Division of Engineering ROC Task#8 - Re-Examining Level of Service as a Measure of Effectiveness for Roadway Improvements

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16. Abstract		

This report evaluates the effectiveness of Level of Service (LOS) as a metric for roadway improvements. The study examines alternative measures, such as Vehicle Miles Traveled (VMT) or Vehicle Hours Traveled (VHT) and other Measures of Effectiveness (MOE) to assess roadway performance beyond traditional peak-hour analyses. By analyzing practices from multiple state Departments of Transportation (DOTs), including California, Colorado, Minnesota, North Carolina, and Virginia, the report identifies best practices and operational methodologies that optimize design, enhance safety, provide access for modes, and address varying land use contexts. The findings suggest that a shift towards more comprehensive metrics like multimodal considerations can provide a more holistic look at how a corridor is operating for all modes. Additionally, looking outside peak hours to see how a corridor operations throughout the day was also discussed. Recommendations for modifying existing practices and guidelines are provided to align with evolving transportation goals, ultimately aiming to "right-size" Ohio's roadway network for improved functionality and sustainability.

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Acronym List

D/C	demand to capacity (also V/C)
DOT	Department of Transportation
Caltrans	California DOT
CDOT	Colorado DOT
MnDOT	Minnesota DOT
NCDOT	North Carolina DOT
ODOT	Ohio DOT
VDOT	Virginia DOT
EDT	Express Design Traffic
FHWA	Federal Highway Administration
GHG	greenhouse gas
HCM	Highway Capacity Manual
HCS	Highway Capacity Software
ICAT	Intersection Control Assessment Tool
LOS	level of service
MOE	measures of effectiveness
MPO	metropolitan planning organization
NCHRP	National Cooperative Highway Research Program
OATS	ODOT Analysis and Traffic Simulation
OLOS	Operational Level of Service
RTP	regional transportation plan
SHAMM	State Highway Access Management Manual
SPOT	Strategic Transportation Prioritization
STIP	State Transportation Improvement Program
TDM	Travel Demand Model
TSMO	Transportation Systems Management and Operations
V/C	volume to capacity (also D/C)
VHT	vehicle hours traveled
VMT	vehicle miles traveled

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Executive Summary

This report addresses the challenges the Ohio Department of Transportation (ODOT) faces when evaluating traffic operations and includes discussion about traditional metrics, other state DOT traffic evaluations, national research on traffic operations, roadway typology comparisons, and recommendations for ODOT moving forward.

The research identified various states that employ unique approaches to assess roadway and intersection improvements, with a growing emphasis on safety, multimodal accessibility, and environmental sustainability. Three state DOTs (California, Colorado, and Minnesota) focus on vehicle miles traveled (VMT) as a key metric when evaluating transportation options. These states also rely on mitigation strategies to offset induced VMT that may occur from roadway expansion. Two other state DOTs were also reviewed (North Carolina and Virginia). These states both provide a standardized process to prioritize projects via operational performance combined with other measures of effectiveness (MOEs).

The research also identified national reports that focused on operational performance:

- **National Cooperative Highway Research Program (NCHRP) 1036** identified key metrics related to a 24-hour operational framework for roadway cross-section reallocation. This framework shifts the thinking from peak-hour performance to identifying which cross-section would operate best for all modes of transportation throughout the day.
- **NCHRP 618** provides a comprehensive list of performance measures for operational performance, including a checklist for practitioners to determine a project's performance measures; it also highlights techniques to focus on during the project development process.
- **Federal Highway Administration- (FHWA-) HRT-11-064** focuses on the need to provide consistent analysis throughout the project life cycle – discussing approaches from sketch planning through design. The guide breaks down MOEs by typology, analysis stage, and category and discusses competing analysis tools and ways to select "official" output results during the project.

This report also provides ways that state methodologies can change based on roadway classification. States have autonomy to implement their own approach on the state or U.S. highway system but need to lean on the local division of FHWA when dealing with interstate facilities. Regardless of the roadway class, states should identify and prioritize projects that align with their policies and goals in early planning stages before starting design stages.

The culmination of the research into state DOTs, national programs or documents, and roadway classifications led to the following recommendations for ODOT:

- Update the *ODOT Analysis and Traffic Simulation Manual*
    - Shift from AM and PM peak hour to the "two highest hours"
    - Report area-wide VMT, vehicle hours traveled, and delay for all TransModeler projects
    - Include metered flow into TransModeler analysis area
    - Provide analysis results for an interim year when the design year is oversaturated
    - Include TransModeler as a requirement for interchange analysis in congested areas
    - Test the sensitivity of volumes (higher or lower) to gauge operational performance
    - Adjust the turning movement count data collection time frame in metropolitan planning organization areas to 6 a.m. to 8 p.m.
    - Adjust the operational goals section for unsignalized intersections and provide operational context examples to use in congested or high-growth areas

- Update the *State Highway Access Management Manual* to refer to *ODOT Analysis and Traffic Simulation Manual* level of service targets
- Right-size its infrastructure
  - Provide a low-cost countermeasure first policy for near-term improvements and delay the need for a major reconstruction
  - Refocus on non-intrusive solutions through technology enhancements, demand management, signal timing, and other Transportation Systems Management and Operations strategies
  - Continue to implement a performance-based project development process
  - Develop a transparent prioritization process that incorporates weighting and other metrics similar to Virginia DOT and North Carolina DOT
  - Continue to innovate on design to reduce overall pavement area through creative intersections and interchange concepts
  - Incorporate multimodal considerations to provide a more balanced approach to transportation infrastructure enhancements that improve all modes in a context-sensitive manner

In conclusion, this report highlights key insights from various state DOTs and national research and provides strategic recommendations for ODOT to implement to help right-size infrastructure investments going forward.

1 Problem Statement

State Departments of Transportation (DOTs) and municipalities throughout the country have their own unique approaches to dealing with increasing traffic congestion on their roadways. From long-range planning to analysis approaches to prioritization to alternatives development and refinement to construction, traffic operations play an important role in the project development process. The Ohio Department of Transportation (ODOT) seeks to gain insight to answer the following questions:

- What other methods and goals (besides peak-hour level of service [LOS] analysis) are states using to determine potential roadway/intersection improvements and their effectiveness?
- Do states have different requirements for interstates/freeways as compared to other road classifications or those located in cities or villages?
- What national research has been done on this topic?

A potential benefit of this research would be revising ODOT's traffic analysis goals to optimize the design of Ohio roadways to improve safety. This could mean less pavement to maintain and lower construction costs as Ohio looks to "right-size" the roadway network for the future.

2 Research Background and Approach

To conduct this research, the study team broke the questions listed in **Chapter 1** into the following tasks and objectives:

- Summarize alternatives to peak-hour LOS findings from five DOTs with a wide range of state-driven approaches
- Summarize alternatives to peak-hour LOS findings from three national research projects
- Summarize the operational methodologies DOTs use on different functional classifications of roadways or different land use contexts (i.e., urban versus rural)
- Provide recommendations for potential modifications to existing DOT operational thresholds, practices, and guidelines to help right-size future capital projects

Recommendations for future research or guides are also included.

The following sections provide a list of DOTs, national research, outreach, and ODOT manuals that were reviewed or referenced for this study. A complete list of citations can be found in **Chapter 5**.

2.1 Review of State Procedures, Tools, and Guidance

The study team reviewed state procedures, tools, and guidance for nine state DOTs relating to LOS and measures of effectiveness (MOEs). The list was reviewed by the project team and reduced to five state DOTs. Brief summaries were developed for the following state DOTs:

- California DOT (Caltrans)
- Colorado DOT (CDOT)
- Minnesota DOT (MnDOT)
- North Carolina DOT (NCDOT)
- Virginia DOT (VDOT)

The summary pages in **Chapter 3** detail the current policies and procedures state DOTs use for operational assessment of state assets. The summaries also touch on alternative MOEs and how states use operational data to prioritize and develop project lists for inclusion in long-range plans or State Transportation Improvement Program (STIPs).

2.2 Review of National Research

The study team reviewed available research relating to MOEs or alternative approaches to LOS. As the team delved into available research, it became apparent that limited national research exists on alternatives to LOS because most research is incorporated into the Highway Capacity Manual (HCM) as new chapters (i.e., pedestrian LOS, interchange or alternative intersection LOS with extra distance travel time). Additionally, other available research is generally biased toward specific modes of travel. The project team agreed to use the following reports and developed brief summaries of each:

- **National Cooperative Highway Research Program (NCHRP) Report 1036**: *Roadway Cross-Section Reallocation: A Guide* (2023)
- **NCHRP Report 618**: *Cost-Effective Performance Measures for Travel Time Delay, Variation, and Reliability* (2008)
- **Federal Highway Administration- (FHWA-) HRT-11-064**: *Guide on the Consistent Application of Traffic Analysis Tools and Methods* (2011)

2.3 Road Classification Comparison

The study team understands that the acceptable level of congestion can change considerably depending on the facility type or land use context. A state highway near the center of a busy metropolitan area may have different operational needs and expectations when compared to a rural interstate. To investigate this, the project team reached out to the five state DOTs for a virtual interview. The team was able to meet with the following:

- NCDOT
- MnDOT

Because the team was unable to connect with some state DOTs, a supplementary review of roadway classification and land use context from state DOT summaries was incorporated into this section of the research.

2.4 Identify Best Practices and Provide Suggestions

The last main objective of the research was to identify best practices and provide suggestions about potential modifications to current ODOT practices going forward. The study team understands the ripple effect of any change in targets or methodologies as it relates to state procedures; this document will capture these ripples at a high level. The suggestions for potential modifications focused on three ODOT references:

- *ODOT Location & Design Manual, Volume 1 – Roadway Design*
- *ODOT Analysis and Traffic Simulation (OATS) Manual*
- *State Highway Access Management Manual (SHAMM)*

2.4.1 ODOT Location & Design Manual, Volume 1 – Roadway Design

The guidance figure from ODOT on LOS is shown in **Table 1**. ODOT notes that “this table should be used as guidance. The designer should use judgement to choose a design level of service that is practical for each location.”

Table 1. LOS Guidance from ODOT Figure 301-1

Functional Classification	Locale and Terrain			
	Rural			Urban & Urbanized
	Level	Rolling	Hilly	
Interstate, Other Freeways, and Expressways	B	B	C	C or D
Arterial	B	B	C	C or D
Collector	C	C	D	D
Local	D	D	D	D

LOS definitions noted in **Table 1** include the following:

- **LOS A**: Free flow, with low volumes and high speeds
- **LOS B**: Stable flow, speeds beginning to be restricted by traffic conditions
- **LOS C**: In stable flow zone, but most drivers are restricted in freedom to select own speed
- **LOS D**: Approaching unstable flow; drivers have little room to maneuver
- **LOS E**: Unstable flow, may be short stoppages
- **LOS F**: Forced or breakdown flow

2.4.2 OATS Manual

The OATS manual was developed to provide practitioners with a guide that establishes uniform methodologies for traffic analysis, including Highway Capacity Software (HCS) (deterministic) and TransModeler (microsimulation) for scoping, study area limits, tool selection, data collection, analysis guidance, tool guidance, and documentation.

2.4.3 State Highway Access Management Manual

The State Highway Access Management Manual establishes policies and standards that support development and access management while also balancing the goals of reducing congestion, minimizing delay, preserving capacity, and improving safety on the state highway system. This manual provides guidance about how to manage access to state highways to ensure that the safety of the public is prioritized while also preserving operations.

3 Research Findings

During the review of state DOT procedures and available research, two distinct schools of thought arose related to MOEs and the traditional peak-hour LOS approach:

- **Approach #1**: Utilize MOEs to understand operations and help drive alternatives development. LOS should be supplemented with real-world metrics (such as travel times) to provide context to a nontechnical audience. This approach tries to achieve intended LOS targets but recognizes that there can be diminishing returns at a certain level and can therefore accept LOS E or LOS F provided that the delay per vehicle is greatly improved for the cost of the project.
- **Approach #2**: Vehicular LOS is a secondary MOE to the main priority of providing access for all modes of transportation. Project objectives should establish a modal hierarchy emphasizing the needs of vulnerable users. Objectives also typically highlight the need to reduce vehicle miles traveled (VMT) and greenhouse gas (GHG) emissions, minimizing the amount of traditional

roadway widenings and focusing more on safety, accessibility, and Transportation Systems Management and Operations- (TSMO-) related solutions. This approach does not believe that a new interchange project should have major congestion or queues but rather emphasizes the need to provide access to all users during the project development process and does not weigh traffic operations as high as other project metrics.

Both approaches have been successfully implemented by different state DOTs based on what the state legislature and the DOT's goals are for its constituents. Officials in California, Colorado, and Minnesota have tailored their approaches for the transportation system to fit the wants and needs of their citizens. This leads to increased spending on transit, trails, and other infrastructure or programs that help reduce overall VMT. Other states may follow a more traditional approach to traffic operations and continue to expand or enhance their systems to meet the needs of their constituents.

3.1 In-Depth Review of DOT Best Practices, Lessons Learned, and Challenges

The project team found that all states still use LOS. However, there are states that choose whether to use LOS as a primary MOE during the alternatives development or prioritization process. While a state is not going to recommend an improvement at an interchange that would cause a bottleneck, some states may emphasize the safety performance of a corridor over operations and will opt for calming traffic and reducing crossing distances for pedestrians. Because these solutions may increase travel times along a corridor, states should manage priorities depending on the needs of all constituents.

The project team initially reviewed DOTs in nine states and their practices. A matrix, shown in **Table 2**, was presented to ODOT during a monthly update meeting to narrow the list down to five: California, Colorado, Minnesota, North Carolina, and Virginia. These state DOTs provide a spread geographically and in terms of agency goals and objectives. Brief summaries for the five state DOTs are listed in **Appendix A**. Highlights from each state summary are included in the following sections.

Table 2. Initial DOT Screening Matrix

State	Operations/Capacity MOEs	Carried Forward?
California	• VMT	Yes
Colorado	• Colorado Intersection Control Assessment Tool • Operation Level of Service	Yes
Florida	• Percent of person-miles that are reliable • Truck Travel Time Reliability Index	No
Minnesota	• VMT	Yes
North Carolina	• Strategic Transportation Prioritization • Express Design Traffic Evaluation • Crash duration (highway reliability)	Yes
Oregon	• Volume to Capacity Ratio • VMT • Ratio of Annual Average Daily Traffic to Hourly Capacity	No
Texas	• VMT • Annual delay per person	No
Virginia	• Person throughput • Person hours of delay	Yes
Washington	• Percent of person-miles traveled that are reliable	No

3.1.1 California DOT

Caltrans was the largest DOT reviewed. In 2020, local jurisdictions throughout California adopted Senate Bill (SB) 743, which reduces automobile trips while promoting alternative modes of travel. Local agencies are required to develop a regional transportation plan (RTP) that meets emissions goals established by SB 743.

