or the local jurisdiction.

- Parking lane: The parking lane should distinguish the presence of the parking lane and if a bicycle lane is also available the combined width of the bicycle lane and the parking lane.
- Volume: Volumes for segments should be assessed in alignment with the APM Section 3.4 (Vehicle Count Surveys) section. In general, the following are found:
    - State Highways have AADT and hourly volumes available from ODOT's website.
    - Arterials and major collectors may have estimated daily volumes available through local transportation plans or count programs.
    - The functional classification may be used in place of volume as a criterion in several conditions: (1) On mixed traffic segments in suburban or urban areas and (2) for unsignalized intersection crossings without a median refuge.
- Functional Class: ODOT maintains networks of functionally classified roadways[5]. Roadways that are not included in ODOT's functionally classified network are considered local roadways.

<u>Analytical methods for this performance measure</u>
The methods of calculating BLTS are discussed in Section 14.4 (Bicycle Level of Traffic Stress). The methodology is modified from work originally documented by Mineta Transportation Institute. Analytical methods are available for segments, intersection approaches, and intersection crossings.

<u>Threshold considerations for this performance measure</u>
The following describes several potential ways a threshold could be established that is more detailed than a generic BLTS 1 or 2 standard applied to all or specific facilities by functional classification.

- A BLTS 2 is often used as the target as it will typically appeal to the majority of the potential bicycle-riding population and maximize the available bicycle mode share.
- When evaluating networks near schools (within ¼ mile), the desirable level of traffic stress is BLTS 1 because BLTS 1 is targeted at 10-year olds (5th grade) or parents of younger children. Elementary school-age children should be able to travel between homes and schools without having to cross arterial streets (BLTS 3 and 4). Ideally, elementary schools and their related attendance boundaries should be placed to allow at least a few BLTS 1 routes. Middle school and high school placement should not be limited to only BLTS 1 routes; however routes should be no more than BLTS 2 because older students can use these without difficulty.
- Percent of collector and arterials streets in priority areas with bicycle and pedestrian facilities that are rated with a BLTS 1 or BLTS 2
- Percent of jurisdiction able to be reached by BLTS 1 routes pedestrian or bicycle LTS score on a roadway segment, intersection, approach, or crossing
- Project study area network locations not meeting LTS threshold

[5] https://www.oregon.gov/odot/data/pages/functional-class.aspx

Mitigations for the performance measure

- Added facilities for bicyclists
- Enhanced bicycle facilities with increased buffer
- Reduced posted speed limit
- Reduced vehicular travel lanes
- Reorganized roadway space with parking as a buffer between bicyclists and vehicular travel lanes

Outcomes for the performance measure

- Increased multimodal mobility and network connectivity
- Improved safety for bicyclists
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

### 9.8.5 Pedestrian Level of Traffic Stress (PLTS)

Pedestrian LTS is an ODOT APM Chapter 14 methodology that rates the level of comfort of 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 PLTS 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 PLTS of an entire route. Refer to APM Chapter 14 for procedures.

PLTS is not by itself an indicator of the potential use of a facility for walking, which would need to consider additional factors such as the proximity and size of land use origins and destinations, topography, and competition with other modes.

PLTS is well suited for high-level plans such as corridor and transportation system plans (TSP). This method can also be used in detailed refinement-level plans and projects as a screening or flagging tool.

Strength of the performance measure

- Considers pedestrian comfort and safety, which may encourage increased pedestrian trips.
- Data collection overlaps with Bicycle LTS allowing both to be completed in tandem.

Limitations of the performance measure

- Some data are not typically readily available for all roadways, notably: sidewalk condition and width, buffer type and width, parking width, and presence of illumination.
- Not sensitive to pedestrian volumes.
- Data collection may require extensive manual review of aerial imagery, field visits, and other means.

Data needs for the performance measure

Data collection for this measure is a medium to high level of effort, dependent on what inventory data is available. Traffic counts/daily volumes are not required except for higher-speed rural applications.

