9 TRANSPORTATION ANALYSIS PERFORMANCE MEASURES

9.1 Introduction

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

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

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

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

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

9.1.1 Selecting Performance Measures

Performance measures to be used in a system plan, corridor study, development review, or project alternatives analysis are driven by the goals and objectives of the project and are identified during scoping and methodology development. Appendix 9A is provided as a general guide to aid in the consideration of potential transportation analysis performance measures by plan or project type, including RTPs, TSPs, MMAs, Facility Plans, Development Review, and NEPA/project development. For each type of study, potentially applicable performance measures are noted and identified as best practice/recommended, supplemental, or for screening purposes.
Performance measures may require varying levels of efforts depending on factors such as project type and tools used. Refer to Chapter 2 for level of effort information.

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

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

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

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

A matrix of typical analysis performance measures including definitions, purpose, modes, level of resolution, data and tool requirements is available in SPR Report 716¹.

9.1.2 Purpose of this Chapter

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

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

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

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

Not addressed in this chapter

- Factors that contribute to or are components of performance but are not typically reported out as stand-alone performance measures. Although not performance measures per se, in many instances these can provide additional useful information on the causes behind performance, which helps to understand or interpret the performance measure result. This includes analysis outputs used as inputs into performance measure calculations performed by other methods. For example, forecasted traffic volumes and speeds which are used to report out air quality and noise performance, or predicted crashes or delays which are used in economic analysis to report out reduced travel time or crash reduction cost performance.
- Preliminary screening criteria or flags are more intermediate in nature, such as those that are used as inputs into following steps and are not typically reported out as performance
measures, for example preliminary signal warrants or turn lane criteria. Refer to Chapter 10.

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

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

9.2 Mobility

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

9.2.1 Volume to Capacity Ratio

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

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

Performance measures

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

Example evaluation criteria

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

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

\[
\frac{V}{C} = \text{volume/capacity}
\]

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

Critical Intersection Volume to Capacity Ratio (for signalized intersections)

\[
X_c = \left( \frac{C}{C - L} \right) \sum_{i \in cl} Y_{c,i}
\]

With

\[
L = \sum_{i \in cl} l_{t,i}
\]

Where

\( X_c = \) critical intersection volume to capacity ratio

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

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

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

- Standardized calculation methodologies and tools
- Easily applied and forecasted
- Planning level methods are available to estimate segment $v/c$ ratios. Volumes are estimated using AADTs along with $K_{30}$ factors and directional factors. Capacity estimates
can include the use of default values in estimating v/c ratios with the results reported out as below, near, or at capacity, as example, HERS-ST performs this level of v/c ratio analysis (refer to Chapter 7). For urban signalized arterials, segment capacity can be estimated using approximate green time to cycle time (g/c) ratio assumptions.

- Can be calculated for segments, intersections, approaches, and turn movements
- Travel demand models calculate a link-based demand to capacity ratio (d/c). Refer to Section 9.2.5 on model based demand to capacity ratios.

Requirements/Limitations

- Does not directly apply to or address safety, non-motorized vehicle modes, operational improvements, and other policy objectives often under consideration because these aspects of the transportation system cannot be directly measured in terms of vehicle demand and vehicle capacity.
- Identifies when capacity is exceeded, but does not address the extent or duration of congestion or queue spill-back effects. By definition, the volume of traffic using a roadway cannot exceed the roadway’s capacity. When demand exceeds capacity, a demand-to-capacity (d/c) ratio may be used (see section on Demand to Capacity Ratio). A d/c ratio that exceeds 1.00 indicates that more vehicles would use a roadway in a given time period if capacity constraints were not present.
- Is focused on a recurring peak period and does not address non-recurring congestion such as from incidents, weather, or special events.

9.2.2 Oregon Highway Plan Mobility Targets

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

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

Targets for state highway motorized vehicle mobility needs are established in the current OHP Policy 1F. Tables 6 and 7 within Policy 1F contain the v/c ratio targets for various combinations of highway classifications and surrounding land uses, with Table 7 applying to the Portland metropolitan area and Table 6 applying to the remainder of the state.
The targets vary the priority for mobility according to facility, area and designation type; mobility is a high priority on freeways, expressways and freight routes, but is a lower priority on District highways or local interest roads in Special Transportation Areas (STA) and Metropolitan Planning Organizations (MPO). It should be noted that the text within Policy 1F contains exceptions to the targets listed in these tables and, therefore, must be consulted as well. Furthermore, the OHP Registry of Amendments webpage should be checked for amendments to the OHP mobility policy where alternative mobility targets have been adopted; for an example refer to the report US 101 Seaside Alternate Mobility Standards.