More details about the Caltrans MOE approach can be found in **Appendix A1**.

Development Projects

The bill requires local agencies to set limits on VMT thresholds for development projects. If VMT thresholds are not met, developers can implement mitigation measures such as parking restrictions to meet the thresholds. VMT per capita thresholds are split by area (for example, VMT per capita thresholds in suburban areas are higher than in central business districts).

Transportation Infrastructure Improvements

If a widening project is recommended in the RTP or a local agency wants to widen a specific roadway that is not included in the RTP, the following mitigation metrics can be used to offset any future increase in VMT caused by the roadway expansion by combining active transportation elements, transit enhancement, and travel demand management strategies:

- Active transportation
- Land use
- Travel demand management
- Transit service improvement
- Local road networks/connectivity
- Micromobility
- Telecommuting
- Schedule shifting
- Road diets
- Pricing
- Lane management
- Parking pricing/restrictions
- Park-and-ride lots
- Land preservation

Other Metrics Considered

During the development of SB 743, there was discussion about the use of other MOEs to supplement or replace LOS, including fuel use, automobile trips generated, multimodal LOS, and vehicle hours traveled (VHT). After consideration, the Office of Planning and Research selected VMT as the primary metric of choice due to its usefulness in measuring GHG emissions and other environmental impacts and because it is already used in California for air quality analyses. Additionally, other metrics require specialized models or software that may not provide a consistent methodology throughout the state.

3.1.2 Colorado DOT

CDOT has implemented a similar approach as Caltrans to statewide transportation investments. Colorado passed several policy directives (12, 1601, and 1610) relating to GHG emissions, VMT targets, travel demand management strategies, and GHG mitigation measures. Additionally, Colorado uses two tools for project operations evaluation and project prioritization: Intersection Control Assessment Tool (ICAT) and Operational Level of Services (OLOS).

More details about CDOT's MOE approach can be found in **Appendix A2**.

Policy Directives

Policy Directive (PD) 12 helps guide future investments in Colorado's transportation system; it includes per capita VMT reductions of 1 percent, transit expansion goals, and GHG emissions reduction by 60 percent by 2037. To reach these goals, total driving must be reduced and personal use and fleet vehicles electrified.

PD 1601 provides guidance about new interchange projects along the state system. It includes travel demand management strategies to reduce average daily traffic at new interchanges or modify an existing interchange. The directive establishes a target of 3 percent VMT reduction in a metropolitan planning organization (MPO) region or 1 percent VMT reduction elsewhere in the state.

PD 1610 provides guidance about mitigation measures. There is some overlap with Caltrans metrics because both approaches use similar research and methodologies to calculate VMT offset from mitigation measures. Mitigation strategies include the following:

- **Pedestrian and bicycle strategies**
  - New facilities (bike lanes, sidewalks, trails, complete streets)
- **Transit strategies**
  - New/increased fixed-route service
  - New/increased demand-response service
  - Reduce fares
  - Bus priority treatments
- **Parking strategies**
  - Additional parking fees
  - Unbundle residential parking
  - Eliminate parking minimums (set low maximum)
- **Travel Demand Management strategies**
  - Commute trip reduction programs
  - Vanpool or carshare
  - Telework
- **Traffic operation strategies**
  - Retime/optimize arterial signals
  - Add roundabouts
- **Land use strategies**
  - Increase residential and job densities
  - Transit-oriented development

Prioritization Tools

Colorado's ICAT allows CDOT to provide a transparent process during alternatives development and refinement. The spreadsheet-based tool combines right-of-way, safety, roadway context, operations and maintenance, and overall costs to score intersection alternatives in stage 1. Alternatives that pass stage 1 move on to stage 2, where more detailed project costs, traffic operations, safety, environmental impacts, and stakeholder support are tabulated into a Final ICAT Stage 2 score.

Colorado developed OLOS to evaluate the performance of state facilities relative to the performance of similar facilities. The methodology is based on the Planning Time Index combined with probe data speeds and safety metrics from other state procedures. All the information is provided in a dashboard on CDOT's website.

3.1.3 Minnesota DOT

Minnesota passed legislation similar to Caltrans and CDOT in 2023 relating to GHG and VMT targets. As of this report, it is the most recent state to adopt procedures reframing the DOT approach around the transportation system.

More details about MnDOT's MOE approach can be found in **Appendix A3**.

House File 3436

The main goal of House File (HF) 3436 is to reduce VMT per capita by 20 percent by 2050 to meet GHG targets. This requires all projects on major highways and MnDOT's trunk highway system to be assessed to ensure conformance with the new guidance and provide mitigation options if the project increases VMT. The state instituted working groups to establish analysis methods and definitions as to what is considered a "capacity expansion."

Discussion with MnDOT

The project team spoke with the group tasked with implementing HF 3436 and discussed how previous legislation from California, Colorado, Washington, Oregon, and other states was used to develop the legislation. The most impactful discussion topic centered around providing access for all users. The example MnDOT provided dealt with travel times along a corridor. The state noted that traditional operations analysis has always tried to reduce travel times for users. However, increased travel speeds and traffic volumes can be detrimental to users who are not in a personal vehicle. Understanding a corridor's holistic picture for all users and shifting the narrative in this regard are MnDOT's focus.

Additionally, MnDOT talked about HF 3436 in terms of other mitigation strategies that agencies use during project development. For example, during the environmental process, if a wetland is disturbed during the construction of a transportation enhancement, there are standard procedures in place to reconstruct or mitigate wetland impacts. MnDOT aims to re-create this mitigation process for VMT using similar metrics as used in California and Colorado. (Refer to **Section 3.1.1** and **Section 3.1.2** for more information.)

Finally, MnDOT noted challenges to implementing mitigation metrics, specifically land use policy changes. Previous research has shown the effect land use policies can have on regional VMT. MnDOT staff discussed the need to figure out how to ensure a municipality implements land use policy changes long term as part of a mitigation strategy and not simply use it as a tool to get an expansion project across the finish line.

3.1.4 North Carolina DOT

NCDOT's procedures were reviewed due to its Strategic Transportation Prioritization (SPOT) and Express Design Traffic (EDT) prioritization process and the early adoption of TransModeler simulation guidelines. As of this report, NCDOT is one of three DOTs (in addition to ODOT and Kentucky Transportation Cabinet) with standards in place for using TransModeler.

More details about NCDOT's MOE approach can be found in **Appendix A4**.

Prioritization Process

NCDOT uses standardized modeling procedures to provide an initial operations assessment that feeds into an overall prioritization score:

- **SPOT:** Considers all projects in the state's long-range plans and develops a project score. One element of the scoring rubric relates to travel time benefits. The program looks at near-term needs and a horizon year of 10 years.
- **EDT evaluation:** Looks at LOS for the existing and horizon year (20 to 25 years) for the local area's transportation plan. This step helps identify whether the metropolitan or regional transportation plan was over- or under-designing the project to improve a corridor's congestion to an acceptable LOS.

These processes help ensure NCDOT projects start on the right foot and help practitioners understand which alternatives will move past the initial screening process and each option's benefits.

Simulation Guidelines and MOEs

NCDOT established TransModeler guidelines in 2016 that follow a regimented process to develop, calibrate, and evaluate alternatives. The guidelines highlight the need to pull LOS metrics during alternatives evaluation and show that many MOEs can be used to supplement LOS analyses to provide context for specific corridor or systemwide needs. The MOEs include the following:

- Number of trips
- Average trip length
- VMT
- VHT
- Average speeds
- Total delay or average delay per vehicle
- Total (or average) stopped time per vehicle
- Total (or average) number of stops per vehicle
- Travel time
- Average speed
- Segment speed
- Planning Time Index

The guidelines also highlight the need to continue to enhance reporting tools, spreadsheets, and figures (such as heat maps) that help tell the story about the need for a project and/or the benefits a project might provide to the public.

3.1.5 Virginia DOT

VDOT's procedures were reviewed due to its SMART SCALE process to prioritize trasnportation projects for funding. VDOT also has a robust *Traffic Operations and Safety Analysis Manual* that discusses MOEs and provides unique add-ons to operational analyses.

More details about VDOT's MOE approach can be found in **Appendix A5**.

SMART SCALE

In 2014, legislation was signed that created a measurable, transparent prioritization process that helped identify the right projects to meet the most critical transportation needs. This bill was renamed "SMART SCALE" in 2016, which stands for System Management and Allocation of Resources for Transportation: Safety, Congestion, Accessibility, Land Use, Economic Development, and Environment.

The evaluation measures fall into six categories that are weighted differently across typologies throughout the state: Safety, Congestion, Accessibility, Land Use, Economic Development, and Environment. To mitigate congestion, the evaluation process focuses on person throughput and person hours of delay using FHWA's CAP-X analysis tool.

Traffic Operations and Safety Analysis Manual

VDOT's operations and safety manual provides guidance about software analysis tools and corresponding MOEs that can be obtained from each tool. Unique features from the manual include the following:

- **Acknowledgment of peak spreading**: Emphasis on the need to establish larger analysis periods or the use of specific tools when peak spreading has or may occur
- **Acknowledgment of oversaturated conditions**: Discussion on the limitations of software in oversaturated conditions and how to select the right tool in those cases
- **Roundabout analysis**: As of 2020, recommendation to use SIDRA's Standard model for roundabout analysis
- **Sensitivity testing**: VDOT project manager recommendation for a sensitivity analysis if there is an increased amount of uncertainty in traffic forecasts (for example, modifying traffic demand up and down by 10 percent to understand change in MOE results)

3.2 In-Depth Look at National Research

The project team reviewed available national research relating to MOEs or alternative ways to approach traditional LOS metrics. Two-page summaries from the available research are included in Appendix B. Highlights from each research summary are listed in the following sections.

3.2.1 NCHRP Report 1036

NCHRP Report 1036 is the most recently published research that was analyzed. This research project focused on safe design and complete streets, and key operations-related takeaways center on analyzing a corridor on a 24-hour framework using these four key metrics:

> More details about NCHRP Report 1036 can be found in **Appendix B1**.

- **Hourly demand-to-capacity ratio**: Determines how many hours of the day a facility is overcapacity.
- **16-hour efficiency metric**: Looks at the core 16 hours of a day (5 a.m. to 9 p.m.). If the demand-to-capacity (D/C) ratio is more than 0.6, the corridor is considered efficient. If the D/C ratio is less than 0.6, it is deemed inefficient. This analysis highlights that excess capacity is not a benefit during off-peak times because it can lead to excessive speeding.
- **16-hour excess capacity metric**: Indicates any unused capacity during the core 16 hours of a day.
- **Total hours below capacity**: Highlights how many hours of the day a facility is undercapacity.

The report includes **Figure 1** to drive home the idea that a roadway should not be sized for the peak hour and that a 24-hour framework provides a more holistic approach to roadway reallocation.

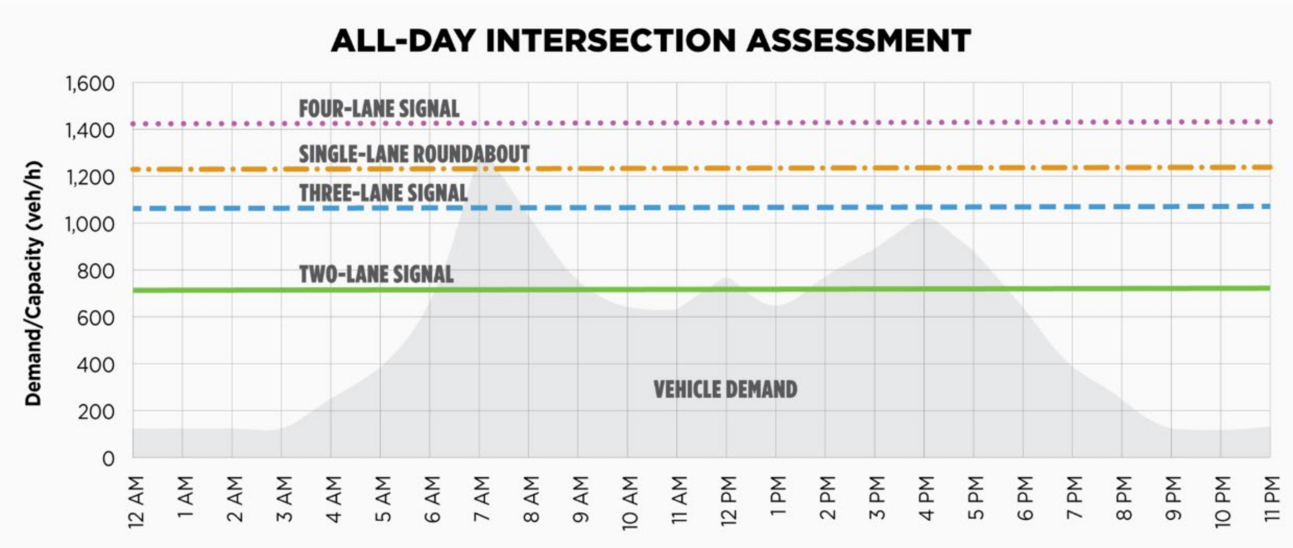


Figure 1. All-day intersection assessment example

NCHRP Report 1036 also notes that research has shown that as cities remove vehicle lanes, they find that traffic volumes shrink in total instead of diverting or rerouting to nearby local streets. This is the reverse of induced demand seen from capacity expansion projects. The report shares examples of how agencies have shifted the way operations are considered during project development. This includes examples like Portland’s modal hierarchy, which establishes the most important modes of transportation when developing and analyzing concepts during project development.

3.2.2 NCHRP Report 618

NCHRP Report 618 research focuses on cost-effective approaches to selecting and analyzing performance measures. It highlights the need to develop a process for performance measure selection on a project-by-project basis. Report highlights include the following:

> More details about NCHRP Report 618 can be found in **Appendix B2**.