- Segment analysis
    - Sidewalk condition and width
    - Buffer type and width
    - Bicycle lane width
    - Parking width
    - Number of lanes and posted speed
    - Illumination presence
    - General land use
- Crossing Analysis
    - Functional class
    - Number of lanes
    - Posted speed
    - Roadway average daily traffic (optional)
    - Sidewalk ramps
    - Median refuge
    - Illumination presence
    - Signalized intersection

Most data is available for state highway segments, through ODOT‘s databases. Data can be collected through aerial review or field review on a site-by-site basis. Data may be more challenging to collect systemwide, without conducting substantial manual review.

If analysis is intended to be completed across the network and data is not available in a local database, use the best available data and consider using assumptions to calculate an interim PLTS. For example, use the functional classification or land use context to approximate conditions of unavailable data. If data becomes available later, the analysis can be updated

Analytical methods for this performance measure

The methods of calculating PLTS are discussed in Section 14.5 (Pedestrian Level of Traffic Stress). As noted, this methodology was created to be a companion to the BLTS methodology. Analytical methods are available for segments and intersection crossings.

Threshold considerations for this performance measure

Section 15.4.3 (PLTS Targets) identifies several considerations for developing thresholds.

- PLTS 2 is generally a reasonable minimum target. Most pedestrians will find PLTS 2 acceptable.
- PLTS 1 is a good target for routes heavily used by children, including routes within a ¼

mile of schools. The area immediately adjacent to elementary schools should contain no PLTS 3 or PLTS 4 segments or intersection crossing.
- PLTS 1 is the preferred target for areas around middle and high schools; however, PLTS 2 facilities are generally acceptable.
- PLTS 1 is the preferred target for land uses including: downtown central business districts, medical facilities, areas near assisted living/retirement centers, and within ¼ mile of transit stops.
- Different land uses have different needs for the pedestrian network, for example, a large study area may have multiple targets for different portions of the area

<u>Mitigations for the performance measure</u>
- Additions or improvements to facilities for pedestrians
- Reconstructed pedestrian facilities to improve the condition and/or increase width
- Updated pedestrian facilities with increased buffer
- Reduced posted speed limit
- Reduced vehicular travel lanes
- Reorganized roadway space to provide parking as a buffer between pedestrians and vehicular travel lanes
- Added illumination, including pedestrian-scale illumination
- New or improved pedestrian crossings
- New or improved sidewalk ramps

<u>Outcomes for the performance measure</u>
- Increased multimodal mobility and network connectivity
- Improved safety for pedestrians
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

### 9.8.6 Walking and Biking Facility Condition

A visual high-level classification of facility condition, ranging from good to very poor. Walking and bicycling facility conditions are collected at the facility level but can be aggregated to a system-wide review.

<u>Strengths of the performance measure</u>
- Once collected, the data for facility condition is easy to work with in programs such as ArcGIS.
- Facility condition data can be used in other metrics, such as PLTS and system completeness.

<u>Limitations of the performance measure</u>
- This measure involves a time-intensive data process. There are some products on the market that are targeting the collection of facility condition data, but they are not currently common. For most applications of this metric, personnel time is used to either review facility condition in person or via aerial imagery review.

Data needs for the performance measure

Data collection for this measure is a medium to high level of effort, dependent on what inventory data is available. Walking and bicycling facility condition is a characteristic that can be collected by block or roadway segment and stored as geospatial data accessible for review, calculation, and visualization in programs such as ArcGIS. The following roadway or facility characteristics are needed for all analysis roadway segments.

- Location (to determine number of roadside miles)
- Walking facility type and condition
- Bicycling facility type and condition

Analytical methods for this performance measure

The methods of collecting walking and bicycling facility conditions are discussed in the APM Section 14.5.4 (PLTS Criteria). As noted, criteria and pictures for each category (good, fair, poor, very poor, no facility) are based off the Good-Fair-Poor (GFP) Pavement Condition Rating Manual for Bicycle and Pedestrian Facilities and the Pavement Distress Survey Manual developed by ODOT's Pavement Services Unit.