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

<table>
<thead>
<tr>
<th></th>
<th>TIS/TIA</th>
<th>Projects</th>
<th>TSPs</th>
<th>Corridor and Refinement Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Conditions</td>
<td>OHP</td>
<td>OHP</td>
<td>OHP</td>
<td>OHP</td>
</tr>
<tr>
<td>Future No-Build</td>
<td>OHP</td>
<td>OHP</td>
<td>OHP</td>
<td>OHP</td>
</tr>
<tr>
<td>Future Modernization Build(s)</td>
<td>OHP</td>
<td>HDM</td>
<td>HDM (OHP in Portland Metro Area(^1))</td>
<td>HDM</td>
</tr>
</tbody>
</table>

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

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

**HDM FHWA-ODOT MOU**

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

### 9.2.5 Supplemental Vehicle Mobility Measures

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

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

**Quantity of Travel**

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

For more information refer to APM Chapters 6 and 7 and the ODOT Planning Section [Technical Tools](#) webpage.

**Percent Change in Volume**

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

**Performance measures**

- Design hour volume on segment or screenline

**Example evaluation criteria**

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

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

Performance measure

- Vehicle-miles of travel on segment or facility

Example evaluation criteria

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

\[ VMT = AADT \times \text{length} \]

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

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

\[ \text{Daily } VMT = AADT \times \text{Length} \]

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

\[ \text{Facility or System } VMT = \sum \text{Segment } VMTs \]
For trucks,

\[ Truck \text{ Miles Traveled} = AADT \times length \times \% \text{ trucks} \]

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

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

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

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

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

**Person-Miles Traveled (PMT)**

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

\[ PMT = AADT \times length \times vehicle \ occupany \]
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 like from a MPO travel demand model. Bicycle and pedestrian counts could also be used to determine PMT if trip lengths are known on a facility basis. PMT has the same limitations as VMT. Calculating PMT may be difficult as occupancy factors may not be available or not enough bicycle/pedestrian counts may be available. OSUM models assume a static value for auto occupancy by trip purpose. In JEMnR and SWIM models, auto occupancy reacts to land use and transportation policies and projects and can be reported. The analyst should coordinate with the modeler as to the applicability of its use.

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

\[
\text{Portion of Drive Alone Mode} = \frac{SOV \text{ VMT}}{\text{Total VMT}}
\]

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. Refer to APM version 1 Chapter 8. Vehicle throughput as reported in SimTraffic is known as “Vehicles Exited”.

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

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

Degree of Utilization/Congestion

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

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

Duration of Congestion

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

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

Example evaluation criteria

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

Exhibit 9-2: Sample Heat Map

Source: Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation, FHWA, 2005
For analysis purposes non-recurring congestion is typically assumed to start when the demand in the analysis time period exceeds capacity. The congested period ends when there is no longer excess or unserved demand in the analysis time period. Other threshold definitions of congestion are sometimes used for other purposes such as for performance monitoring or investment decisions, such as using a speed threshold and speeds obtained from a travel demand model. Travel speeds from a travel demand model are approximate and should only be used on a relative basis to compare alternatives/scenarios.

**Average Daily Traffic to Capacity Ratio (ADT/C)**

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

Performance measure

- ADT/C

Example evaluation criteria

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

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

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

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

Queue Length

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

Performance measures

- 95th percentile queue length

Example evaluation criteria

- 95th percentile queue length by approach (refer to APM v1 Chapter 7 and v2 Chapter 8)
- Queue blocking of turn or through lane
Typically a travel demand model run would be a constrained run. An unconstrained (infinite capacity) run can be requested that will show the full desired demand on a facility.

This means that for a given time period, there are more vehicles desiring to use a facility than it can accommodate. This is also known as oversaturation. The actual volume will never exceed the capacity of the facility. Instead, the excess demand (unserved trips) may do one or more of the following:

- Intersection queue blocking percentage exceeding 5% of peak hour
  - Queue spillback to railroad crossing
  - Queue spillback to functional area of intersection
  - Queue on exit ramp extending to deceleration area or mainline as calculated using design speed
  - Queue occurring in area with insufficient sight distance

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

A queue blockage or spillback condition should be reported when the duration exceeds five percent of the peak hour. See Chapter 8 of APM v1. Queue spillbacks need to be evaluated with other contextual information to determine the extent and nature of the problem. Spillback queues can reduce both safety and capacity. Spillback occurs when a queue at one intersection extends into a second signalized intersection. This is typically reported as the total length of oversaturated queue beginning from bottleneck where the queue started.

