Assessing and Improving the Application of Multimodal Performance Measures in WSDOT Projects

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Borna Arabkhedri
Daniel Malarkey
Yuanjie Tu
Don MacKenzie

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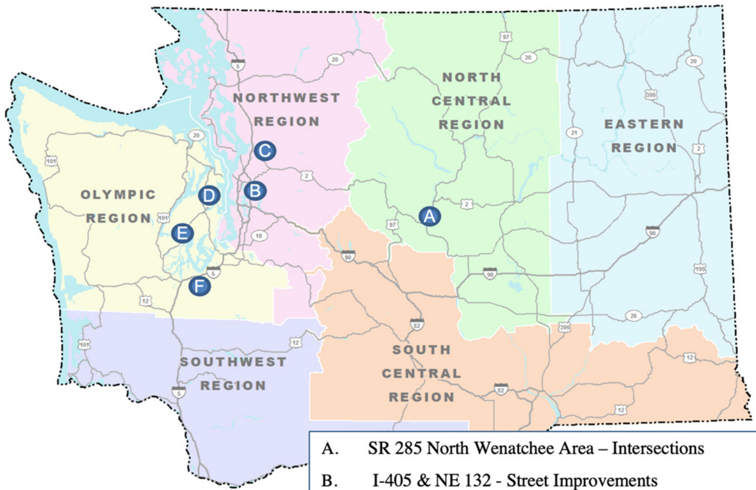

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B. I-405 & NE 132 - Street Improvements
C. SR 9 & South Lake Stevens Rd - Intersection Improvements
D. SR 305 Winslow Ferry to Poulsbo – Safety & Mobility
E. SR 3 Freight Corridor - New Alignment
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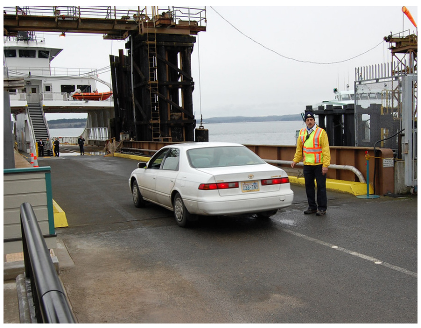
Project locations for multimodal case studies



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ASSESSING AND IMPROVING THE APPLICATION OF MULTIMODAL PERFORMANCE MEASURES IN WSDOT PROJECTS

by

Borna Arabkhedri, MS Student
Civil and Environmental Engineering

Daniel Malarkey, Senior Research Scientist
Sustainable Transportation Lab

Yuanjie Tu, Ph.D. Student
Civil and Environmental Engineering

Don MacKenzie, Associate Professor
Civil and Environmental Engineering

University of Washington
Seattle, Washington 98195

Washington State Transportation Center (TRAC)
University of Washington, Box 359446
University Tower, 4333 Brooklyn Ave NE
Seattle, Washington 98195-9446

Washington State Department of Transportation Technical Monitor
John Tevis, Transportation Technical Engineer
WSDOT Development Division

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16. ABSTRACT

This report assesses the application of multimodal performance measures and indicators in WSDOT's design process. It characterizes the "state of the knowledge" as reflected in the scholarly research on how best to achieve multimodal goals in projects. It characterizes the "state of the practice" by reviewing the design manuals, guidebooks, and handbooks of leading state departments of transportation to better understand their methods and performance measures for implementing multimodal design. It concludes with six case studies of multimodal projects across several WSDOT regions and evaluates how these projects integrate best practices for multimodal planning and performance measurement and opportunities for improvement.

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EXECUTIVE SUMMARY

This report aims to assess and help improve the application of multimodal performance measures and indicators in WSDOT's design process. We started the project by characterizing the "state of the knowledge" as reflected in the scholarly research that has been done on how best to achieve multimodal goals in projects. In this first phase, we reviewed the published research on the processes that support effective multimodal design and the development of performance measures to assess multimodal goals for specific projects and integrated transportation systems. We then investigated the "state of the practice" by reviewing the design manuals, guidebooks, and handbooks of leading departments of transportation to better understand the methods and performance measures they use to implement multimodal design. Finally, we examined six case studies of multimodal projects in Washington state and evaluated how these projects integrate best practices for multimodal planning and performance measurement and where there are opportunities for improvement.