- A discussion on how the goals of each project should help determine performance measures – not the ease of data collection
- Checklist for practitioners to use when developing a set of performance measures
- Available performance measures relating to travel time, delay, congestion, and reliability
- Solutions such as travel demand management and TSMO strategies to improve congestion and reliability in a non-intrusive manner

3.2.3 FHWA-HRT-11-064

FHWA-HRT-11-064 research focuses on the project development process and how to weave in analysis during different project stages. It provides guidance on when and where to implement sketch planning tools, Travel Demand Models (TDMs), deterministic tools, microsimulation tools, or optimization tools and what MOEs each tool provides. Highlights from the guide include the following:

> More details about FHWA-HRT-11-064 can be found in **Appendix B3**.

- Explains the need to provide a consistent analysis throughout the project to reduce subsequent costs for analysis (i.e., updating an analysis instead of starting from scratch) and to maintain credibility through the project life cycle (i.e., providing a consistent story of operations from sketch planning through design).
- Emphasizes the importance of the analyst identifying whether a tool or approach is not going to provide results that can distinguish among alternatives. The ability to pivot to a different approach that can provide quantifiable results is valuable.
- Breaks down MOEs by typology, analysis stage, and category and provides tables that break down these elements.
- Discusses competing analysis tools and what to select as the “official” value for a specific analysis. It recommends giving greater confidence to more sophisticated tools but notes that it is up to the analyst to understand the approach of every tool and pick a numerical value that is either A, B, or somewhere in between.
- Provides a discussion on visualization, highlighting the need to understand the audience and provide simple and clear graphics that illustrate the intended message.

3.3 Road Classification Comparison

State DOT’s have a wide range of facility types to manage, upkeep, and enhance. This includes state routes, U.S. highways, and interstate highways. Depending on roadway typologies and land use context, these assets tend to look different and serve different needs based on their location.

3.3.1 State Routes

State routes can range from a rural two-lane to an urban four-lane arterial to an urban six-lane freeway. All variations of state routes do not have the same underlying analysis needs when assessing opportunities for improvements. Needs for a rural two-lane arterial may change depending on land use context. Rural areas may have an entirely different set of needs if the two-lane route goes through a small town, with safety and solutions to calm speeds through the community a priority.

It is up to the state to determine project needs on a case-by-case basis. This approach could be policy driven by the DOT or state legislature or determined through project outreach with stakeholders and the public.

3.3.2 U.S. Highways

Similar to state routes, U.S. highways can have a wide array of roadway typologies. They often pass through commercial areas and may parallel portions of the interstate because they were established before the interstate highway system. As with state routes, rural needs are different from urban needs on these corridors.

It is up to the state to determine project needs on a case-by-case basis. This approach could be policy driven by the DOT or state legislature or determined through project outreach with stakeholders and the public.

3.3.3 Interstate Highways

Although state DOTs own and operate the interstate highway system, funds distributed by FHWA help states manage and enhance the system. During alternatives development and evaluation for the interstate system, DOTs are prohibited from adding any point of access to or from the interstate without the Secretary of Transportation's approval. FHWA 2017 policy provides two considerations and requirements:

- An operations and safety analysis has concluded that the proposed change in access does not have a significant adverse impact on the safety and operation of the interstate facility (which includes mainline lanes; existing, new, or modified ramps; and ramp intersections with crossroad) or on the local street network based on both the current and planned future traffic projections.
- The proposed access connects to a public road only and will provide for all traffic movements. Less than "full interchanges" may be considered on a case-by-case basis for applications requiring special access, such as managed lanes (e.g., transit or high-occupancy vehicle and high-occupancy toll lanes) or park-and-ride lots.

FHWA's policy does not impact the initial planning efforts that may lead to an interstate enhancement. Initial sketch-level planning and prioritization can determine what enhancements a state DOT would want to pursue. In states like California, Colorado, or Minnesota, this may lead to minimal interstate widening and a larger focus on nonintrusive TSMO enhancements or travel demand management strategies.

States noted that they rely heavily on direction from the FHWA local division for interstate improvements. They also reiterated the importance of crafting a purpose and need that incorporates the goals and objectives of the agency/state. States rely on initial planning efforts to help determine the way operations can be woven into a purpose and need. These planning efforts should take a cursory look at future forecasts, land use context, planning-level operations, and potential improvement options.

3.3.4 Area Context

A common theme from discussions with state DOTs and a review of available guidance was the LOS targets or emphasis on traffic operations depending on the land use context. A few examples of LOS changing based on area type or land use are listed in the following sections.

North Carolina DOT

NCDOT's approach to LOS target setting always starts with a general rule of LOS D or better. The state's innovative approach to alternatives development tries to reach this target during the SPOT and EDT process. There are examples, particularly in metropolitan areas, where the costs of reaching LOS D outweigh the benefits. In these situations, NCDOT approaches operations by looking at the total amount of delay that can be reduced. It may still pursue a project even if the future year LOS is F as long as the incremental change in delay is significant enough for the DOT to construct the project.

What determines the threshold for the delay savings relies on NCDOT's prioritization and benefit/cost approach to recommending projects for including in the STIP. NCDOT also recognizes that portions of its system are at a "full build-out" and rely on TSMO strategies to improve operations and reliability or shifts its focus to other nonoperational metrics (i.e., safety) when reviewing projects.

Virginia DOT

VDOT's SMART SCALE approach for project prioritization incorporates different weighting for urban versus rural areas throughout Virginia. Areas in northern Virginia or Hamton Roads are weighted heavily toward congestion mitigation and accessibility due to heavy population centers. Rural areas in the state are weighted heavily toward safety and economic development.

Florida DOT

Florida DOT was initially reviewed for inclusion of DOT best practices. During the initial screening, the project team reviewed Florida DOT's *Multimodal Access Management Guidebook* and the *Multimodal Quality/LOS Handbook*. The handbook notes that Florida DOT's LOS targets for vehicle modes on the state highway system during peak travel hours are LOS D in urban areas and LOS C outside urban areas. The handbook also includes a discussion about exceptions to this rule in urban centers where one of the following exist:

- Mobility cannot be improved through the expansion of roadway capacity.
- Expansion is not physically or financially possible.
- Range of transportation options are essential to satisfy all needs of users in the area.

Lastly, when local governments support and invest in multimodal transportation systems, Florida DOT allows and promotes lower travel speeds for longer time duration. The state recognizes that reallocation of the right-of-way to other modes will increase delay for automobiles but promotes mode shift in these areas.

4 Recommendations and Conclusions

4.1 Figure 301-1

With regard to LOS guidance, providing a clear starting point for LOS targets is recommended in Figure 301-1. Changes, noted in red in **Table 3**, recommend removing the LOS C targets from the urban and urbanized columns and modifying collector and local route targets to LOS E. Additionally, a note referencing the *OATS Manual* should be included on Figure 301-1. The *OATS Manual* provides additional context about a wide range of scenarios when LOS D cannot be reached and approaches the analyst can use to provide adequate analysis to compare/contrast results.

Table 3. LOS Guidance Changes for ODOT Figure 301-1

Functional Classification	Locale and Terrain			
	Rural			Urban & Urbanized
	Level	Rolling	Hilly	
Interstate, other freeways, and expressways	B	B	C	**D**
Arterial	B	B	C	**D**
Collector	C	C	D	**E**
Local	D	D	D	**E**

Instead of rural and urban, the *OATS Manual* uses a distinction of inside or outside an MPO. This distinction may provide a better understanding of targets because there can be small, urbanized areas with minimal baseline congestion.

4.2 OATS Manual

The *OATS Manual* provides practitioners a step-by-step process to set up and run deterministic or microsimulation projects. The following sections provide potential updates or enhancement to the manual. These updates may impact more than the noted section.

4.2.1 Study Periods and Analysis Years

The manual discusses a typical analysis of the AM and PM peak hours and notes the need for scoping justification to deviate from AM and PM peak hours. The addition of the following note is recommended:

In general, two 1-hour analysis periods should align with the two highest hours of recurring congestion. If the analysis area does not experience significant recurring congestion, one analysis period will suffice.

4.2.2 Performance MOEs

The manual states that for reporting purposes, "At a minimum, the outputs of LOS, delay or density, 95th percentile queue lengths, volume-to-capacity (V/C) ratios, and queue storage ratio should be reported for all analyses." The addition of the following note is recommended:

Area-wide VMT, VHT, and delay should be reported for all projects using TransModeler.

4.2.3 Spatial Boundary Limits

The manual discusses how bottlenecks and queues near model limits may impact analysis. Special consideration should be given to built-out areas where additional capacity may not be feasible and the downstream or upstream impacts of a bottleneck area or heavy queuing. It is recommended that ODOT develop a map of locations throughout the state that will not be expanded in the future. If an area overlaps the spatial limits or is near the spatial limits of a study, special consideration should be given to metered flow (if any) that may impact the alternatives development process. This metered flow could be validated via traffic data collection and incorporated into TransModeler to understand the difference between demand volumes and demand served at bottleneck locations.

4.2.4 Temporal Boundary Limits

The manual discusses the use of multiperiod versus a single analysis period. Study periods and analysis years should be referenced to highlight the potential of an interim year scenario that is not oversaturated. This can help the team determine alternatives that provide the best operational performance.

4.2.5 Analysis Tool Selection

The FHWA-HRT-11-064 guide emphasizes the need to understand the limitations of software platforms. The team believes that any interchange alternatives analysis should use TransModeler in congested areas. What determines a "congested area" can be subjective; it is up to the ODOT project manager to determine whether TransModeler should be used. The analyst can review area-wide metrics to help determine the most appropriate treatment from an overall delay metric instead of an LOS-based metric.

Additionally, lane utilization is generally variable at interchanges. The team also believes that for multilane radial-type movements (roundabouts, bowtie intersections, etc.), TransModeler should be used, but more research on the accuracy of TransModeler's model behavior at radial-type movements may be needed.

4.2.6 Traffic Forecasting

The direction of the alternatives development process can be impacted by future traffic forecasts. Many times, this process is developed and documented as one set of numbers to incorporate into the analysis. Virginia DOT's guidance highlights the potential for a project manager to recommend sensitivity testing for projects with some uncertainty of future volume projections. Incorporating a standard process for all HCS or TransModeler analysis to test the operational characteristics of a range of volumes may be valuable for the following reasons:

- A higher sensitivity volume may highlight alternatives with additional reserve capacity not in the baseline certified traffic volumes.
- A lower sensitivity volume may highlight the ability for the no-build option to be considered with some minor improvements instead of a complete rebuild.

If incorporated into the OATS process, the sensitivity test should be descriptive enough to minimize the additional work the analyst needs to perform. In TransModeler, the analyst could simply increase the entire origin-destination table by a factor of 1.2, run the model with no additional changes, and pull area-wide MOEs to compare/contrast with other alternatives.

4.2.7 Turning Movement Counts

The manual states that for traffic data collection, "Counts should be conducted in 15-minute intervals typically between 6:00 AM - 10:00 AM and 3:00 PM - 7:00 PM to capture both of the required AM & PM Peaks." As noted in NCHRP Report 1036, hourly efficiency metrics for the core hours of a day are recommended to determine how a corridor operates and can provide important planning insights. Additionally, more data is always useful to determine whether additional peaks throughout the day need to be accommodated or incorporated into future signal timing adjustments or optimization. The following change is recommended:

- *Rural Areas: Counts should be conducted in 15-minute intervals, typically between 6 and 10 a.m. and 3 and 7 p.m. to capture both AM and PM peaks.*
- *MPO Regions: Counts should be conducted in 15-minute intervals between 6 a.m. and 8 p.m.*

4.2.8 Operational Goals of Mainlines and Intersections

The manual provides operational goals for mainlines and intersections both inside and outside an MPO. Due to the different approaches for signalized versus unsignalized intersections, the study team recommends splitting out all-way stop control, two-way stop control, and roundabouts from the signalized intersections and providing modified LOS targets of E for all.

Additionally, context for cases when operational goals are not met may be beneficial. These could supplement the tables and provide analysts with common situations and ODOT recommendations. For example, there may be times when a side street slips to LOS F for the overall intersection to operate at LOS D.

4.3 State Highway Access Management Manual

Chapter 9 in this manual deals with traffic impact studies, whose focus is to provide DOTs with changes to the adjacent roadway network from a proposed development. The following recommendations include the following:

- In the Capacity Analysis section, refer to the *OATS Manual* instead of the *ODOT Location & Design Manual*.
- In the Significant Adverse Impacts section, *SHAMM* refers to the operational goals listed in the *OATS Manual*. There may be a need to have different guidelines listed directly in the *SHAMM*.

4.4 Recommendations for Right-Sizing Infrastructure

During the review of state examples and national research, the team developed a larger list of areas or programs that can ultimately "right-size" the roadway network longer term. These are not MOE specific but can ultimately impact the overall pavement area for improvement alternatives:

- **Low-cost countermeasures first policy**: Many times, a relatively small cost can provide improvements to operations and safety to accommodate near- and mid-term needs. If operational planning and design studies were required to recommend low-cost countermeasures as part of their ultimate recommendations, these could provide nearer-term benefits
- **Nonintrusive solutions:** Managing the existing system through technology enhancements, demand management, signal timing improvements, and other TSMO strategies can help manage near-term issues. These management strategies could be recommended similar to low-cost countermeasures.
- **Performance-based practical design**: ODOT's performance-based project development process can reduce overall pavement area and cost during design. This process is already implemented in many of ODOT's projects and should continue to be emphasized during all project phases.
- **Transparent prioritization process**: ODOT currently has a prioritization process for large infrastructure investments. The Transportation Review Advisory Committee oversees a selection process that includes prioritization and approval for funding. This process could incorporate weighting changes similar to Virginia or added planning level benefit/cost similar to North Carolina.
- **Innovative**: North Carolina's approach to right-sizing infrastructure leans heavily on innovative solutions to improve operations while reducing overall pavement area.
- **Incorporate multimodal considerations**: California, Colorado, and Minnesota have emphasized multimodal improvements over roadway expansion to provide a more balanced roadway approach to serve all modes and provide a more right-sized approach to infrastructure.

5 Research Links

The following links were used to document the state summaries, national research, and to provide recommendations to ODOT guidance.