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

95th 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 v1 Chapter 7 for deterministic queue calculation procedures. Queuing is provided by microsimulation models where v/c ratios are high or conditions are congested (refer to APM v1 Chapter 8).

**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.
following: divert to other routes; change the time of the trip; distribute to other destinations; change the travel mode; or queue up to be served in following time periods (incurring additional delay).

Performance measure

- d/c ratio

Example evaluation criteria

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

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

Over capacity: d/c > 1.10

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

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

Travel Time

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

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

Example evaluation criteria

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

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

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

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

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

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

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

Where

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

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

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

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

**Average Delay**

Performance measures

- Average delay per vehicle (sec/veh)

Example evaluation criteria

- Average delay for intersection
- Average delay for lane group

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

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

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

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

\[
Vehicle\ Hours\ of\ Delay = \left[ \frac{Average\ travel\ time - threshold\ travel\ time}{traffic\ volume} \times \frac{60\ min}{hour} \right] \times average\ vehicle\ occupancy
\]

Where

\[Delay = \text{vehicle-hours of delay per given time period for the study segment}\]

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

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

### 9.3 Travel Time Reliability

Travel times can vary considerably by time of day, day of the week, and month of the year because of changes in traffic demand and/or capacity associated with recurring congestion,
incidents, weather and work zones. Everyday recurring congestion is common and most travelers expect and plan for some level of delay based on when and where they are going. The unexpected delay encountered by a traveler due to such things as weather, incidents and work zones can have a significant impact on the effectiveness of the transportation system. The goal of travel time reliability analysis is primarily to reduce non-recurring congestion. Travel time reliability is especially critical to freight.

Travel time reliability is a newer, emerging performance measure for the purposes of system and project planning, and attempts to represent the variability in travel time. It is used to evaluate corridor performance and strategies to reduce the variability and uncertainty of travel times, such as TSMO solutions. Travel time reliability measures account for the unexpected elements that conventional performance measures such as average travel time do not capture. An example reliability measure would be “the reliability of travel in the northbound direction on segment A from 4-5 pm for all weekdays except holidays over the course of a year”. The diagram in Exhibit 9-4 shows the typical dimensions of reliability in terms of time and space.

Exhibit 9-4 Reliability Analysis Time-Space Domain

Source: Estimating FAST Act Reliability Measures with the HCM6, January 24, 2017

Reliability quantifies the uncertainty in travel times that a traveler might experience from day to day, across different times of day, over a period of time from a few months up to a year. Key reliability time periods are defined below.
1. The reliability analysis period is the smallest time unit for which the analysis procedure is applied. In the case of freeway and urban street facility analysis, the analysis period is typically 15 min, although it can be of greater or lesser duration, at the discretion of the analyst. Alternative tools may define different analysis period lengths.

2. The study period is the sum of the sequential 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 number of days for which the reliability analysis is to be performed.

9.3.1 Travel Time Index (TTI)

The travel time index (TTI) is the primary measure of travel time reliability. For a given segment, TTI represents the ratio of the travel time for a point on the travel time frequency distribution divided by the free flow travel time. A sample travel time frequency distribution is shown in Exhibit 9-5.
Performance measure

- 80th Percentile TTI (TTI$_{80}$)
- 95th Percentile TTI (TTI$_{95}$ or PTI)

Travel Time Index

\[
\text{Travel Time Index} = \frac{80\text{th Percentile Peak Period Travel Time}}{\text{Free Flow Travel Time}}
\]

A TTI value can be calculated at any percentile of the travel time distribution. The 80th Percentile Travel Time Index (TTI$_{80}$) measures the travel time reliability of the roadway system during the peak period at the 80th percentile travel time.

TTI is a rough indicator of the severity of congestion, and is defined as the ratio of the travel time during the peak period to the free-flow travel time, where free-flow is an off-peak period of unobstructed traffic flow. An index of 1.0 indicates that the average peak travel time is the same as the free-flow travel time, so there is no delay in the system. The closer the TTI is to 1.0, the
more reliable travel time on the facility is for that time period and direction of travel. TTI_{80} of 1.3 shows that it will take 30% longer to travel in the peak time as compared to the free-flow time.