As part of the Oregon Pedestrian and Bicycle Performance Measure Recommendation report from September 2021, ODOT created a methodology for the percent of ODOT priority pedestrian and bicycle corridors with walking and bicycling facilities in fair or better condition. To calculate a similar percent of walking and bicycling facilities with fair or better condition, apply the following steps:

1. Confirm the corridors where the facility condition will be reviewed. For example, ODOT is interested in the walking and bicycling facility condition on their designated priority pedestrian and bicycle corridors.
2. Gather existing data for the analysis roadway segments. If data is not available, collect walking and bicycling facility condition data to fill the gaps.
3. In GIS or another geospatial program, conduct the following steps:
    a. **Setup**: Establish spatial correlation between the analysis roadway segments and walking and bicycling facilities if not already linked.
    b. **Target Roadside Miles**: Measure the total roadside miles located on the analysis roadways that should have walking and bicycling facilities, including bicycle lane, shared lane, shoulder bikeways, and sidewalk.
    c. **Fair or Better Condition Roadside Miles**: Measure roadway miles of walking and bicycling facilities in fair or better condition,
    d. **Percent Analysis**: Calculate the percentage of walking and bicycling facility roadside miles with fair or better condition using the equation presented below.

$$\begin{array}{l}\textit{Percent Analysis}\\ \textit{Roadways with}\\ \textit{Walking and}\\ \textit{Bicycling Facilities}\\ \textit{of Fair or Better}\end{array} = \frac{\begin{array}{c}(Roadside\ Miles\ with\ Walking\ Facilities\ of\ Fair\ or\ Better\\ +\ Roadside\ Miles\ with\ Bicycle\ Facilities\ of\ Fair\ or\ Better)\end{array}}{\begin{array}{c}(Target\ Roadside\ Miles\ for\ Walking\ Facilities\\ +\ Target\ Roadside\ Miles\ for\ Bicycle\ Facilities)\end{array}}$$

Threshold considerations for this performance measure
For walking and bicycling facility conditions, the target is to reach a 100 percent complete network of priority walking and bicycling facilities with fair or better condition. But the reality of reaching that goal will vary greatly based on the existing conditions of the area that is being analyzed. In addition, the planned walking and bicycling network of priority corridors may change over time, especially when Transportation System Plans (TSPs) or other planning documents are created or updated. A threshold could be based on maintaining or increasing the percent of priority corridors with walking and bicycling facilities in fair or better condition.

Mitigations for the performance measure
- Added facilities for pedestrians and bicyclists
- Reconstructed pedestrian and bicycle facilities to improve the condition

Outcomes for the performance measure
- Increased multimodal mobility and network connectivity
- Improved safety for pedestrians and bicyclists
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

### 9.8.7 Pedestrian Crossing Spacing

The distance between marked pedestrian crossings along a corridor or roadway segment. Pedestrian crossing spacing is calculated at the facility level but can be aggregated to a system-wide review.

Strengths of the performance measure
- Once collected, the data for pedestrian crossing spacing is easy to work with in programs such as ArcGIS.
- Different target crossing spacings can be set based on land use and context of the corridors.

Limitations of the performance measure
- Calculating percent of analysis roadway segments meeting target crossing spacing may require multiple iterations per report if different target crossing spacings are established (i.e. instead of using a single target for the whole study area).
- While jurisdictions may have pedestrian crossing data, it may be in different formats that require additional analysis steps to join into a single dataset. For example, ODOT’s pedestrian crossing data includes both point and line files.

Data needs for the performance measure
Data collection for this measure is a medium to high level of effort, dependent on what inventory data is available. Pedestrian crossing location data can be stored as geospatial data accessible for

review, calculation, and visualization in programs such as ArcGIS. The following roadway or facility characteristics are needed for all analysis roadway segments.