State Summaries

California

- transportation.gov/sites/dot.gov/files/docs/LOS%20Case%20Study%20California_508.pdf
- dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/sb-743/2020-05-20-approved-vmt-focused-tisg-a11y.pdf
- dot.ca.gov/-/media/dot-media/programs/esta/documents/vmt/vmt-mitigation-playbook-07-2022.pdf
- ceqadevelopments.com/2014/02/13/opr-mulls-changes-in-ceqa-traffic-metrics/

Colorado

- highways.dot.gov/safety/hsip/hsip-noteworthy-practice-series-hsip-project-identification/level-service-safety-and#:~:text=The%20Colorado%20Department%20of%20Transportation%20%28CDOT%29%20uses%20two,developed%20around%20the%20idea%20of%20statistical%20pattern%20recognition.
- nrdc.org/press-releases/cdot-commission-adopts-new-safety-climate-and-multimodal-transportation-goals-guide
- codot.gov/programs/planning/projects/policy-directive-1601-interchange-approval-process
- codot.gov/programs/environmental/greenhousegas/assets/colorado-carbon-reduction-strategy-repaired.pdf
- codot.gov/safety/traffic-safety/tsmo-evaluation
- codot.gov/safety/traffic-safety/assets/traffic_analysis_forecasting_guidelines
- codot.gov/programs/tam/pd-14-performance-targets
- drive.google.com/file/d/1ltnNkUsGx_7ZgpAR1LeFzLczQu7DRbZR/view
- highways.dot.gov/safety/hsip/hsip-noteworthy-practice-series-hsip-project-identification/level-service-safety-and

Minnesota

- dot.state.mn.us/sustainability/ghg-assessment.html
  - Including the working group & GHG working group PDF (edocs-public.dot.state.mn.us/edocs_public/DMResultSet/download?docId=38085629)
- house.mn.gov/members/profile/news/15523/39210
- srfconsulting.com/vmt-legislation-provides-opportunity/
- revisor.mn.gov/statutes/cite/161.178

North Carolina

- Express Design: https://connect.ncdot.gov/projects/planning/Pages/ProjectScoping.aspx
  - Guidelines: connect.ncdot.gov/projects/planning/Project%20ScopingExpress%20Designs%20Docs/ExpressDesignTrafficEvaluationProcedures.pdf
    Starting on page D-15 (75/100) there's a breakdown of EDTE vs SPOT process. It notes Guidelines that are specific to the EDTE Process are shown in blue, while guidelines specific to SPOT Prioritization are shown in green.

- Detailed Microsimulation Guidelines: connect.ncdot.gov/resources/safety/Congestion%20Mngmt%20and%20Signing/Congestion%20Management/NCDOT%20CONGESTION%20MANAGEMENT%20SIMULATION%20GUIDELINES%20-%20TransModeler.pdf

Virginia

- vdot.virginia.gov/media/vdotvirginiagov/doing-business/technical-guidance-and-support/technical-guidance-documents/traffic-operations/traffic-operations-and-safety-analysis-manual-tosam.pdf
- smartscale.virginia.gov/how-it-works/
- smartscale.virginia.gov/media/smartscale/documents/508_R6_Technical-Guide_FINAL_FINAL_acc043024_PM.pdf
- vdot.virginia.gov/doing-business/technical-guidance-and-support/transportation-and-mobility-planning/transportation-modeling/
- vtrc.virginia.gov/projects/all-projects/124614/

National Research

NCHRP Report 1036: Roadway Cross-Section Reallocation: A Guide (2023)

- nap.nationalacademies.org/catalog/26788/roadway-cross-section-reallocation-a-guide
- kittelson.com/ideas/the-24-hour-capacity-framework-an-alternative-to-using-the-peak-hour-to-design-roads/

NCHRP Report 618: Cost-Effective Performance Measures for Travel Time Delay, Variation, and Reliability (2008)

- trb.org/publications/nchrp/nchrp_rpt_618.pdf

FHWA-HRT-11-064: Guide on the Consistent Application of Traffic Analysis Tools and Methods

- fhwa.dot.gov/publications/research/operations/11064/11064.pdf

ODOT Guidance

- transportation.ohio.gov/working/engineering/roadway/manuals-standards/location-design-vol-1/
- transportation.ohio.gov/working/engineering/roadway/studies-access-management/oats
- transportation.ohio.gov/wps/wcm/connect/gov/fa232810-eba9-4bff-9fe0-8cccbbc51f79/SHAMM%282025-01%29.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_79GCH8013HMOA06A2E16IV2082-fa232810-eba9-4bff-9fe0-8cccbbc51f79-piJRGJN

List of Appendices

Appendix A: State DOT Summaries

- A1: California
- A2: Colorado
- A3: Minnesota
- A4: North Carolina
- A5: Virginia

Appendix B: Research Summaries

- B1: NCHRP Report 1036 – *Roadway Cross-Section Reallocation: A Guide* (2023)
- B2: NCHRP Report 618 – *Cost-Effective Performance Measures for Travel Time Delay, Variation, and Reliability* (2008)
- B3: FHWA-HRT-11-064 – *Guide on the Consistent Application of Traffic Analysis Tools and Methods* (2011)

California

California was selected for an in-depth review of state procedure and approach because it passed SB 743, which shifted the focus from LOS to VMT for all agencies in the state.

SB 743

This bill was passed in 2013 and implemented in 2018 through the California Environmental Quality Act. The goal of SB 743 is to reduce automobile trips while promoting alternative modes of travel. Each local jurisdiction in California had to adopt a plan by July 2020. The plans are typically broken into development-based VMT thresholds and transportation infrastructure improvements.

Development Projects

Developers throughout California are held to locally established thresholds. For example, there are different thresholds for VMT in different parts of the Los Angeles metropolitan area. The suburbs allow a slightly higher VMT allotment because development is more spread out. A spreadsheet-based approach called VMT Calculator yields the estimated VMT for a specific development. If the VMT is higher than the allotted threshold, the developer must implement mitigation strategies (discussed in a later section) to reduce the VMT. Shifting some of the focus of VMT reduction to developments helps address how land use type and location play a large role in the overall travel patterns around the state.

Transportation Infrastructure Improvements

From the transportation network side, local agencies all develop an RTP that includes roadway improvements, transit enhancements, and other multimodal accommodations. If a local agency considers a roadway expansion project, it must align with the proposed roadway expansion for the region. Projects aligning with the RTP have a better chance of funding and quicker approvals and are considered to not have significant VMT impacts because the improvements identified in the plan are considered to promote reduction in GHG and other environmental concerns.

A local agency may allow the widening of a corridor because of the modeling efforts in the RTP. Although certain corridors may have an increased VMT due to roadway improvements, the overall VMT for the region is offset by other investments in multimodal enhancements (transit, bicycle, pedestrian).

If a local agency plans to expand a corridor that is not included in its RTP, the project must go through the area's TDM to determine the impact or change in VMT. If the project increases VMT, it must include costs to improve multimodal enhancements to offset the increase along the project.

Mitigation Strategies

The following mitigation strategies apply to either development projects or transportation network improvements. These strategies are only needed if a development project's VMT exceeds established thresholds or a non-RTP transportation project increases VMT.

- Active transportation
- Land use
- TDM
- Transit service improvement
- Local road networks/ connectivity
- Micromobility
- Telecommuting
- Schedule shifting
- Road diets
- Pricing
- Lane management
- Parking pricing/restrictions
- Park-and-ride lots
- Land preservation

As the transportation industry continues to evolve, the mitigation strategies will likely change to meet future needs and adapt to new technologies.

Other Metrics Considered for SB 743

LOS has widely been used in California to assess the operational efficiency of transportation system impacts. However, the discussion around LOS has recently changed with critics noting that it is difficult and expensive to calculate, and mitigation efforts tend to focus on growing outward to increase roadway vehicle capacity, which in turn may result in an increase in vehicle demand. Based on the identification of several shortcomings associated with using LOS, California's Office of Planning and Research proposed the following alternatives:

- VMT
- Automobile trips generated
- Multimodal LOS
- Fuel use
- Motor VHT

The Office of Planning and Research reviewed each proposed alternative based on criteria that promoted GHG emission reductions, led to the development of multimodal transportation networks, and diversified land uses. After consideration, the Office of Planning and Research selected VMT as the primary metric of choice due to its usefulness in measuring GHG emissions and other environmental impacts and because it is already used in California for air quality analyses. However, the required use of VMT is only applicable for projects that fall under the California Environmental Quality Act.

Los Angeles DOT Example

LADOT works to reduce VMT at a transportation infrastructure level as well as on developer projects. Developer projects use a spreadsheet-based approach to understand the VMT that will be generated with a proposed development and identify countermeasures to incorporate if the VMT is higher than the allowed amount listed in **Table 4**. Areas in more urbanized settings (like Central Los Angeles, which is in the downtown region) have a lower threshold because conditions would be greatly impacted by additional VMT.

Table 3-1. Vehicle Miles Traveled Impact Criteria

Area Planning Commission	Daily Household VMT per Capita	Daily Work VMT per Employee
Central	6.0	7.6
East Los Angeles	7.2	12.7
Harbor	9.2	12.3
North Valley	9.2	15.0
South Los Angeles	6.0	11.6
South Valley	9.4	11.6
West Los Angeles	7.4	11.1

Source: LADOT 2020

The RTP, combined with smart developer growth, is LADOT's approach to right-sizing its transportation network and challenging the metropolitan area to provide multimodal improvements to ultimately reach the goal of reducing GHG emission.

Interstate Context

Improvements to the interstate system throughout California still follows the FHWA process to provide justification for modified or new interchange access. This involves traditional LOS analysis along the interstate, interchanges, and adjacent intersections to show that the proposed changes do not have a significant adverse impact on the operation of the interstate facility. These projects must either (A) be included in the RTP or (B) modeled in the TDM to gauge the impact on VMT if not included in the approved RTP. In scenario B, any VMT increases need to be offset with mitigation strategies.

Potential Downsides

While the VMT-based approach aligns with GHG emission reduction goals, there are some potential downsides to this approach.

Data Availability

The VMT-based approach relies solely on calibrated TDMs throughout the state. Getting an accurate picture of the potential changes to VMT on a project-by-project basis has many modeling assumptions tied to it. Additionally, VMT estimates can be difficult to develop in fringe areas of the model or in rural areas where a statewide model may be the only resource.

Resistance from Agencies or Public

The shift away from LOS is a contrarian view to most of the transportation infrastructure investments in the past. Some stakeholders may view reducing the amount of roadway expansion as a hinderance to growth in a region for housing or industry. Providing clear messaging on the purpose of the VMT-based approach is important for SB 743.

Other Metrics

When applicable, metrics that consider other factors in addition to VMT would provide a more holistic understanding of the transportation system. However, developing a consistent process across all projects would require additional data and resources that may not ultimately change the recommended projects for the RTP.

Level of Service

During project development, local government authorities still have authority to make planning decisions and can still measure LOS and congestion for planning purposes. These HCM-based metrics can provide insights to failing movements, critical intersections, and queuing impacts at various times of day. As this relates to the potential "right-sizing" of the California transportation network, the shift to VMT-based analysis signals the state's approach to moving people via all modes and relying on transportation system management and operations projects to improve congestion and reliability rather than focusing expansion of the current system.

Colorado

Colorado was selected for an in-depth review of state procedure and approach due to PD 14, 1601, and 1610, which establish the following:

- PD 14: Details GHG emissions and VMT-based performance targets
- PD 1601: Outlines TDM strategies to improve the operational performance of CDOT's highway system
- PD 1610: Fulfills the requirements of the GHG Planning Standard that was adopted by CDOT in 2021, including direction on GHG mitigation measures

Additionally, Colorado uses two evaluation tools for project operations evaluation and project prioritization: ICAT and OLOS.

PD 14

In September 2024, the transportation Commission of Colorado voted to update its goals and performance targets to guide future investments in the state's transportation system. This directive provides performance targets to measure the success of key emphasis areas, including safety, asset management, and mobility. Several new performance targets related to sustainably and mobility were identified:

- Reduce transportation GHG emissions by 60 percent by 2037 (compared to 2005 baseline)
- Expand statewide transit service by 66.7 million miles by 2037 (compared to the 2023 baseline), representing an 83 percent increase (about 6 percent per year)
- Per capita VMT reduction target of 1 percent per year

Achieving those targets requires a two-pronged approach:

- Increasing electric vehicle adoption
- Reducing total driving, or VMT, by expanding access to nondriving transportation options, such as transit, biking, and walking, and building housing and jobs closer together so commuters do not have to drive as much

PD 1601

This policy requires that new interchanges and major improvements to existing interchanges on the state highway system are reviewed and evaluated in a fair, consistent manner to help drive informed decisions. As part of this process, TDM strategies are implemented to lower VMT, highway congestion, and GHG emissions by reducing reliance on travel in a single-occupant vehicle and promoting transit, mobility hubs, rideshare, walking, biking, or telework.

LOS is used to determine when TDM strategies would apply for new interchanges (on the interstate system) or modifications to existing interchanges (not on the interstate system). If the current operational LOS is F during peak hours or if the predicted LOS is F at the 20-year design year under a no-build scenario, TDM strategies are required.

The goal of the directive is for TDM strategies to reduce the average daily traffic for the preferred alternative by the following percentages:

- 3 percent or greater reduction in an MPO boundary
- 1 percent or greater reduction outside an MPO boundary

TDM effectiveness can vary significantly based on location, type, and outreach/education. CDOT notes that strategies can be individual or grouped together depending on location. CDOT also notes the need to include partnerships with other public and private sectors to be successful.

PD 1610

PD 1610's intent was to establish the administrative process and guidelines for selecting, measuring, confirming, verifying, and reporting GHG mitigation measures for planning purposes. Colorado developed a list of measures based on available research. It notes that all mitigation measures cannot be modeled or detected from a GHG emissions standpoint. This policy focuses on measures that cannot be accurately calculated with existing TDMs and notes that tools/software will continue to evolve, and the directive will evolve with it. The directive includes the following categories of strategies.

- **Pedestrian and bicycle strategies**
  - New facilities (bike lanes, sidewalks, trails, complete streets)
- **Transit strategies**
  - New/increased fixed-route service
  - New/increased demand-response service
  - Reduce fares
  - Bus priority treatments
- **Parking strategies**
  - Additional parking fees
  - Unbundle residential parking
  - Eliminate parking minimums (set low maximum)
- **TDM strategies**
  - Commute trip reduction programs
  - Vanpool or carshare
  - Telework
- **Traffic operation strategies**
  - Retime/optimize arterial signals
  - Add roundabouts
- **Land use strategies**
  - Increase residential and job densities
  - Transit-oriented development

GHG Pollution Reduction Roadmap

Colorado published a roadmap for GHG pollution reduction, which was revised in February 2024. The state's goals incorporate many aspects of the transportation system, but the following actions relate directly to the reduction of VMT or specific projects to improve GHG pollution:

- Encourage land use policies to build more housing that grows walkable neighborhoods with transit access
- Build more complete and connected streets
- Expand statewide transit (including passenger rail)

Intersection Control Assessment Tool

Colorado's ICAT evaluates alternatives and ranks them based on their safety and operational performance, allowing CDOT to remain transparent with a consistent approach during alternatives development stage. This spreadsheet-based tool combines right-of-way, safety, roadway context, operations and maintenance, and overall costs to score intersection alternatives in stage 1. Alternatives that pass stage 1 move to stage 2, where more detailed project costs, traffic operations, safety, environmental impacts, and stakeholder support are tabulated into a Final ICAT Stage 2 score.