Planning Time Index (PTI) is a standard measure of travel time reliability and is an indicator of the variability in the average peak travel time. It is a special case of TTI that is typically computed as the 95th percentile of TTI (TTI_{95}). It reflects the near-worst case travel time and is an indicator of the extra time required to arrive at a destination ‘on-time’ 95 percent of the time. For a commuter it is the total travel time needed to ensure an on-time arrival to work 19 days out of 20. The 95th percentile is more likely than the 80th percentile to include longer travel times from non-recurring events such as incidents. PTI is typically calculated for segments or corridors.

\[
\text{Planning Time Index (PTI)}
\]

\[
\frac{\text{95th Percentile Travel Time}}{\text{Free Flow Travel Time}}
\]

TTI can be used to screen segments with high travel time variability, as well as to evaluate alternatives that improve reliability, such as TSMO strategies including incident management or ITS deployments.

Other variations on travel time index exist, such as those used for federal FAST Act reporting purposes. These include Level of Travel Time Reliability (LOTTR), defined as the ratio of the 80th percentile travel time to the 50th percentile travel time for Interstates and NHS routes, and Truck Travel Time Reliability (TTTR), defined as the ratio of 95th percentile truck travel time to the 50th percentile truck travel time reported for the Interstate Highway System. For more information on these measures, refer to the FAST Act website.

9.3.2 Tools to Calculate TTI

The following methods and tools are available to calculate travel time index.

**Highway Economic Requirement System (HERS-ST)**

HERS-ST can be used to perform a planning level analysis of reliability. The following describes the approach in use at this time. The method is based in part on the SHRP 2 L08 project \(^3\) urban streets framework, which employs scenarios to diagnose the causes of unreliable performance and to predict the impacts of specific operational improvements on reliability. Each scenario is a specific combination of demand, weather, incidents, special events, and work zones. Segment performance including average speed or travel time for each analysis period is calculated separately for each scenario using HCM methods.

For weather and incidents, special adjustment factors developed as part of Project L08 are used to adjust capacity and speed. The results are then summed and weighted according to the
The application of HERS-ST for reliability analysis is an evolving methodology. The process discussed here and in Chapter 7 represents the process currently in use. It may be modified as the result of a SHRP 2 research project currently underway.

In order to account for weather, incident, and work zone events, a number of capacity and demand adjustments are developed for the corridor. The analysis covers multiple demand and capacity adjustment factors to create event scenarios. The scenarios involve varying levels of volume demand, incidents and weather combinations that could be expected in the project area. The scenarios result in capacity adjustment factors that cover a combination of events from no impact (i.e. clear weather, no incident, no work zone) to heavy impact (i.e. heavy snow, fatal crash, long term work zone). The capacity adjustments cover ranges of events (i.e. weather) and have the largest impact although a large number of scenarios may likely show a probability of less than one percent. All scenarios should be included in the analysis to avoid skewing the results. For the US97 project, mentioned above, the HERS-ST reliability analysis utilizes 712 scenarios based on 8 demand adjustment events (percentiles) and 89 capacity periods.

A dataset is developed for the project analysis, consisting of uniform analysis segments, with minimal variation in basic parameters such as AADT, number of lanes, median width, and median type to name a few.

HERS-ST outputs the following performance measures directly.
• Average travel speed (mi/hr)
• Total hours of delay (hr/1000 VMT)
• Incident delay (hr/1000 VMT)
• Congestion delay (hr/1000 VMT)

Performance measures

• Travel Time Index
• Planning Time Index

The selected segment or facility length can have a significant effect on results of the reliability analysis. The effects of a bottleneck may be diluted if the facility length is too long.

HERS-ST is useful for sketch planning level reliability forecasting. It is the only method available to forecast reliability on mixed corridors and two-lane highways. The HERS-ST methodology is still evolving. At least a working-level expertise in HERS-ST is needed for this methodology. Contact TPAU for further information on using HERS-ST.

**HCM 6th Edition Reliability Methods**

More robust but data-intensive reliability methods have been developed and incorporated into the 6th Edition of the HCM. In these methods, a travel time distribution is generated for all days of the year, or a subset such as all weekday non-holidays. Reliability performance measures are calculated based on the generated travel time distribution.

The HCM 6 reliability methods are applicable to either freeway or urban street segments. The method starts by creating a base dataset for each segment. Then, reliability scenarios are generated for different combinations of demand, weather and incidents. Each scenario, segment and time period are modeled using HCM methods and adjustment factors to represent non-base demand, capacity, speed, and number of lanes. Scenarios are assigned to individual days/time periods using either deterministic or stochastic methods. Travel times are calculated for each time period, typically 15 minutes in duration. The individual time period travel times are then used to generate a travel time distribution for the year. A TTI distribution can then be created. TTI, PTI, VHD, and other reliability measures can then be calculated. These reliability methods have been incorporated into the latest versions of the HCM 6 FREEVAL and STREETVAL software tools.