LESSONS FROM THE LITERATURE

- Over the last thirty years, transportation planning and design have evolved from an emphasis on *standards-based design,* which focuses primarily on reducing the total number of vehicle crashes, to *performance-based design,* which balances the interests of truck and car users with those of local communities and other transportation modes such as transit, bicycling, and walking.
- We identified several reports that have lists of potential multimodal performance measures, but we found no consistent and comparable set of multimodal performance measures for project evaluation and decision-making. The literature lacks a set of consistent standards for measuring accessibility, connectivity, and productivity across modes, and researchers have reported different approaches to scoring and weighting key aspects of transportation performance.
- While the research literature reveals no widely agreed upon set of multimodal performance measures, it does show some convergence in the process of multimodal planning and design that can lead to project-appropriate performance measures.

LESSONS FROM MULTIMODAL PRACTICE LEADERS

- Practice leaders among state transportation departments have adopted similar multimodal planning and design approaches that align with the National Cooperative Highway Research Program's publication on performance-based highway design (NCHRP 839). The relevant steps are as follows:
    1. Define the transportation problem or need.
    2. Include at least one quantifiable goal for improvement.
    3. Identify and charter a group of project stakeholders.
    4. Prepare and implement a community awareness plan.
    5. Develop the project scope. Refine and confirm the problem statement and goals.
    6. Determine the project type.
    7. Identify land use and transportation context for each mode.
    8. Select design controls compatible with the project context.
    9. Formulate and assemble the geometric alternatives that solve the problem.
    10. Make and document the final design decision.
    11. Monitor and gather data after project completion to inform future project design decisions.
- Practice leaders tailor performance measures to the project and include both supply-side and demand-side measures. In the case of transit, for example, supply-side measures could include the percentage of transit stops accessible via sidewalks and curb ramps and demand-side measures could include the reliability of transit vehicles on the route as measured by the standard deviation of travel time.

FINDINGS FROM SIX WSDOT MULTIMODAL CASE STUDIES

1. WSDOT has adopted performance-based design within its "Practical Solutions" framework as a means to balance competing stakeholder interests and improve cost-effectiveness by not following rigid design standards.
2. WSDOT project engineers have embraced Practical Solutions, and in almost every case they discussed the approach when asked to describe their design process.

3. WSDOT project engineers view the WSDOT Design Manual as their key resource for project planning.
4. WSDOT's design process includes a standard Basis of Design document format that requires engineers to address all modes when evaluating design alternatives.
5. The Basis of Design document, in all six case studies, lacked quantitative performance measures for the non-automotive modes. Engineers would typically model delay and queue length for cars and trucks but would not formally model other modes. Stakeholder opinions, especially those of the local government and transit agencies, often served as a proxy for performance measures for designs about the geometry of sidewalks and pathways.
6. Every project included sidewalks and pathways for pedestrians and bicycles.
7. The WSDOT Design Manual recommends using the Highway Capacity Manual (HCM) process to calculate Level of Service (LOS) for transit, bicycles, and pedestrians, but the six case studies did not use these measures for evaluating non-automotive modes.
8. Opportunities for improving multimodal design and planning include the following:
    a. Ensure that the alternatives development phase includes different configurations for sidewalks and bicycle lanes, including some that are appropriate for the context and speed from auto and truck traffic by utilizing a different right-of-way than that used by the main project.
    b. Develop guidance on when engineers should take the step of conducting quantitative analysis using HCM LOS methods or other analytic approaches to inform design decisions for the non-motorized elements in their Basis of Design documents.

CHAPTER 1
LITERATURE REVIEW

In this section, we review literature related to multimodal level of service and methods for evaluating projects through performance-based design and developing multimodal performance indicators. The documents used for this literature review included journal articles, conference proceedings, and national-level research reports (e.g., NCHRP reports). This literature review builds upon the work of previous review papers and reports including Dowling et al. (2008) and Lasley (2016) while also integrating newer studies.

FROM AUTO CENTRIC TO MULTIMODAL DESIGN

Traditionally, the Highway Capacity Manual (HCM) (1) was used for measuring the performance and operations of highways and other transportation facilities. Measures such as automobile and truck delay and travel speed played significant roles in establishing the appropriate size and configuration of road facilities. The focus on automobile and truck movement resulted in projects that increased speed and expanded roadway capacity (Seskin et al., 2015). A recent study by Dock et al. (2017) found through interviews with peer agencies that congestion and delay measures remain important to the public and policymakers and continue to influence design decisions.