The overall process helps practitioners consider alternatives that may not have been considered previously. Downloads and training for the ICAT tools can be found here: codot.gov/safety/traffic-safety/tsmo-evaluation.

Operational Level of Service

Colorado developed OLOS to evaluate the performance of different state facilities relative to the performance of similar facilities. The methodology is based on probe data speeds and the use of Planning Time Index, which is calculated as the ratio of the 95th percentile travel time to the ideal travel time. CDOT also compares the Planning Time Index with its Level of Service of Safety, which indicates a segment's performance in relation to the expected crash frequency and severity based on annualized daily traffic.

The OLOS dashboard provides six case studies that CDOT project managers can use to evaluate the transportation system:

- Bottleneck identification for Corridor Operations Bottleneck Reduction Assistance
- Improvement potential for ranking corridors based on their greatest opportunities for improvement
- Operational evaluation (peak period, day-of-week, month of year, OLOS to Level of Service of Safety comparison, and nonrecurring issues)

- Incident, weather, event, and construction management
- Efficient analysis for funding pool approvals using the following:
    - Planning Time Index/Travel Time Index historical trend
    - OLOS by facility type
- Project prioritization for long-term planning, which tracks annual progress toward the following objectives:
    - Achieve a 20-minute incident clearance time for specific areas
    - Achieve an OLOS grade C or better for 80 percent of the state highway system
    - Manage congestion by reducing VMT by 10 percent by 2030 relative to current levels

A quick guide will be published on the TSMO evaluation page when it is complete.

Minnesota

Minnesota was selected for an in-depth review of state procedure and approach due to HF 3436, which shifts the focus toward VMT metrics to reduce GHG emissions in the state by 2050.

In general, the goal of this bill is to provide mitigation options similar to other aspects of a transportation project, such as wetland mitigation. During the environmental process, if a wetland is disturbed during the construction of a transportation enhancement, there are standard procedures in place to reconstruct or mitigate the wetland impacts. Minnesota aims to do this for VMT. If VMT is increased due to a capacity expansion, the project then needs to identify mitigation strategies that will offset the VMT increase.

HF 3436

This bill was passed in 2023 with updates added in early 2024, which were approved by the Minnesota House and Senate. The bill was signed into law in April 2024. It includes many policy updates from MnDOT, public safety, and vehicle services.

The following sections discuss the goals of the bill, policies and procedures that MnDOT plans to implement, the development of HF 3436 working/advisory groups, project definitions, and balancing the system objectives.

Goals of HF 3436

Minnesota's goal is to reduce VMT per capita by 20 percent by 2050 to meet GHG targets. Starting in early 2025, all capacity projects on major highways and the state's trunk highway system must be assessed to ensure conformance with the VMT guidance and provide mitigation options if the project increases VMT.

Policies and Procedures

MnDOT's approach to reduce VMT per capita by 20 percent mandates that capacity expansion projects must assess their impact on VMT and GHG emissions before inclusion in the STIP.

Working Group Findings

HF 3436 established working groups and advisory committees to determine the approach for various projects. The working group published its GHG emissions mitigation report in 2024. In this report, the group distinguished between types of studies and the appropriate assessment tools for each.

- **Level 1**: Project
- **Level 2**: MPO Plan
- **Level 3**: Regional and Statewide Plan

The figure from the report is included in **Attachment 1**.

Analysis Methods

The working group highlighted existing analysis methods specific to FHWA or MnDOT that could be used to develop a framework for analyzing VMT impacts at the project and regional levels. The following tools were discussed:

- **TDM**: Levels of sophistication can impact a TDM's usefulness. Model results can vary based on the development and application of the models, from activity-based models for Metropolitan Council's TDM to more traditional four-step models in other MPOs in Minnesota.
- **VMT Analysis**: VMT can be tracked as traffic counts are updated throughout the state and multiplied by the mileage of the corresponding roadway link. This does not allow for future projections.
- **Environmental Protection Agency's Motor Vehicle Emissions Simulator**: This emissions model provides GHG estimates at a project or regional level based on travel speeds and VMT.
- **Minnesota Infrastructure Carbon Estimator**: A spreadsheet-based tool that develops GHG emissions throughout the project life cycle based on VMT estimates.
- **Multimodal Accessibility Tools**: This tool measures the level of access to destinations by all modes. This is an emerging area of

research, and 13 states are currently developing or enhancing accessibility tools.

- **Induced Demand Calculators**: A spreadsheet-based tool using elasticities to estimate additional travel from capacity expansion. The group noted limited functionality in the tool and plans for future enhancements.

Future Updates and Analysis Method Enhancements

The GHG emissions mitigation report highlights that the process for implementation must continue to be flexible because this program is in its infancy and will be upgraded and enhanced over time. The GHG group listed several recommendations for tool and analysis upgrades, including the following:

- Develop and enhance a statewide model to aid in Level 3 analysis and any VMT assessments outside MPO boundaries
- Enhance and update tools such as the Minnesota Infrastructure Carbon Estimator to incorporate VMT mitigation metrics

In general, there is a need to enhance existing tools to ensure that VMT reductions are not double-counted when mitigation metrics are developed regionally or for a specific project.

Project Definitions

During the development of HF 3436, it was important to establish definitions for a capacity project so that resources were being used wisely during the assessment process of GHG emissions. The bill notes that any project that adds highway capacity or provides grade separation (excluding auxiliary lanes less than 2,500 feet) is considered a capacity expansion and needs to compare/contract VMT.

Balancing System Objectives

There are other Minnesota statues that may contradict the VMT goals of HF 3436, specifically related to transportation safety. HF 3436 does not supersede any previously established safety goals. An example of this would be a rural interchange or restricted crossing intersection that may increase VMT slightly but would have a major safety benefit.

Discussion with MnDOT

The project team had a virtual meeting with MnDOT staff from the Office of Transportation System Management who have been at the forefront for developing HF 3436 and are currently working through the implementation process for Minnesota.

Previous Guidance and Tools

The team at MnDOT focused its initial efforts on identifying tools and guidance from FHWA or other states to help them develop mitigation measures for VMT reduction. The team focused on work done by the California Air Pollution Control Officers Association, CDOT's work on mitigation measures, and references of working groups in the northwest focused on VMT reduction efforts.

The team at MnDOT plans to use existing tools to estimate VMT impacts, including FHWA's VisionEval tool.

Access Gained Metrics

MnDOT's team talked about the state's shift in thinking from traditional travel benefit metrics to an emphasis on access gained for all modes. For example, the old way of thinking was to reduce travel times for vehicles, while the new way of thinking would slow speeds, which may increase travel times but will create safer crossings for bikes and pedestrians and improve safety along a corridor. MnDOT noted there is current research underway on this topic

Potential Gaps in Current Approach

The MnDOT team noted that this program is in its infancy and will evolve over time. There are current gaps in the approach that will be continually improved, developed, or enhanced as HF 3436 is implemented throughout the state highway system, including the following:

- The team reiterated some of the working group's findings during the call, noting that projects outside MPO limits are a challenge due to the lack of a statewide model.

- MnDOT noted that interchanges and the interstate system are a work in progress. It noted the need for traditional traffic tools to ensure changes do not cause a backup or worsen operations.
- The team also highlighted the process of tracking mitigation metrics and the need for agencies to "follow through" on selected metrics throughout the state.

Interstate Context

Changes to Minnesota's interstate system must still follow the FHWA process. The state plans to work through these challenges of combining its VMT reduction goals with the FHWA process.

Level of Service

Through discussions with MnDOT, there will still be a place for traffic analysis in a general sense for project development and evaluation. The main difference will be a shift toward access gained and multimodal metrics with traffic analysis as an operations check to ensure backups are not occurring as opposed to traffic operations helping develop the concept.

Attachment 1

GHG Assessment Implementation Maturity Model from the Transportation GHG Emissions Impact Mitigation Working Group Report (February 2024)

Assessment Maturity	Level 1: Project	Level 2: MPO Plan (Metro & greater MN MPOs)	Level 3: Regional and Statewide Plan (Not currently available)
Summary	A trunk highway capacity expansion project is analyzed. The network directly within the project is analyzed for emissions and VMT impacts. If interlinking /mitigation is needed, the project proposers develop a mitigation plan.	A trunk highway capacity expansion project is analyzed in the context of an MPO plan of projects. All projects are evaluated for their emissions and VMT reduction benefits and impacts. If interlinking /mitigation is needed, the MPO develops a mitigation plan.	A trunk highway capacity expansion project is analyzed in the context of a region and state. All multimodal investments are evaluated for their emissions and VMT reduction benefits and impacts. If interlinking /mitigation is needed, the region develops a mitigation plan.
Assessment Area + Method(s) (Area of analysis and determination of current and future speeds, traffic volume, etc.)	Affected network of project is analyzed using currently available travel demand forecasts for a project area to determine build/no build operational impacts	MPO region and plan of projects evaluated with the Regional Model in the metro area and using greater Minnesota MPO transportation demand models in MPO's outside the metro	Regional plan of multimodal investments evaluated regionally such as an ATP or Statewide (not available)
Analysis Validation (Determining net change in VMT and carbon emissions)	• Minnesota Infrastructure Carbon Estimator (MICE) • Motor Vehicle Emission Simulator (MOVES) project level tool	• Minnesota Infrastructure Carbon Estimator (MICE) • Motor Vehicle Emission Simulator (MOVES) program level tool • Off-the-shelf program of projects evaluation tool (e.g. Georgetown Climate Center TEA-CART)	• Motor Vehicle Emission Simulator (MOVES) program level tool • Emissions evaluation integrated into TDM analysis • Off-the-shelf program of projects evaluation tool (e.g. Georgetown Climate Center TEA-CART)
Conformance	Project build results in a reduction of emissions and VMT per capita over the 20 years of the project	Multimodal MPO program of projects conforms with net emissions and VMT per capita reduction targets for 2025, 2030, 2040, and 2050	Multimodal regional program of projects conforms with net emissions and VMT per capita reduction targets for 2025, 2030, 2040, and 2050
Mitigation/Interlinking Management Plan	Project proposer develops offsetting mitigation management plan	MPO develops offsetting mitigation management plan	Region develops offsetting mitigation management plan

North Carolina

North Carolina was selected for an in-depth review of state procedure and approach due to the state's shift to Caliper's TransModeler microsimulation software and standardized guidelines. This section focuses on the congestion management guidelines that support project development and implementation because they directly relate to the goal of "right-sizing" improvements.

Initial Planning and Prioritization

NCDOT uses two standardized modeling procedures to take projects identified by MPOs and regional planning organizations and provide an initial look at the operational items that feed into the overall prioritization:

- **SPOT**: Takes all projects in all long-range plans throughout the state and develops a project score. One of the elements of the scoring rubric relates to travel time benefits. The program looks at near-term needs of today and a horizon year of 10 years.
- **EDT evaluation**: Looks at LOS for the existing and horizon year (20 to 25 years) of the local area's transportation plan. This step helps identify whether the metropolitan or regional transportation plan was over- or under-designing a project to improve congestion in a corridor to an acceptable LOS.

If a project makes it through the SPOT and EDT processes, it moves to the congestion management simulation guidelines for a more refined analysis.

Congestion Management Simulation Guidelines

NCDOT developed simulation guidelines in 2016 that standardized the development process and reporting requirements for operational studies in TransModeler. These guidelines are for projects that are typically funded and headed to preliminary design stages.

Project Setup

Project setup is a vital component of the TransModeler guidelines so that practitioners and reviewers can provide a consistent model and folder hierarchy. This starts with pre-developed NCDOT-specific project preferences and default parameters, file-naming conventions, folder structure, and folder-naming conventions.

Model Development

The guidelines for model development and validation provide insight into standard procedures used to maintain consistency across hundreds of models that are developed each year and used to compare the effectiveness of proposed projects throughout the state. These procedures include roadway lengths, speeds, road classes, speed distributions, lane widths, grades, intersection layouts, traffic control, signal optimization, and volume/vehicle class inputs. The guidelines also include samples of best practices to help NCDOT and consultants be on the same page.

The guidelines emphasize the need for the modeler to "zoom out" and determine whether any neighboring, fiscally constrained projects are in the vicinity and whether the improvements may impact the project in focus.

Model Validation

Three levels of validation are available for the modeler to use during the validation process:

- **Level 1 – Default Values**: No changes made
- **Level 2 – Visual Validation**: Most common validation where a series of field observations are re-created in TransModeler by adjusting speeds, headways, stopped gaps, and lane changing behavior to more closely match field observations
- **Level 3 – Calibration**: Required for projects involving the modification of interstate highways and their interchanges by reproducing field-collected data

Measures of Effectiveness

Level of Service

NCDOT uses LOS to document MOEs, but the guidelines recommend additional metrics to supplement the LOS determination. When documenting LOS, the guidelines require simulation LOS to include a subscript S to signify that LOS_S is derived from simulation results and not from empirically derived HCM methodologies.

MOE Results

For any selected MOE, NCDOT guidelines ask the modeler to document the 95th percentile worst result from a minimum of 10 runs. NCDOT references the *FHWA Traffic Analysis Toolbox, Volume III* to determine the 95th percentile worst result from a batch number of simulations:

$$95th\ Percentile\ Worst\ Result = m + 1.64 \times s$$

$$Where\colon m = mean, s = standard\ deviation$$

System- or Network-wide MOEs

Depending on the project's objective, the following outputs may be used to compare no-build and build alternatives:

- Number of trips
- Average trip length
- VMT
- VHT
- Average speeds
- Total delay or average delay per vehicle
- Total stopped time or average stopped time per vehicle
- Total number of stops or average number of stops per vehicle

Corridor or Route MOEs

MOEs for specific corridors or routes provide a more direct comparison between the no-build and alternatives or between alternatives. The following MOEs may be selected depending on project objectives:

- Travel time
- Average speed
- Segment speed
- Planning Time Index

NCDOT acknowledges the benefits of graphical speed displays using heat maps to highlight speed changes over the course of the simulation period. Additionally, NCDOT continues to expand the list of model and spreadsheet templates to provide a consistent way to pull MOEs, such as average speeds, at a consistent interval along a corridor that previously would have taken more processing time.