The HCM 6th Edition method can be used to assess benefits of alternative ATDM strategies including demand management, weather management, incident management, work zone management and other special strategies. Published adjustment factors for ATDM or TSMO strategies are available from the literature, developed from before/after studies. Benefits are shown as reductions in measures such as TTI or PTI.
Volume distributions such as hour of day, day of week, and month of year proportions are developed from continuous traffic count stations (ATRs). Default distributions are available in the HCM if local data are not available.

The HCM 6th edition reliability measure can be used in data rich environments such as Portland metro area freeways, however, extensive data coding is required.

9.4 Level of Service (LOS)

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

9.4.1 Motorized Vehicle Level of Service

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

Performance measure

- Level of Service letter grade A-F

Example evaluation criteria

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

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

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

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

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

9.4.2 Multimodal Level of Service (MMLOS)

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

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

Pedestrian and Bicycle Level of Service

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

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

Performance measure

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

Example evaluation criteria

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

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

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

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

**Transit Level of Service**

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

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

9.4.3 Truck Level of Service Index

Truck Level of Service is a recently developed measure of the quality of service provided by a facility for truck hauling of freight, as perceived by shippers and carriers. Truck LOS was developed as part of NCFRP Report 31\(^{(5)}\). 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 6\(^{th}\) Edition.

Performance measure

- Truck LOS on highway facility

Example evaluation criteria

- Relative difference in facility Truck LOS letter grade

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

Where

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

\(U(x)\) = truck utility function, and
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.

$e$ = 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 $\leq 1.33$ (freeways and highways) or $\leq 3.33$ (urban streets),

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

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

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

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

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

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

(6)

9.5 **Accessibility**

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

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

9.5.1 **Accessibility for Motorized Vehicles, Pedestrians and Bicyclists**

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

Performance measure

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

Example evaluation criteria

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

The area or distance that can be accessed within a given travel time can be shown using isochrone lines or by shading of TAZs to reflect numbers or percent changes in accessibility variables. Isochrones are contour lines which show the spatial extent of the area or network that can be accessed from a given location given different travel time thresholds, such as 5 minutes, 10 minutes or 20 minutes. Travel demand models and GIS tools are typically used to produce isochrones lines for motorized vehicle travel, whereas GIS tools are typically used to measure bicycle and pedestrian accessibility. It is critical to measure actual network travel time and distance, not “as the crow flies”, especially for pedestrian and bicycle accessibility. Pedestrian network analysis which codes each side of a street separately and which includes improved crossings is superior to street centerline-based analysis, since lack of improved street crossings can be a major barrier to safe pedestrian travel. See Exhibit 9-6 below for an example of an isochrone map.

**Exhibit 9-6 Isochrones**
Accessibility may be used to evaluate land use scenarios/changes, such as those that increase density and diversity, for example Transit Oriented Developments (TODs). Travel demand models can evaluate these changes as well as RSPM for use in scenario planning (refer to Chapter 7).

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

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

**Bike, Walk and Transit Scores**

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

Such scoring methods may be identified using GIS, or using commercial products such as Walk Score, an application used in evaluating the accessibility of candidate residential properties. Commercial tools may create a combined measure or index that accounts for factors other than just travel time. For example, a more complete bicycle score might include consideration of topography. Other non-travel time based measures or indices may be included as well, such as crime statistics, or hilliness of an area. Scoring methods may be aggregated into a rating for an entire city, region or neighborhood, or can be localized to individual properties by address. Heat maps may be created to visualize variations in accessibility throughout an area.
Accessibility scores may be useful in a sketch planning level analysis, but may be limited to existing conditions only. Network-based accessibility measures can show improvements in accessibility when certain links or crossings are added to the network. Commercial software is generally used, as GIS analysis effort can be high, although there may be a cost associated with obtaining the data. Commercial software may not share the complete algorithm or data sources the score is based upon. ODOT has no proposed way to calculate these scores.

9.5.2 Accessibility for Transit Riders

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

Performance measures

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

Example evaluation criteria

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

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

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

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

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

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

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

9.6 Safety

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

9.6.1 Crash Rate

Crash rates are a commonly used safety performance measure for a wide range of planning and project analysis studies as part of identifying safety improvement needs. Crash rates are easy to calculate and require little data. Crashes should be based on the official data published by ODOT’s Crash Analysis and Reporting (CAR) Unit. AADTs are required for segments and Total Entering Volume (TEV) AADTs are required for intersections. See APM Chapters 3 and 4 for detailed information.