Over the last thirty years, the transportation planning and design profession has expanded upon the traditional approach of auto-centric performance measurement. Federally, actions such as the enactment of the Intermodal Surface Transportation Act (ISTEA) of 1991 shifted transportation policy from a focus of building out and maintaining the national highway network to integrating multimodal transportation systems (Sinclair et al., 2019). Federal policymakers continue to invest in multiple transportation modes in other national legislation including the Moving Ahead for Progress in the 21st Century (MAP-21) Act of 2012 (Sinclair et al., 2019).

Parallel movements have also occurred outside of the federal government, including efforts such as the National Complete Streets Coalition. This nationwide movement, launched in 2004, aims to integrate people and facilities in all dimensions of transportation networks, including planning, design, construction, operation, and maintenance. Seskin et al. (2015) described the National Complete Streets Coalition as “a non-profit, non-partisan alliance of public interest organizations and transportation professionals committed to the development and implementation of Complete Streets policies and practices." More than 700 agencies have adopted Complete Streets policies as of 2015.

The consequences of auto-centric design policies and their adverse effects on the users of other transportation modes and local communities disrupted by construction, noise, and pollution have motivated the shift towards multimodal planning. Pedestrians and bicyclists have especially felt the unfavorable effects resulting from high volumes of fast-moving motorized vehicles in urban areas, which decrease roadway safety for pedestrians and bicyclists and increase air pollution from vehicle emissions (Sanders et al., 2010).

Notwithstanding the pressure on departments of transportation (DOTs) and metropolitan planning organizations (MPOs) to adopt more multimodal approaches to project evaluation and decision-making, the transportation planning and design profession has not developed consistent and comparable multimodal performance measures that planners can apply over time and across geographic regions (Wang et al., 2016). The absence of a shared evaluation framework has inhibited progress towards the broad objective of multimodality (Sanders et al., 2010). State DOTs routinely use performance measures to assess transportation systems, but this assessment remains mostly based on the traditional highway engineering perspective of prioritizing automobiles while non-automotive measures have been applied in more limited contexts (Dock et al., 2017).

LEVEL OF SERVICE, QUALITY OF SERVICE, AND PERFORMANCE MEASURES

The terms "quality of service," "level of service," and "performance measures" have similar but distinct meanings (Phillips et al., 2001). The first edition of the Transit Capacity and Quality of Service Manual defines the terms as follows (Kittelson & Associates, Inc. et al., 1999):

Quality of Service: "The overall measure or perceived performance of service from the passenger's or user's point of view."

Level of Service: "LOS is a range of six designated ranges of values for a particular aspect of service, graded from "A" (best) to "F" (worst) based on a user's perception."

Performance Measures: "A quantitative or qualitative factor used to evaluate a particular aspect of service."

“Service measures” is another term used in this context, which differs from performance measures in that it represents the passenger's or user's point of view specifically, whereas performance measures can reflect any number of points of view. Level of service grades (A-F) are typically also applied to service measures (Kittelson & Associates, Inc. et al., 1999; Phillips et al., 2001). Traditionally, however, performance measures often have been viewed as from the “operator’s” point of view, and they have been more vehicle-oriented, including a variety of utilization and economic measures (Phillips et al., 2001).

Level of service remains a vital communication tool for planners and engineers to communicate the results of their technical analyses to decision-makers, elected officials, and the general public in a way that is easy to understand and interpret (Dowling et al., 2002). However, many analysts have observed that ease of understanding and the echoes of letter grades that the public are familiar with from schooling can not only make LOS scores attractive to policy makers but also obscure other factors that influence the overall quality of service that do not easily show themselves in an A to F classification (Kittelson & Associates, Inc. et al., 1999; Phillips et al., 2001). The weaknesses of LOS measures have helped drive the development of other multimodal performance measures.

According to Heller (2014), transportation performance measurement is defined by the FHWA as a “strategic approach that uses system information to make investment and policy decisions to achieve national performance goals.” The word "multimodal" is seen increasingly in the literature; however, different people may use the term in different ways and to represent different concepts (Sinclair et al., 2019). The performance of a multimodal system can be expressed through measurement initiatives such as multimodal accessibility (focusing on the ability to reach destinations), multimodal connectivity (quantifying the cohesiveness of travel across modes), or multimodal productivity (the productivity of actual person trips made across the network through all modes) (Sinclair et al., 2019).

Lasley (2016) argued that there are two main approaches to multimodal performance measurement: (1) “a collection of single-mode measures bound in a single resource” or (2) “a single resource/measure that examines multiple modes simultaneously using a common comparison factor.” Often times, multimodal performance measures are developed for estimating progress towards a broader goal. However, there is no single broad goal for multimodal performance measures, since effective multimodal performance measurement should include metrics that examine a variety of goals, e.g., system quantity, effectiveness, efficiency (delay), connectivity, competitiveness, and safety (Lasley, 2016).