Uninterrupted-Flow MOEs

Uninterrupted flow includes freeway facilities, multilane highways, and two-lane highways as referenced in the HCM uninterrupted flow chapters.

- **Freeway facilities**: Densities and areas of influence match the HCM
- **Multilane highways**: Similar to freeway facilities with adjusted LOS densities corresponding to the HCM
- **Two-lane highways**: Utilized percent time for the three classes of two-lane highways:
  - **Class I**: High-speed routes serving long-distance trips
  - **Class II**: Access routes to Class 1 routes (typically scenic or recreational)
  - **Class III**: Highways in moderately developed areas

Interrupted Flow

Interrupted flow includes facilities with intersections with traffic control devices. The MOEs used on these facilities include delay, LOS_S, and queue lengths. Delay and LOS_S are reported at the intersection level, approach level, and lane group level. Lane groups are defined as a unique movement or set of movements (i.e., a through-right is a different lane group than an exclusive through). For queues, both lane queue and spillback queue are reported.

For design-level storage lengths, the 95th percentile worst result over a 1-hour period is used. Turn bays should be designed to accommodate the queue length reported at the lane group level, and justification is required for storage lengths that do not accommodate the 95th percentile queue.

NCDOT acknowledges the HCM's approach to interchange ramp terminals and alternative intersection designs. In practice, individual intersections are still reported, and network-wide or corridor MOEs are used to help compare and contrast build alternatives.

Technical Documentation

Technical reporting in a consistent format is vital to the review and consistency across models. NCDOT uses a variety of MOE spreadsheets and table/figure requirements in technical documentation. Additionally, model submittals are standardized with a submittal checklist, including file-naming conventions and removing themes, labels, and selection sets prior to submittal.

Interstate Context

NCDOT follows *FHWA Traffic Analysis Toolbox, Volume III*, including microsimulation guidance when applicable, on all interstate highways in North Carolina. Until the federal process changes, NCDOT uses microsimulation with calibration or analytical tools such as McTrans Highway Capacity Software following FHWA's guidance.

Potential Downsides

TransModeler Expertise and Training

The shift to TransModeler in North Carolina required the state and consultants to become proficient in a new software. Microsimulation models can be complex, and minor changes or fixes can sometimes result in major changes to MOEs. Much of the state's TransModeler program is distributed through consultant agreements, so having a core foundation of practitioners who meet regularly, share ideas, and collaborate is an important step to provide the best product for NCDOT. This process is never ending and needs to continually be improved as Caliper releases new versions with greater functionality. NCDOT has worked with Caliper in the past to develop trainings to build expertise in NCDOT and with the consultants.

Origin-Destination Demand Development

Generating a defendable origin-destination matrix can be complicated depending on the complexity of the network, adjacent projects that may impact demand, or availability of data.

During the planning stages, the SPOT and EDT processes provide a broad-brush approach to traffic forecasting to replicate a standardized process across multiple projects. When a refined set of volume forecasts are developed for NCDOT's process, there is always room for improvement on how best to develop an origin-destination matrix. Recently, incorporating new datasets like Streetlight to more accurately capture linked trips throughout the network has yielded different recommendations from previous origin-destination development that relied on turning proportions to develop origin-destination pairs.

This highlights the need for continued standardization and independent reviews of the volume development process, which can be incorporated in future updates to the SPOT, EDT, and TransModeler processes.

Level of Service

During project development, LOS is still used by NCDOT as one of many metrics pulled from TransModeler. Recently, LOS has been used as a formality during alternatives development, while other metrics such as VHT, speeds, and travel time comparisons provide a more holistic view of total travel time along and through the corridor or area being studied.

As this relates to the potential “right-sizing” the North Carolia roadway network, the state continues to prioritize and reprioritize projects based on its fiscal budget. TransModeler allows the state to directly compare a portion of the operational considerations to only promote and fund projects that provide the best return on investment. The corridors or infrastructure projects that do not make the cut sometimes go back to the drawing board or low-cost countermeasures are implemented to improve near-term conditions before a larger infrastructure investment is made. Additionally, using TransModeler throughout the entirety of the project allows models to be reused in multiple phases of a project’s lifetime for a more efficient project flow.

Virginia

Virginia was selected for an in-depth review of state procedure and approach due to the state's use of the SMART SCALE process to prioritize transportation projects for funding. The process uses tools like travel demand modeling to evaluate congestion scoring measures. If a project is selected and moves to more detailed analysis, VDOT uses a *Traffic Operations and Safety Analysis Manual* in its governance document to navigate project development as it relates to operations and safety.

SMART SCALE

In 2013, House Bill 2313 was signed to create a more consistent and significant revenue source to support transportation funding. However, Virginia was still having trouble addressing all the state's transportation needs, and the current funding process created confusion and uncertainty with local communities and businesses. Therefore, in 2014, new legislation was signed that created a measurable, transparent prioritization process that helped identify the right projects to meet the most critical transportation needs. In 2016, the process was renamed "SMART SCALE," which stands for System Management and Allocation of Resources for Transportation: Safety, Congestion, Accessibility, Land Use, Economic Development, and Environment.

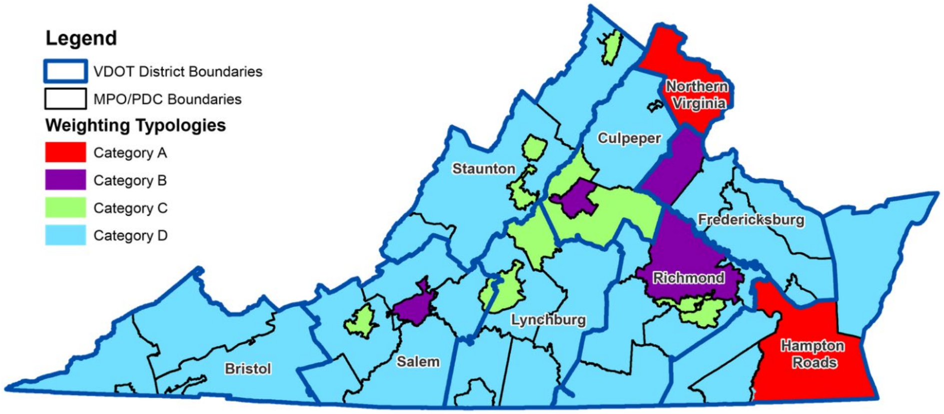
Transportation projects are scored based on a quantitative, outcome-based process that is transparent and consistent. After projects are scored and prioritized, the Commonwealth Transportation Board can use the information to select the projects for funding.

Evaluation Measures

The identified evaluation measures are both quantifiable and objective and consider all modes of transportation. All measures fall into six categories, including safety, congestion mitigation, accessibility, environmental quality, economic development, and land use coordination for areas with a population of more than 200,000.

Factor Weighting

The SMART SCALE legislation recognized that the needs of the transportation system vary throughout the state of Virginia. Therefore, a weighted framework was developed that assigned different weights to the various performance measures based on location. Four area weighting typologies were established based on an analysis of transportation, land use, demographic indicators, and public input to facilitate evaluation of each project's benefit on a scale relative to the needs of that region as compared across the commonwealth. The weighting typologies are shown in **Figure 3** and **Table 5**.



Source: How It Works | Smart Scale

Factor totals are weighted and summed, and the final score is determined by dividing the benefit score by the SMART SCALE cost. Lastly, projects are ranked and provided to the Commonwealth Transportation Board for funding consideration.

Factor	Safety	Congestion Mitigation	Accessibility	Economic Development	Environmental Quality
Category A	15%	45%	25%	5%	10%
Category B	20%	25%	25%	20%	10%
Category C	30%	20%	15%	25%	10%
Category D	40%	10%	10%	30%	10%

Congestion Mitigation

The focus of this review was on the congestion mitigation measures that analyze how projects address a transportation system's ability to move people and reduce travel delay. The measures recommended for this category are person throughput and person-hours of delay.

Person Throughput

The main objective for using person throughput as an evaluation measure is to assess the potential benefit of a project based on how the number of users served in the peak period increases. This performance measure uses peak period flow rate, capacity values, and average vehicle occupancy rate to calculate person throughput. Intersection analysis uses the FHWA CAP-X analysis tool. New service for modes such as transit, bicycle, pedestrian, or freight rail supports change in person throughput and can be analyzed. Using this performance measure is only recommended if a facility is overcapacity in the no-build condition.

Person-Hours of Delay

This calculation type allows a project to be analyzed based on its ability to reduce peak period person-hours of delay. It uses peak period flow rates, travel speeds, delay, and average vehicle occupancy rate to calculate person-hours of delay. Similar to person throughput, intersection analysis includes the use of FHWA's CAP-X. While transit and freight rail projects can result in a change in delay, it is assumed that there is no reduction due to a standalone bicycle or pedestrian project.

Future Considerations

A project is in the works to explore the use of VMT as an evaluation metric in Virginia's transportation planning process. This effort is being undertaken by the Virginia Transportation Research Council with a target completion date of February 28, 2026.

Traffic Operations and Safety Analysis Manual

Version 2.0 of this manual was released in 2020, using guidance definitions similar to the *Manual of Uniform Traffic Control Devices* (such as shall, should, or may) to help practitioners throughout their analyses.

Common Analysis Scenarios

The *Traffic Operations and Safety Analysis Manual* discusses the typical area or facility types, modes of travel, intersection or interchanges, and traffic management strategies to be evaluated. The manual also acknowledges peak hour spreading and the impact it can have on software tool selection or the length of an analysis period. It notes that special consideration should be given to the selection of analysis tools when future conditions are oversaturated.

Analysis Tools

This section details the tools VDOT allows to be used during project development. If the analyst strays outside the following operational analysis tool list, the district traffic engineer must approve the change:

- VDOT Work Zone Tools
- VJuST: Modified version of FHWA's CAP-X tool
- HCS
- SIDRA Intersection (SIDRA Standard model)
- Synchro
- SimTraffic
- FREEVAL
- Vissim

As of 2020, the manual recommends supplementary analysis via multiple software packages for the evaluation of roundabouts. It notes the need to use SIDRA to supplement Vissim's modeling of roundabouts. It also notes when it recommends software provider output that differs from the HCM, including Synchro traffic signal optimization and the SIDRA Standard model.

Analysis Measures of Effectiveness

The manual details the following traffic operations MOEs approved by VDOT:

- 95th percentile queue length
- Control delay
- Density
- Maximum queue length
- Microsimulation delay
- Percent time spent following
- Percent of free-flow speed
- Space mean speed
- Time mean speed
- Travel time
- Volume-to-capacity ratio
- Reliability (95th percentile, 80th percentile, 50th percentile travel time indices, and level of travel time reliability)

Attachment 1 contains a summary table that links MOEs to available VDOT-approved software platforms.

Note on Sensitivity Testing

The manual allows a VDOT project manager to recommend sensitivity tests of operational or safety analysis depending on the uncertainty of input parameters. It gives the example of modifying the traffic demand up and down by 10 percent to understand the change in MOE results.

Attachment 1

Traffic Operations Analyses MOEs from Traffic Operations and Safety Analysis Manual

Table 2: Traffic Operations Analyses MOEs

Traffic Operations MOE	VJuST	HCS7	SIDRA Intersection	Synchro	FREEVAL	SimTraffic	Vissim
95th Percentile Queue Length, ft		✓	✓	✓		✓	
Control Delay, sec/veh		✓	✓	✓			
Density, pcplpm		✓					
Density, vplpm		✓					✓
Experienced Travel Time (ETT), sec/veh		✓					
Maximum Queue Length, ft						✓	✓
Microsimulation Delay, sec/veh						✓	✓
Percent of Free-Flow Speed		✓					
Percent Time Spent Following		✓					
Reliability							
95th Percentile Travel Time Index					✓		
80th Percentile Travel Time Index					✓		
50th Percentile Travel Time Index					✓		
LOTTR (80th/50th)					✓		
Space Mean Speed, mph		✓	✓	✓		✓	✓
Time Mean Speed, mph							✓
Travel Time, sec		✓				✓	✓
Volume to Capacity (v/c) Ratio	✓	✓	✓	✓			

NCHRP 1036

NCHRP 1036 was selected for an in-depth review of relevant research due to its approach to right-sizing a corridor and options to incorporate a 24-hour framework into traffic operations to make informed decisions and overcome barriers to safe design.

This guide was developed around the U.S. Department of Transportation's 2022 National Roadway Strategy that put safety as the top priority. Because of this, the guide prioritizes safety for all roadways users, starting with users who are least protected (pedestrians and bicyclists). It also emphasizes that street transformations can impact people's lives profoundly, specifically those who use a variety of modes.

New Decision-Making Process

During project development, it is not generally known how a street improvement design will impact the surrounding community. In the past, traffic operations were traditionally emphasized as whether an alternative "worked" or not. This led to the development and enhancement of tools to measure delay, travel times, and other car-centric metrics. Recently, there has been a shift to incorporating metrics related to safety, health, livability, accessibility, comfort (or stress), travel speeds, and land use context into projects. These metrics, combined with robust community outreach efforts to understand specific needs, provides a more holistic view of the issues and opportunities for improvement.

Figure 4-2. Modal Hierarchy for Portland, Oregon.

The research shares examples of modal hierarchy that cities have used when establishing goals for a specific plan or project. Figure 4-2 from NCHRP 1036 is a great example of Portland's approach to providing access and safety for vulnerable users first and foremost.

Overcoming Barriers to Safe Design

The guide discusses how certain constraints, user concerns, stakeholder concerns, and limited resources can be a hindrance to implementing a project.

Geometric Constraints

The research highlights that both limited space and excess space can be an issue when reconfiguring a roadway. The guide highlights three approaches to provide safe facilities when geometric constraints exist:

1. **Reduce design speeds**, Which reduces the space needed to achieve a safe design
2. **Reallocate high-capacity modes** to prioritize moving more people along constrained streets (depending on land use context)
3. **Zoom out and view** the street's role in the broader network to identify nearby opportunities to reduce needed space

The guide warns about widening a cross-section simply because there is excess space available. Minimum safe widths should be prioritized to avoid a wider facility that may encourage speeding.