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 90th percentile intersection crash rate for similar intersection type (APM Exhibit 4-1)
• Crash rate exceeding site critical crash rate based on reference population of similar sites
• Pedestrian and/or bicycle involved fatal and severe injury crashes

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

Requirements/Limitations –

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

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

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

9.6.2 Safety Priority Index System (SPIS)

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

Example evaluation criteria

• Top five and ten percent SPIS locations
9.6.3 Change in Crash Frequency Using Crash Modification Factors (CMFs) or Crash Reduction Factors (CRFs)

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

Example performance measures

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

9.6.4 Excess Proportions of Specific Crash Types

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

Example evaluation criteria

- Target crash type or severity exceeding threshold

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

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

9.6.5 Expected or Predicted Crash Frequency

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

Example performance measures

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

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

\[
\text{Excess Expected Average Crash Frequency} = \text{Expected Crashes} – \text{Predicted Crashes}
\]

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

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

\[
\text{Net Change in Expected/Predicted Average Crash Frequency} = \text{Expected/Predicted No Build Crash Frequency} - \text{Expected/Predicted No Build Crash Frequency}
\]

9.6.6 Conflicts

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

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 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.

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 is highly influenced by the vehicle’s fuel efficiency (e.g., electric vehicles can cost a fraction to fuel relative to internal combustion vehicles, with hybrids somewhere in-between, depending upon the share of miles driven with electricity). Typical transit cost factors include bus fares and subsidies. Bike mode share is also affected by topography, and increasingly bike-share programs (e.g., Portland and Rogue Valley) and their cost schedule.

Performance measure

- Mode share

Example performance measures

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

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

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

9.7.2 Transit Service Miles per Capita

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

- Transit service miles per capita

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

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

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

9.7.3 Multimodal Mixed-Use Area (MMA)

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

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

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

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

9.8.1 **Network Connectivity and System Completeness**

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

Performance measure

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

Example evaluation criteria

- Percent local I-I versus regional external –internal or internal-external (E-I/I-E) versus external-external through trips (E-E) on highway – using select links relative to study area
- Percent completeness of bike and walk facilities within ¼ mile of transit stops or ½ mile of schools
- Percent of planned network with sidewalks and/or bicycle facilities
- Percent of network restricted to heavy vehicles
- Capacity available on parallel local facilities
- Ratio of shortest network path distance (driving, walking, or biking) to shortest straight-line distance (as shown in Exhibit 9-7). 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 9-8).²

² A higher index indicates that travelers have increased route choice, allowing more direct connections for access between any two locations. Links are the segments between intersections, nodes the intersections themselves. Cul-de-sac heads count the same as any other link end point. A higher index means that travelers have increased route
choice, allowing more direct connections for access between any two locations. According to this index, a simple box is scored a 1.0. A four-square grid scores a 1.33 while a nine-square scores a 1.5. Dead-end and cul-de-sac streets reduce the index value. This sort of connectivity is particularly important for nonmotorized vehicle accessibility. A score of 1.4 is an example threshold for a ‘walkable’ community.
**Exhibit 9-8 Links/Nodes Ratio**

<table>
<thead>
<tr>
<th>Network Connectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Link-to-Node Ratio = 1.61" /></td>
</tr>
<tr>
<td><img src="image2" alt="Link-to-Node Ratio = 1.13" /></td>
</tr>
<tr>
<td><img src="image3" alt="Link-to-Node Ratio = 1.16" /></td>
</tr>
</tbody>
</table>

**Out-of-direction Travel**

Example performance measures

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

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

**Intersection Density**

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

Example performance measures

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

9.8.2 Bicycle or Pedestrian Level of Traffic Stress (LTS)

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

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

Example performance measures

- Pedestrian or bicycle LTS score on a roadway segment, intersection, approach, or crossing
- Project study area network locations not meeting LTS threshold
Appendix 9A – Applicability of Analysis Performance Measures by Plan or Project Type

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

References


(3) Strategic Highway Research Program (SHRP) 2 L08 Project, Incorporation of Travel Time Reliability into the Highway Capacity Manual

(4) US-97: South Century Drive to United States Forest Service (USFS) Boundary: HERS-ST Reliability Analyses, Phase One, January, 2017


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