Lasley (2016) reviewed the recent relevant literature to identify common themes and recommended steps to create useful multimodal performance measures. The paper concluded that measures that examine network performance among and between multiple modes are rare. Furthermore, Kanafani et al. (2010) and Cambridge Systematics (2010) also mentioned that there is a need for measures that use a common denominator (e.g., delay, travel time, etc.) to allow the evaluation of the system and compare one mode against the others to match the mode and route decisions.

Seskin et al. (2015) observed that performance measures can generally be interpreted to indicate the data inputs that are needed when agencies

- Tackle long-term planning efforts
- Select projects to fund
- Perform an alternatives analyses (evaluating all feasible options for a project)
- Consider specific elements when finalizing a project's design
- Display the present state of a system using tools such as a dashboard and
- Evaluate the outcomes of a built project.

According to Seskin et al. (2015), performance measurement is the process of "establishing performance targets, modeling impacts, and monitoring results." They pointed out that simple before-and-after analyses may demonstrate how well a project achieved its intended goals for elected leaders and residents. However, for transportation planners, designers, and engineers, such measurement provides an additional benefit: "measuring the actual results of projects allows them to make better-informed choices for future projects."

Seskin et al. (2015) recommended that measures should be chosen thoughtfully and with consideration of scale and scope to avoid misinformation in decision-making and evaluating results. For example, measuring vehicular LOS at only one intersection may lead the planner or engineer to conclude that a wider intersection is needed, which may unintentionally cause bottlenecks elsewhere on the corridor. Such inattention to scale could potentially reduce safety and quality of the environment for individuals using other modes such as walking or bicycling in a nearby intersection. Conversely, if a particular segment has not yet been connected to a larger walking and bicycling network, perhaps taking a before-and-after measure of the number of people walking or bicycling only on that street segment may be misleading, as the broader network level may be overlooked. Heller (2014) reinforced the notion that scope and scale are important when performance measures are considered, since metrics can be applied at an entire transportation system level, a corridor level, or at the facility level.

THE HIGHWAY CAPACITY MANUAL AND MULTIMODAL ANALYSIS

Although the focus of the Highway Capacity Manual published in 1985 (HCM 1985) was on auto-centric design, it also included methods for evaluating pedestrian and bicycle modes. According to Phillips et al. (2001), HCM 1985 offered very limited scope for the pedestrian and bicycle modes, and it defined performance measures for the environments of these two modes plainly as the degree of discomfort to the user due to overcrowding of the facilities. The applicability of this sort of measure is limited and offers limited understanding of the actual performance of those modes. HCM 1985 did not make mention of the concept of multimodality.

By contrast, HCM 2000 contained significant new methods for analyzing pedestrian and bicycle LOS while also including a summary of the Transit Capacity and Quality of Service Manual (TCQSM) for transit analyses (Dowling et al., 2002). However, somewhat similar to the methods provided in HCM 1985, these new methods use sidewalk and bicycle lane capacity for measuring pedestrian and bicycle level of service and neglect the impacts of facility design and the interaction of those modes with vehicular traffic on peoples' perceived level of service. Such design features have a real influence on pedestrian and bicyclist satisfaction with a facility and consequently its quality of service (Dowling et al., 2002).

For transit, however, because of the publication of the TCQSM (Kittelson & Associates, Inc. et al., 1999), several methods, performance measures, and LOS measures were made available that took the perspective of transit riders into account. These LOS measures were provided for transit systems, transit route segments, and transit stops (Dowling et al., 2002).

Elefteriadou et al. (2015) summarized the multimodal aspects in the next edition, HCM 2010. Their study covered three different methods presented in the HCM for (1) uninterrupted-flow facilities (Chapter 15); (2) interrupted-flow facilities or urban streets (Chapters 16-18); and (3) off-street pedestrian and bicycle facilities (Chapter 23). All are discussed below to understand the HCM’s approach to multimodality.

Uninterrupted Flow

Uninterrupted flow refers to facilities where traffic is not controlled by traffic signals, stop signs, or yield signs. A method for evaluating bicycle operations on multi-lane and two-lane highways is provided in the manual. A bicycle LOS (BLOS) score scaled from A to F is reported which represents "the quality of service for the bicycle mode when it is traveling along the highway within the same right of way as other motorized vehicles." It is assumed that bicyclists always use the rightmost lane of the highway (or shoulder when available). The factors that the BLOS score is sensitive to are “the vehicular demand in the rightmost lane of the highway, the width of that lane, the width of the shoulder, percentage of heavy vehicles, the speed limit of the facility, presence of parking, and pavement surface condition” (Elefteriadou et al., 2015).