User and Stakeholder Concerns

The guide notes each mode used along a corridor will have unique concerns related to its specific needs. A pedestrian may be concerned about gaps in traffic to safely cross a facility, while a transit operator may be concerned about the space to maneuver around turns or through a corridor. A deeper dive into traffic operations related to user and stakeholder concerns is discussed in the **Traffic Operations** section.

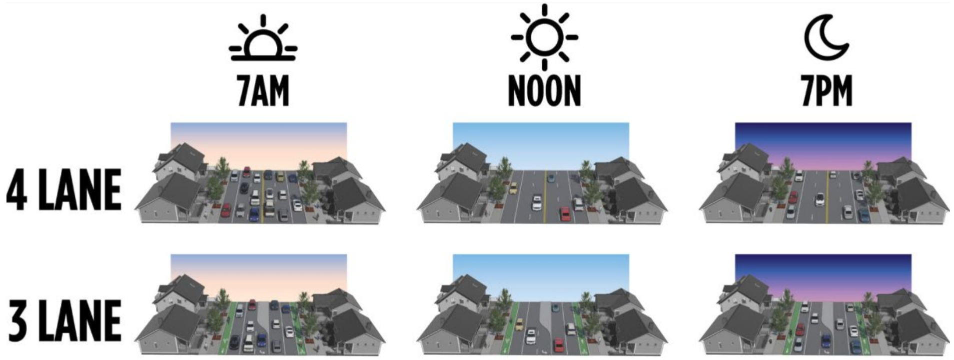
Limited Resources

Funding is always top of mind for agencies and decision-makers. This guide highlights the use of quick-build projects that can be implemented at relatively low cost compared to a full reconstruction of a corridor or intersection. These projects typically involve temporary materials (paint, delineators, planters, and signs) in conjunction with signal timing or other minor adjustments and often show the benefits of safer walking and biking networks on a calmer street.

Traffic Operations

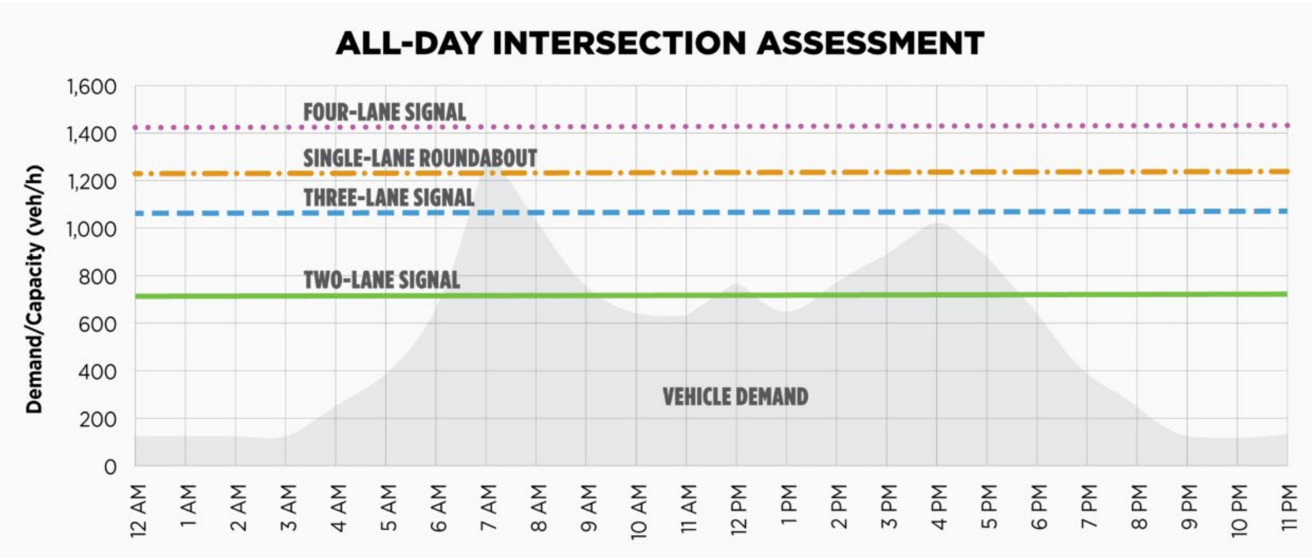
During cross-section reallocation efforts, road diets are generally considered to add space to fit facilities for other modes (walking, biking, transit), which can lead to concerns regarding traffic diversion. Research shows that as cities remove vehicle lanes, they find that traffic volumes shrink in total instead of diverting or rerouting to nearby local streets. This is the reverse of induced demand seen from capacity expansion projects. The guide notes that more research is needed on this topic.

This guide offers up a more holistic approach to discuss traffic operations with users and stakeholders that focuses on the traffic throughout the entire day instead of only peak hours. Kittelson & Associates developed the following graphics that help drive home the 24-hour framework. They highlight the potential safety issues of overbuilding a facility that could serve more users throughout the day with a couple hours of congestion during a peak hour.



The guide breaks down the 24-hour framework into four key metrics:

- **Hourly D/C ratio**: Determines how many hours of the day a facility is overcapacity.
- **16-hour efficiency metric**: Looks at the core 16 hours of a day (5 a.m. to 9 p.m.). If the D/C ratio is more than 0.6, it is considered efficient. If the D/C ratio is less than 0.6, it is deemed inefficient. This analysis highlights that excess capacity is not a benefit during off-peak times because it can lead to excessive speeding.
- **16-hour excess capacity metric**: Indicates any unused capacity during the core 16 hours of the day.
- **Total hours below capacity**: Highlights how many hours of the day a facility is undercapacity.



Decision Tradeoffs

NCHRP 1036 devotes Chapter 7 to identifying cross-section elements and their planning-level safety, economic, environmental, social (health, equity, quality of life), and mode shift impacts. A summary of the following cross-section elements is provided in **Attachment 1**:

- Adding general purpose lanes
- Reallocating space to bus lanes
- Adding bicycle lanes
- Adding sidewalks
- Adding a sidepath/shared-use path
- Adding medians
- Adding curb extensions
- Adding multimodal parking and pickup/drop-off
- Adding street eateries/food trucks
- Adding parklets

Level of Service

In summary, a 24-hour framework provides practitioners with a planning-level view of how a roadway would function throughout the day instead of only during peak hours. The 24-hour metrics can show if travel lanes could better serve other modes and result in safer speeds and safety for all users.

Attachment 1

The following treatments and rankings are summarized in Chapter 7 of NCHRP 1036. Each ranking is broken into five categories: safety, economic, environmental, social, and mode shift.

Treatment	Safety	Economic	Environmental	Social	Mode Shift
Adding general purpose lanes	-2	-1	-2	-2	-3
Reallocating space to bus lanes	1	2	2	2	3
Adding bicycle lanes	3	2	2	3	3
Adding sidewalks	3	2	2	3	3
Adding a sidepath/shared-use path	3	2	2	3	3
Adding medians	3	-1	2	3	No Change
Adding curb extensions	3	No Change	No Change	2	2
Adding multimodal parking and pickup/drop-off	1	3	No Change	1	-3* 3*
Adding street eateries/food trucks	1	3	No Change	2	No Change
Adding parklets	1	1	1	3	No Change

** -3 for Personal Vehicles; 3 for Bicycle Parking and Transit Stops*

Key: Types of Impact

-3: Adverse (Very Poor) | -2: Adverse (Poor) | -1: Adverse (Slightly Poor) | 1: Positive (Slightly Good) | 2: Positive (Good) | 3: Positive (Very Good)

NCHRP 618

NCHRP 618 was selected for an in-depth review of relevant research due to its approach in developing a process for performance measure selection on a project-by-project basis. This guide also touches on how to apply performance measures during alternatives analysis.

Performance Measure Selection

NCHRP 618 includes a checklist for performance measure considerations. The guide notes that data collection efforts should not determine which performance measures should be selected. The goal of the study should help determine the performance measures, not the ease of data collection.

Checklist of Considerations

- **Relate to goals and objectives**: Find performance measures that can be measured toward a collective goal
- **Clearly communicate results to audiences**: Take technical calculations and pair them down into terms that are relevant to users and stakeholders
- **Include urban travel modes**: Break down metrics into different modes of transportation that are relevant to the area (car, freight, pedestrian, bicyclist, transit user, etc.)
- **Have consistency and accuracy**: Check results from analytical tools against field data and check that the perceived mobility from users matches analytical tool data
- **Illustrate the effect of improvements**: Use a broad set of measures to include users and modes that are represented in the analysis
- **Be applicable to existing and future conditions**: Understand current and future issues
- **Be applicable at several geographic levels**: Able to be zoomed in or out depending on the situation (intersection versus corridor; subregional versus regional)
- **Use person and goods movement terms**: Understand how persons or tonnage can move along a corridor
- **Use cost-effective methods to collect and/or estimate data**: Use readily available data and make efficient use of data collection funding

Congestion Effects

During the selection of performance measures related to congestion, it is difficult to use a single value to describe a user's experience. The guide recommends breaking congestion into the following components:

- **Duration**: Understand when the congestion occurs throughout the day
- **Extent**: Calculate the number or people/vehicles impacted by congestion
- **Intensity**: Determine the severity of congestion
- **Variation**: Determine whether congestion recurring or random (i.e., due to incidents or inclement weather)

Mobility and Reliability Effects

Mobility and reliability components are similar to congestion measures with the following slight modifications:

- **Time**: The time that mobility is provided (either through the presence of a transit service or when travelers can reach their destination in a satisfactory amount time)
- **Location**: Using travel sheds, accessibility contours, and descriptions of services to understand where mobility is possible by options other than a personal vehicle
- **Level of mobility**: Related to the intensity of congestion for personal vehicles but can be more nuanced for other modes of travel
- **Reliability**: Understanding of how the levels of mobility can change

Specific Performance Measures
The guide continues to break down congestion, mobility, and reliability effects into tangible individual and area measures that can be applied to a project. Performance measures are broken into three categories: travel time measures, delay/congestion measures, and reliability measures. **Attachment 1** includes a summary of the measures from NCHRP 618 Exhibit 8.3.

Travel Time Measures

- Travel time
- Total travel time
- Accessibility

Delay and Congestion Measures

- Delay per traveler
- Total delay
- Travel Time Index (or Travel Rate Index)
- Congested travel
- Percent of congested travel
- Congested roadway
- Misery index

Reliability Measures

- Buffer index
- Percent on-time arrival
- Planning Time Index
- Percent variation
- 95th percentile travel time

Data Elements
When working with variable data sources, the guide lists several factors to consider when aggregating mobility and reliability analysis:

- A larger data collection window for traffic volumes is recommended, especially in or near large cities.
- Daily volume variations can highlight some of the heavy volume days that may impact an area (Fridays, weekends).
- Incident, weather, and road work information should be overlaid to understand what conditions are causing reliability issues.
- Parallel routes that may funnel demand if an improvement on a primary route is constructed should be understood.
- Seasonality should be understood if adjacent land use or peaking characteristics cause unique conditions throughout the year.

Applying the Right Measure
Exhibit 2.6 from NCHRP 618 is included in **Attachment 1**. This exhibit breaks down the primary and secondary measures that are recommended depending on the type of analysis area. It highlights the need for a smaller number of metrics for small study areas or short road sections and a larger set of metrics for regional studies. The guide notes that establishing what is considered “too much congestion” is key for agencies to understand that the goal of the project may not be free-flow conditions but mitigation of gridlock conditions.

Alternatives Analysis Process

During the alternatives analysis process, initial steps are important to the project’s overall success. Goals and objectives must align with community and agency priorities, performance measures should be selected based off the goals and objectives, and the correct tools and data collection methods should be determined. These steps help establish the approach for understanding and identifying deficiencies while developing a defendable process to compare alternatives.

The guide highlights some root causes of congestion or reliability issues in Exhibit 5.2 and offers improvement alternatives in Exhibits 7.1 and 7.2. These exhibits 618 are included in **Attachment 1**. The guide notes that a wide range of solution strategies should be considered, including nonintrusive widening projects such as the following:

- Use TDM strategies to shift demand to other corridors with excess capacity, other time periods, or other modes that can improve person throughput
- Increase capacity at bottlenecks by improving signal timings, ramp metering, allowing peak shoulder use, or restricting turn movements or freight during peak times
- Develop TSMO strategies, traffic incident management strategies, and safety strategies to reduce the probability of incidents, incident detection times, and the impact of incidents on capacity; improve emergency response times; and clear incidents quickly

Attachment 1 lists the development process strategies in detail. The guide also points to the following previous research:

- *Unclogging Arterials: Prescriptions for Relieving Congestion and Improving Safety on Major Local Roadways (FHWA-OP-03-069) (2003)*
- *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility (1997)*

Level of Service

NCHRP 618 helps inform practitioners that LOS service is only a piece of the overall puzzle when developing performance measures and applying them to the alternatives analysis process. It is important to understand accessibility for all modes and determine the root cause of why there may be an issue in the first place.

Attachment 1

NCHRP 618 Exhibit 8.3 details performance measures, what they address, the geographic area they are intended for, and how to report each performance measure.

Recommended Performance Measures	Congestion Component Addressed	Geographic Area Addressed	Typical Units Reported
Travel Time Measures			
Travel Time	Duration	Region	Person-minutes/day, person-hours/year
Total Travel Time	Duration	Region	Person or vehicle hours of travel/year
Accessibility	Extent, Intensity	Region, Subarea	# or % of "opportunities" (e.g., jobs) where travel time ≤ target travel time
Delay and Congestion Measures			
Delay per Traveler	Intensity	Region, Subarea, Section, corridor	Person-minutes/day, person-hours/year
Total Delay	Intensity	Region, Subarea, Section, Corridor	Person- or vehicle-hours of delay/year
Travel Time Index or Travel Rate Index	Intensity	Region, Subarea, Section, Corridor	Dimensionless factor that expresses ratio of travel conditions in the peak period to conditions during free-flow (e.g., TTI of 1.20 = congested trip is 20% longer than free-flow trip)
Congested Travel	Extent, Intensity	Region, Subarea	Vehicle-miles under congested conditions
Percent of Congested Travel	Duration, Extent, Intensity	Region, Subarea	Congested person-hours of travel (PHT) as % or ratio of total PHT
Congested Roadway	Extent, Intensity	Region, Subarea	# (or %) of miles of congested roadway
Misery Index	Duration, Intensity	Region, Subarea, Corridor	Proportion or percentage (e.g., 1.50) (expressing time difference between the average trip and the slowest 10 percent of trips)
Reliability Measures			
Buffer Index	Intensity, Variability	Region, Subarea, Section, Corridor	% extra time to be allowed to ensure on-time arrival, e.g., "BI of 30%"
Percent On-Time Arrival	Variability	Facility, Corridor, System	% of trips meeting definition of "on time"
Planning Time Index	Intensity, Variability	Region, Subarea, Section, Corridor	Dimensionless factor applied to normal trip time, e.g., PTI of 1.20 x 15-min. off-peak trip = 18-min. travel time for travel planning purposes
Percent Variation	Intensity, Variability	Region, Subarea, Section, Corridor	% of average travel time required for on-time arrival of given trip, similar to Planning Time Index
95^{th} Percentile	Duration, Variability	Section or Corridor	Trip duration in minutes and seconds

Exhibit 8.3. Recommended measures for reporting travel time, delay, and reliability.