- Location (to determine number of centerline miles)
- Marked pedestrian crossing locations

<u>Analytical methods for this performance measure</u>
Table 300-4 of ODOT's **Highway Design Manual (HDM)**, includes recommended pedestrian crossing spacing ranges by urban context, as shown below.

**Exhibit 9-21 ODOT HDM Target Crossing Spacing**

| Urban Context | Target Spacing (ft.) |
|---|---|
| Traditional Downtown/ CBD | 250-550 |
| Urban Mix | 250-550 |
| Commercial Corridor | 500-1,000 |
| Residential Corridor | 500-1,000 |
| Suburban Fringe | 750-1,500 |
| Rural Community | 250-750 |

Source: ODOT Highway Design Manual

As part of the Oregon Pedestrian and Bicycle Performance Measure Recommendation report from September 2021, ODOT created a methodology for the percent of ODOT priority pedestrian and bicycle corridors meeting target crossing spacing. To calculate a similar percent of walking and bicycling facilities meeting a **750-foot target crossing spacing**[6], apply the following steps:

1. Confirm the corridors where pedestrian crossing spacing will be reviewed. For example, ODOT is interested in knowing pedestrian crossing spacing on their designated priority pedestrian and bicycle corridors.
2. Gather existing data for the analysis roadway segments. If data is not available, collect marked pedestrian crossing location data to fill the gaps.
3. In GIS or another geospatial program, conduct the following steps:
    a. Determine the marked crossings along each high priority corridor and locate marked crossings on the linear referencing method (LRM) system for the roadway

[6] The buffer distance used in Step 3b is half of the target crossing spacing. The Oregon Pedestrian and Bicycle Performance Measure Recommendation report used a target spacing of 750 feet for all priority corridors since it fell within the target spacing for most ODOT Highway Design Manual recommendations for target spacing by urban context. An agency using this methodology can select a different target spacing for all priority corridors or select different target spacings for different corridors and then adjust the buffer distance accordingly.

geospatial data. Consider what type of crossings will be included in the analysis. For example, will all marked crossings be included? Or only marked crossings that include enhancements like signal control, pedestrian refuge, or beacons?

b. Create a 375-foot buffer on the highway in the area around marked crossings. The buffer distance should be half of the target crossing spacing, as two crossings with adjacent 375-ft buffers will have 750-ft spacing between them.
c. Establish which marked crossings serve the priority corridors by referencing the LRM keys and milepoints for both data sets.
d. Clip out the priority corridor segments that are covered by the marked crossing buffer area.
e. Calculate the percentage using the equation presented below.

$$\begin{array}{l} \textit{Percent Analysis} \\ \textit{Roadways Meeting} \\ \textit{Target Crossing} \\ \textit{Spacing} \end{array} = \frac{\begin{array}{c} \textit{Centerline Miles Covered by Marked Crossing} \\ \textit{Buffer Area on Analysis Roadway} \end{array}}{\textit{Centerline Analysis Roadway Miles}}$$

<u>Threshold considerations for this performance measure</u>

For pedestrian crossing spacing, the target is to reach a 100 percent complete network of priority corridors or priority areas meeting target crossing spacings. But the reality of reaching that goal will vary greatly based on the existing conditions of the area that is being analyzed. In addition, the planned walking and bicycling network of priority corridors may change over time, especially when Transportation System Plans (TSPs) or other planning documents are created or updated. A threshold could be based on maintaining or increasing the percentage of priority corridors or priority area meeting target crossing spacings.

<u>Mitigations for the performance measure</u>

- New or improved pedestrian crossings, which may include ramps.

<u>Outcomes for the performance measure</u>

- Increased multimodal mobility and network connectivity
- Improved safety for pedestrians
- Decreased reliance on the automobile and reduced climate pollution
- Ability to focus on equity by increasing accessibility in areas with underserved populations

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

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

## References

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(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