Interrupted Flow

HCM 2010 provides LOS calculation procedures for on-street transit, bicycles, and pedestrians on urban streets. The manual uses multiple performance measures in determining LOS, rather than the more traditional single-measure approach (e.g., speed, delay, density).

Transit Analysis for Urban Street Facilities and Segments

Transit LOS measures are provided in the HCM for evaluating on-street public transit service in a multimodal context. On-street transit service is in contrast to off-street service, which refers to transit in its own right of way (e.g., a transit lane) or transit that travels along a street without stopping to serve passengers (e.g., express bus). The TCQSM provides more performance measures, computational methods, and spreadsheet tools for evaluating capacity, speed, reliability, and quality of service of both on- and off-street transit services. The method provided in the HCM simply provides a grade of A to F and is sensitive to the following: the frequency of on-street transit service, perceived bus speed (includes variables like on-board crowding, reliability, and other factors), and the quality of the pedestrian and waiting environments at bus stops.

Bicycle Analysis for Urban Street Facilities, Segments, and Intersections

The HCM provides BLOS for various scales and facilities, namely signalized intersections, links (between intersections), segments (links plus intersections), facilities (multiple consecutive segments), and off-street bicycle and shared-use paths/trails. The signalized intersection BLOS—stratified as usual into LOS A to F—is sensitive to the following variables: “lateral distance between the bicyclist and traffic, volume of traffic in the right lane, percent of heavy vehicles, presence of on-street parking, and cross-street width" (Elefteriadou et al., 2015). Bicycle speeds and volumes, and signal delay for the bicycles are not factored in the bicycle LOS. No methods are provided for BLOS for unsignalized intersections including roundabouts, due to a lack of research.

BLOS is also calculated for links and is sensitive to all the variables mentioned above (except the width of a cross-street, since it is inspecting links and not intersections) in addition to the following variables: the speed of traffic, the number of unsignalized access points, and pavement conditions. Finally, for BLOS of urban street segments, a weighted combination of the signalized intersection and link LOS values is used, and for the facility LOS, a weighted average of the segment LOS values is utilized.

Pedestrian Analysis for Urban Streets and Intersections

Pedestrian LOS (PLOS) is performed for the same geographic types/levels as for the bicycle analysis. In addition to those levels, "street corner pedestrian storage and crosswalk circulating capacity checks for pedestrians" are also provided in the HCM for signalized intersections. The PLOS methods provided in the HCM do not take into account Americans with Disabilities Act (ADA) accessibility; analysts should perform a separate assessment to incorporate that when evaluating the overall quality of service.

The PLOS at a signalized intersection is sensitive to "pedestrian delay due to the signal, lateral distance between the pedestrian and traffic, the volumes of traffic in the right lane, the left and right turning volumes crossing the crosswalk while pedestrians have the walk indication on, the percent of heavy vehicles, and the presence of on-street parking" (Elefteriadou et al., 2015). PLOS also depends on the number of lanes on the cross-street, as well as the number of right turn channelization islands that the pedestrian has to cross.

Finally, the PLOS at the link level is sensitive to "the lateral and buffer separation between pedestrians and traffic, the traffic volume in the right hand lane, the percent of heavy vehicles, the speed of traffic, the presence of on-street parking and barriers such as street trees, and the difficulty of making mid-block crossings (where legal)" (Elefteriadou et al., 2015). Moreover, a density-based pedestrian LOS is calculated for sidewalks with high pedestrian volumes, and the lower of the two LOS values is reported as the link LOS. Segment LOS, similar to that of the bicycle analysis, is calculated through a weighted combination of the signalized intersection and non-density link LOS values; but, it is also compared with the density-based link

LOS, and the worst is selected. Finally, facility LOS is a weighted average of the segment LOS values.

Off-Street Pedestrian and Bicycle Analysis

The recent versions of the HCM also provide methods for analyzing off-street pedestrian and bicycle facilities where three situations are considered: (1) a pedestrian only facility (e.g., stair, pathway, etc.) where LOS is estimated by the available space for the average pedestrian; (2) a pedestrian LOS on a shared-use path, where LOS is estimated by the number of times an average pedestrian meets or is passed by bicyclists; and (3) bicycle LOS on a shared-use path, determined by the number of times the average adult bicyclist meets, passes, or is passed by other path-users.