NCHRP 618 Exhibit 2.6 details mobility and reliability measures and how they relate to different analysis area sizes.

	Mobility and Reliability Measures									
Analysis Area	**Travel Time**	**Travel Rate**	**Annual Delay Per Traveler**	**Travel-Time Index**	**Buffer Index**	**Total Delay**	**Congested Travel**	**Percent of Congested Travel**	**Congested Roadway**	**Accessibility**
Individual Locations	S		S	P	P	S				
Short Road Sections	P	P	S	P	P	S				
Long Road Sections, Transit Routes or Trips		S	S	P	P	S				
Corridors		S	S	P	P	P				S
Subareas		S	P	P	P	P	P	P	P	P
Regional Networks		S	P	P	P	P	P	P	P	P
Multimodal Analyses		S	P	P	P	P				P

P = Primary measure, and S = Secondary measure.

Note: Measures with delay components can be calculated relative to free-flow or posted speed conditions.

Exhibit 2.6. Recommended mobility and reliability measures for analysis levels (1).

NCHRP 618 Exhibit 5.2 details common deficiencies and likely root causes.

Deficiency	Proximate Causes	Likely Root Causes
Travel Time is excessive, but no significant delay or reliability deficiencies.	• Free-flow speeds are too low or travel distances are too great.	• Low-speed facility perhaps due to inadequate design speed (not a freeway). • Road System does not provide a straight line path between origin and destination (such as in mountainous terrain).
Delay is regular but excessive. (There may be excessive variability in travel time, but delay recurs regularly.)	• Inadequate capacity when compared to demand.	• Insufficient number of lanes. • Inadequate design. • Poor signal timing. • Too much demand. • Lack of alternative routes or modes for travelers.
Excessive Variability in Delay.	• Facility is prone to incidents and/or response to incidents is inadequate. • There may be surges in demand.	• Facility is accident prone due to poor design. • Frequent days of poor weather. • Incident detection and response is poorly managed or nonexistent. • Travelers not provided with timely information to avoid segments with problems. • There are unmetered surges of demand (often from large special generators).

Exhibit 5.2. Diagnosis chart for travel time, delay, and variability deficiencies.

NCHRP 618 Exhibit 7.1 details strategies and improvement alternatives for excessive peak period delay.

Problem	Likely Cause	Solution Strategies	Improvement Alternatives
Excessive Peak-Period Delay (on average day without incidents)	Peak Demand > Capacity	Travel Demand Management to shift demand to other corridors, other time periods, and/or other modes.	• Establish TDM Program for Employers • Staggered work hours • Construct Transit improvements • Increased transit service • Construct HOV lanes • Carpool parking • Construct bypass for bottleneck(s) • Peak-hour tolls • Auto restricted zones • Service vehicle hour restrictions • Parking supply management • Concierge shopping services • Satellite work stations • Work at Home Program • Ramp and signal metering
		Increase capacity at bottlenecks.	• Add lanes • Change signal timing • Correct substandard geometry • Allow peak period shoulder lane use • Reversible lanes • Peak period turn prohibitions • Ramp metering • Heavy vehicle restrictions

Exhibit 7.1. Alternative improvements to solve delay problems.

NCHRP 618 Exhibit 7.2 details strategies and improvement alternatives for excessive variability in peak travel times.

Problem	Likely Cause	Solution Strategies	Improvement Alternatives
Excessive Variability in Peak Travel Times	Demand exceeds capacity, and incidents are too frequent and too damaging	Reduce probability of incidents.	• Bring road design up to agency standards • Accident history investigation • Vehicle regulations • Reduce roadside distractions • Reduce in-vehicle distractions
		Reduce incident detection times.	• Real-Time Monitoring of traffic flow
		Improve emergency response times.	• Establish roving response teams • Service patrols
		Reduce incident clearance times.	• Integrate 911 emergency responders and maintenance operations • Contract towing services dedicated to road sections • Off-road pullouts for exchanging accident info
		Reduce impacts of incidents on capacity.	• Wider shoulders • Off-road pullouts for exchanging accident info • Gawker Screens
		Traveler information systems to help people avoid incident locations.	

Exhibit 7.2. Alternative improvements to solve reliability problems.

FHWA-HRT-11-064

FHWA-HRT-11-064 was selected for an in-depth review of relevant research due to its recommendations about the management, planning, and selection of traffic analysis tools over a project's entire life cycle. This report provides guidance about when and where to implement sketch planning tools, TDMs, deterministic tools, microsimulation tools, or optimization tools and what MOEs each tool provides.

Project Development Life Cycle

This guide emphasizes the need to use different tools throughout the project life cycle because one size does not fit all. The guide also stresses the importance and challenge of consistency across different platforms as a project progresses from one stage to the next. The stages discussed in this guide include the following:

- Project need identification
- Project initiation
- Project clearance
- Plans, specifications, and estimates
- Construction
- Operation

The guide highlights the need for sketch planning and TDM tools early in a project during the need identification and project initiation stages. The recommended tools change to more deterministic, optimization, or microsimulation categories as a project progresses into plans, specifications, and estimates; construction; and long-term operations. During this process, there are challenges to keep analysis consistent and representative of previous stage analyses tools. These challenges include, but are not limited to, the following:

- The lengthy time between project need identification and construction and operations
- That no tool can provide the needed information all the way through project's life cycle
- Existing limitations to methodologies and software that incorporate manuals and guidance
- Training needs and general cost for various software tools

The guide goes on to talk about the efficiency and benefits of consistent analysis throughout a project:

- There is reduced cost and time for analysis (minor updates to analysis instead of throwing away results and starting with a new software platform).
- The results from previous studies can be refined in previously developed analysis tools.
- Credibility of the project development process improves if a consistent message is provided throughout the project life cycle.
- Agency decision-making is more effective.

There are many factors that can derail or delay the project life cycle, which is why it is important to get a project started on the right foot during project initiation. As stages progress, the initial decisions used to advance the project should be checked and confirmed so the correct choice for the project is selected at the end of the process.

Project Delivery Analysis Plan

FHWA-HRT-11-064 discusses the risks associated with a complex project, including having multiple stakeholders, analysts, and analysis tools. It notes the way to manage risk throughout the project life cycle is to develop a Project Delivery Analysis Plan during project initiation, which is similar to a systems engineering management plan and should cover the following:

- Conceptual project description
- Objectives of traffic analysis
- MOEs
- Traffic analysis approach
- Risk management plan
- Resource requirements
- Schedule

The guide discusses the need for traffic analysis study objectives to be quantifiable throughout all stages of the project even though the specifics and analysis details might change. It also discusses the use of MOEs and the need to develop a draft technical analysis approach for each stage; the Project Delivery Analysis Plan can help identify key decision points. Many times, the most important decision during analysis is to identify whether a tool or approach is not going to provide results that can distinguish among alternatives or provide the expected level of detail required for decision-making.

Selecting Consistent MOEs

Chapter 4 is the main chapter that relates to ODOT's research on re-examining LOS. It provides a guide of MOEs that can be used throughout the project life cycle and how they can align with agency goals or project objectives. The guide provides a series of tables that summarize the typologies of MOEs, MOEs by analysis stage, and MOEs by tool category. These tables are listed in detail in **Attachment 1**.

Typology of MOEs

A key consideration during the selection of MOEs is determining whether MOEs will be applied to a corridor/bottleneck area or systemwide. The guide provides a good example of this by discussing how V/C ratios may be important along a corridor, but one systemwide V/C ratio does not mean much because systems typically have reserve capacity on underutilized routes. A list of these considerations is shown in **Attachment 1**.

Typical MOEs by Analysis Stage

One of the main points the guide continues to drive home is the need to use different tools throughout the project life cycle. These tools aim to provide answers to the project objectives for each specific stage. The guide provides a table that breaks down MOEs by study focus and analysis stage, shown in **Attachment 1**.

MOEs by Tool Category

Software platforms are limited by the number of outputs they can provide. This section in the guide breaks down what types of MOEs can be obtained from sketch planning tools, TDMs, deterministic tools, optimization tools, or simulation models. A table is provided in **Attachment 1**.

Using Outputs from Different Tools

The guide discusses four core principles to manage consistency in outputs:

- The analyst produces outputs, not the tool/software. It is important to review outputs and determine whether they are acceptable before publishing.
- Greater confidence should be given to outputs from better tools when comparing results.
- The capabilities and limitations of the analysis tools are understood.
- Inconsistencies among tools need to be managed. Different platforms provide different numerical values, but it is up to the analyst to determine whether A or B is documented or somewhere in between.

It discusses how these output differences may arise, which can vary from the tools themselves, versions of the software, different analysts, input parameters, or temporal data inputs/outputs. The guide wraps up with a discussion about how an issue may be perceived by the public compared to an output from a software platform. If possible, the guide recommends site visits during the time periods being analyzed and the development of clear talking points that explain potential consistency issues or use field data to calibrate existing tools.

Visualization and Communication

The guide concludes with a discussion on the end product that will be used to communicate analysis findings to the project team, stakeholders, and the public. Many times, illustrations must be easily digestible for a wide range of audiences. The guide uses the following questions to help with the development of illustrations:

- What illustrations are the most suitable for the intended audience based on available data?
- What tables/graphics most clearly illustrate the intended message?
- How informative/legible/readable are the illustrations?

The guide goes on to talk about how data results should be conveyed to decision-makers who are not analytically oriented. It recommends picking one value or measure that best fits the objective or situation. The important takeaway is to understand the audience and provide a clear message while keeping backup results available to provide additional context, if needed.

Level of Service

FHWA-HRT-11-064 provides practitioners with important information about tool selection, software limitations, alternatives to LOS, and incorporating MOEs throughout a project life cycle. A key takeaway from this guide is to tie project objectives during each stage of the project to software platforms that can provide defendable results. Additionally, analysts should work toward clear, digestible results for decision-makers.

Attachment 1

FHWA-HRT-11-064 Chapter 4 provides the following tables relating to MOEs:

- Table 2: Typology of MOEs
- Table 3: Typical MOEs by analysis stage
- Table 4: MOEs by tool Category

Table 2. Typology of MOEs.

MOE Type	Bottleneck and Facility-Specific	System Measures	Indices of Performance
Utilization	Vehicles per hour, V/C or D/C	PMT, VMT	V/C or D/C, level of service
Time	Mean travel time, 80 percent travel time	PHT, VHT	Travel time index, planning time index
Delay	Mean delay/vehicle	PHD, VHD	Level of service
Speed	Mean	VMT/VHT, PMT/PHT	Percent free-flow speed, level of service
Stops	Mean stops/vehicle	Total stops	Probability of stopping
Queue	Mean, 95 percent	Stopped delay	Queue storage ratio
Density	Mean	N/A	Level of service
Collisions	Collisions/million VMT (or per million vehicles)	N/A	Actual/typical facility rate
Emissions	Tons/day	Tons/day	N/A

Notes: V/C and D/C are the volume/capacity ratio and demand/capacity ratio, respectively. PMT, PHT, and PHD are person-miles traveled, person-hours traveled, and person-hours of delay, respectively. VMT, VHT, VHD are the vehicular equivalent of the person measures. The queue storage ratio is the ratio of the predicted queue length to the available storage length. N/A indicates not applicable.

Table 3. Typical MOEs by analysis stage.

Dimension (Study focus)	Project Initiation (System, 20 years)	Project Clearance (Facility, 5 to 25 years)	PS&E (Design, < 5 years)	Construction (< 5 years)	Operations (Facility, day to day)
Utilization	VMT, PMT	VPH, D/C	V/C	V/C	VPH
Time	VHT, PHT	Mean, 80 percent	N/A	N/A	Mean, 80 percent
Delay	VHD, PHD	LOS	LOS	Delay/vehicle	Delay/vehicle
Speed	Mean	LOS, Mean	LOS	N/A	Mean
Stops	N/A	N/A	N/A	N/A	Stops/vehicle
Queue	N/A	N/A	95 percent QSR	95 percent QSR	95 percent QSR
Density	N/A	LOS	LOS	N/A	Mean
Collisions	Rate	Rate	N/A	N/A	N/A
Emissions	Tons	Tons	N/A	N/A	N/A

VPH = vehicles per hour, D/C = demand/capacity ratio, V/C = volume/capacity ratio, LOS = level of service, QSR = queue storage ratio, N/A = not applicable.

Table 4. MOEs by tool category.

Dimension (Tool focus)	Sketch Planning Tools (System)	Travel Demand Models (System)	Deterministic HCM-Based Tools (Facility, bottlenecks)	Optimization Tools (Facility)	Simulation Models (Facility)
Utilization	VMT, PMT	VMT, PMT, D/C	D/C	V/C	VMT, V/C
Time	VHT, PHT	VHT, PHT	Mean	Mean	VHT, Mean
Delay	VHD, PHD	VHD, PHD	Delay/vehicle, LOS	Delay/vehicle	VHD, Delay/vehicle
Speed	Mean	Mean	Mean, LOS	Mean	Mean
Stops	N/A	N/A	Stops/vehicle	Stops/vehicle	Stops/vehicle
Queue	N/A	N/A	95 percent QSR	95 percent QSR	95 percent QSR
Density	N/A	N/A	Mean, LOS	Mean	Mean
Collisions[a]	N/A	[a]	[a]	[a]	[a]
Emissions[a]	N/A	[a]	[a]	[a]	[a]

[a] Collisions and emissions are not usually directly predicted by the tool types described in this chart. The outputs of the traffic analysis tools usually must be input into the appropriate highway safety or emissions analysis software.
D/C = demand/capacity ratio, V/C = volume/capacity ratio, LOS = level of service, QSR = queue storage ratio,
N/A = not applicable.