HCM analysis provides performance measures from a traffic operational quality viewpoint, and its provided methods estimate performance measures particularly related to that aspect of transportation. Elefteriadou et al. (2015) concluded that comprehensive planning requires a wider set of performance measures that consider other aspects beyond that of traffic operational analyses, such as environmental, financial, and community support measures.

The sixth edition of the HCM, issued in 2016 (HCM6), and the seventh edition, issued in 2022 (HCM7), are both subtitled "A Guide for Multimodal Mobility Analysis," pointing to the shift in perspective toward multimodal analysis. These recent editions of the manual incorporate the latest research findings into an extensive set of analysis tools for the operational analysis of traffic.

Elefteriadou (2016) categorized four dimensions mentioned in the scope of the HCM6, namely: capacity, quality of travel, quantity of travel, and accessibility. The HCM6 still mainly focuses on evaluating the capacity and quality of service of facilities and modes through data related to quantity, especially demand, as an input. They provide LOS as one of the best-known measures for assessing the service of a facility; however, "they also provide tools for estimating additional performance measures for a variety of modes and facilities" (Elefteriadou, 2016). Elefteriadou (2016) also clarified that LOS measures are intended to communicate about the operations of a facility to a non-technical audience and that performance measures recommended in the HCM6 can be used by themselves without the use of LOS.

Two new automobile-related chapters were added to the HCM6, listed in Elefteriadou (2016), including Chapter 11, Freeway Reliability Analysis, and Chapter 17, Urban Street

Reliability and Active Traffic and Demand Management. The focus of these new chapters is on evaluating travel time reliability through the distribution of travel times, over a broad period of time (e.g., a year) (Elefteriadou, 2016), and they do not seem to incorporate a multimodal context. But the study also mentioned that "in response to the increasing need to estimate the performance measures for pedestrian, bicycle, and transit facilities, as well as the interactions with vehicles," the HCM provides certain methods for those assessments, namely, chapters 16 through 23 (methods for assessing non-automobile modes and their interactions with vehicles) and Chapter 24 (off-street pedestrian and transit facilities). Chapter 15 of the manual evaluates bicycle operations on highways (multilane and two-lane) with the addition of information from newer research. The manual still recommends the use of the TCQSM for the evaluation of transit facilities; however, it does consider the effects of transit along urban streets within a "multimodal analysis framework" (Elefteriadou, 2016).

HCM7 published in 2022 updates the methodology for two-lane highways, provides a new network analysis method for evaluating queue spillback effects between freeways and urban streets, and addresses new planning-level methods for evaluating the effects of connected and automated vehicles on freeway, signalized intersection, and roundabout operations. This edition also updates the HCM's pedestrian analysis methods for signalized intersections and uncontrolled crossings.

LOOKING BEYOND THE HIGHWAY CAPACITY MANUAL

In the late 1990s, several studies addressed multimodality and the need for multimodal performance measures in the context of the federal ISTEA legislation. The Florida Department of Transportation (FDOT) was one of the earliest funders of research in this area. Guttenplan et al. (2001) were among the earliest to study multimodal level of service analysis at the planning level. The research focused on methods for determining the level of service (LOS) to pedestrians, bicyclists, scheduled fixed-route bus users, and through vehicles on arterials. It was based on work by FDOT, which had developed a multimodal LOS analysis process to measure and provide mobility for diverse roadway users.

In another project, FDOT entered into a contract with the University of Florida and two consulting firms that were the leaders of research in quality and level of service methodology development at the time to address the need for a planning level and quality of service analysis for Florida (Phillips et al., 2001). Some of the objectives of the project (which were shaped in the summer of 1998) were to (1) perform a national literature review of multimodal level of service methodologies to implement the best possible methodology in Florida; (2) measure the performance of corridor segments in two districts by applying and validating Bicycle LOS and Roadside Pedestrian Condition techniques; and (3) apply and test new HCM performance measures for transit (in test districts).

The study showed that there were some concerns across local governments, questioning whether statewide requirements would shift to standardizing and requiring use of multimodal performance methods (Phillips et al., 2001). However, the focus at that time appeared to be on developing techniques, not standardization, and to enable and support "local government efforts for multimodal planning by offering professionally acceptable techniques." They suggested several performance measures in the report and offered a literature review of processes used up until that point (being now somewhat outdated, it is not included in this study).

In addition, Dowling et al. (2002) developed and tested a method that measured the user-perceived quality of service from a multimodal perspective. The study also asserted that in the HCM 2000 release, there was a shift towards analyzing automobiles and transit in the same corridor for the first time; but it indicated that there were not any efforts to compile the auto and transit levels of service into an aggregate measure for corridor-level assessment.

The proposed methods in Dowling et al. (2002) estimated automobile and transit LOS analyses based on the HCM 2000 and TCQSM, respectively, while calculating bicycle and pedestrian levels of service based on models developed by the researchers. Four classes of corridors were recommended, and the methods were tested on two classes of urban corridors, with and without a freeway.

In more recent years, other methods for evaluating level of service across modes have emerged. One study identified eight different multimodal evaluation methods for an arterial corridor section case study in Austin, Texas. Zuniga-Garcia et al. (2018) evaluated the following methods:

1) Highway Capacity Manual
2) Transit Capacity and Quality of Service Manual
3) Charlotte, NC, Urban Street Design Guidelines (USDG)
4) Pedestrian and bicycle environmental quality indices (Pedestrian Environmental Quality Index (PEQI) and Bicycle Environmental Quality Index (BEQI))

5) Assessment of level of traffic stress (LTS)
6) Bicycle compatibility index (BCI)
7) Deficiency index (DI) and
8) Walk Score, Bike Score, and Transit Score.

The study focused on evaluating pedestrian, bicycle, and transit modes in particular, and on comparing letter-metric grades (e.g., HCM and TCQSM) with the use of different score measures (e.g., BCI, Walk Score, etc.). The researchers found that although the multimodal assessment methods in the HCM are well supported by research, they require user training and significant data. TCQSM can be used hand in hand with HCM to complement the transit mode for corridor evaluation. The authors identified some of the strengths and weaknesses of different approaches, for instance USDG being appropriate for intersection analysis but not for corridor evaluation, and PEQI and BEQI being appropriate for corridor analysis but not sufficient for robust intersection evaluation. Finally, they recommended applying the HCM and TCQSM methods to assess multimodal performance in corridors. They found that there is no single measure of multimodal performance and recommended applying different evaluation methods for each mode. The authors noted that in order to aggregate the results to provide a single unified score requires knowledge and judgment of how to weight different modes, making any aggregated mode results subjective and biased (Zuniga-Garcia et al., 2018).

Ni et al. (2013) proposed a new evaluation method that attempts to capture the efficiency and safety of all road users at the same time in one level of service metric. Their approach evaluates delay (using methodologies similar to that of Dowling et al. (2008)) and safety through conflict checks at the intersection using the VISSIM-SSAM simulation platform. Delay and safety are ranked 1 to 6 and combined.

The work of Sinclair et al. (2019) focused on developing performance measures that help assess the performance of a multimodal design project (e.g., an intersection, a street, etc.), also known as facility-based performance measurement. The research discussed a Multimodal System Productivity (MSP) score, which is the number of completed person trips per network minute. This research referred to "multimodal trips" in a network-level and trip-based context (i.e., trips that use different modes along their path). This measure was defined on the basis of the definition of productivity: "the ratio of input to outputs in the production process." For multimodal transportation systems, completed person trips are production output, and network travel times are production inputs; therefore, the MSP score is the number of completed person trips per network minute.

Kanafani et al. (2010) identified the attributes that affect multimodal performance from the demand and supply perspectives, and their roles in multimodal transportation. The research offered a utility-theory-based analytical framework, leading to the construction of an indirect utility function that quantifies the user's perception of level of service for multimodal alternatives. A set of metrics were also developed to quantify the measures of performance from the supplier's standpoint. This work emphasized the intermodal integration of various modes (using an entire trip that consists of several links of different modes) rather than focusing on what metrics can individually be used to measure the performance of each mode for a certain project. Their utility function is based on the following factors from the user's perspective: time (access, waiting, in-vehicle traveling, transfer), money (out of pocket, indirect, bundle), safety, reliability, and flexibility (Kanafani et al., 2010). The first two are disaggregate factors (meaning that they vary for each mode-link of the entire trip) whereas the latter three are aggregate factors (meaning that if even one of the mode links of that entire trip is unsafe, unreliable, or inflexible, the user may disregard that entire multimodal bundle as a whole). They also apply a utility function for the supplier's side, which is broken down into the government's perception (issues of concern are equity, energy, emission, monetary cost, and level of service) and the agency's perspective (factors are cost, revenue, and subsidy).

Sinclair et al. (2019) recently conducted a literature review to find an "ideal" multimodal system performance measure. They reported conducting a detailed literature search and concluded that they did not find an "ideal" multimodal transportation performance measure in their literature review, although the details of their search were not mentioned in the report. They therefore developed their own measure called Multimodal System Productivity (MSP).

All of these efforts to develop multimodal evaluation methods that extend beyond those in the Highway Capacity Manual reflect a sustained interest in the design and planning community to wrestle with the challenges of analysis, process, and public choice involved with making transportation investment decisions that will influence human experience and behavior across multiple modes, time scales, and geographies.

SELECTING THE RIGHT MULTIMODAL PERFORMANCE MEASURES

Harvey et al. (2018) observed that each agency may have to develop context-specific design guidelines for their projects rather than directly applying national or state-level guidelines. Local control will lead local agencies to develop their own “Complete Streets design guidelines” that balance the interests of people who use different transportation modes. If a region does not have Complete Streets design guidelines for its locality, Harvey et al. (2018) recommended that they determine their community needs and preferences while examining existing street typologies, climate, and current and planned transport modes. The study further anticipated that in the future, with more data collection, analyses, and information documentation being readily available, Complete Streets design guidelines will likely change in consideration of what has and has not worked (Harvey et al., 2018).

Similar guidelines have been offered in the literature regarding project evaluation through the development of objectives and performance measures. A study recommended four general steps for agencies undertaking project evaluation (Seskin et al., 2015):

1. **Agree to goals and objectives of the project**: The goals of the project need to be established and agreed upon. This can be a challenging process since different needs are expressed by residents, elected officials, and transportation leaders. However, challenges can be overcome by encouraging participation and engagement in dialogue leading to consensus and mutual understanding. Furthermore, certain goals may exist on a network level rather than a project level. For example, a project by itself may not achieve many goals for a particular street segment, but any contributions to a broader goal, when viewed in the context of an entire funding program or the entire network, should be considered (e.g., there may be a citywide goal to build a certain amount of accessible curb ramps each year).

2. **Determine the best ways to measure goals**: Engaging both analysts and community members about what they will want to know about the project once completed can help identify which data to collect. Some of those goals may require alternative data sources collected by agencies other than the transportation agency, such sales data from business improvement districts, crash data from local police departments, and health data related to active transportation.

3. **Implement measures**: Baseline data should be collected at this time for each measure, and an appropriate timeframe for evaluation after completion should be established. One best

practice is to measure conditions a year before, a year after, and three years after the project is completed. Continuous data collection may be needed for some measures. Notably, not all measures need to be quantitative, and qualitative ones may be more relevant in some cases (e.g., collecting quotes from people's experiences with the street and what they like about it, either collected in the project outreach or through additional interviews after completion).

4. **Share results**: Sharing results with the public allows members of the public, elected officials, and other partner government agencies to understand results. It is important to design and package an attractive final product. Photos should be included, accompanied by quotes regarding the project.

Seskin et al. (2015) underscored that data can help make better decisions when performance measures are devloped to suit the goals of a project, but it is not a substitute for community vision. Furthermore, another recommendation was that performance measures do not have to be complicated and sophisticated mathematical models; they can be as simple as “blocks of sidewalk added” or “number of trees planted.”

Seskin et al. (2015) outlined useful performance measures for seven common complete streets goals, namely access, economy, environment, place, safety, equity, and public health. The focus of these goals is on project-level evaluation, but some related network-level measures are also included. The report further provided a very long list of performance metrics, which are included in Appendix B.

Lasley (2016) further agreed with previous findings that agencies should consider asking several questions that impact a multimodal performance measure before creating or deciding on using that metric. These questions include the following:

1. “How will the measure be used?
2. What are the ultimate goals of measurement?
3. What exactly is being measured and does this match planning objectives?
4. Is each mode treated fairly within the measure?
5. Are both people and goods considered?
6. What are the likely and worst-case impacts of the use of the measure? and
7. Who is the audience and could they understand the measure?”

Furthermore, agencies should also examine which factors are already being measured well, and which factors could use improvement (Lasley, 2016). Multimodal performance measurement generally measures one of six factors: 1- Quantity (volume/tonnage); 2- effectiveness (throughput, such as person- or vehicle-throughput per hour or other similar measures); 3- Efficiency (travel time or delay); 4- Competitiveness (reliability or cost); 5- Connectivity (LOS measures or connectivity to other modes and/or facilities); and 6- Safety. These share similar terms with those mentioned in Elefteriadou et al., (2012).

The study further recommended that in developing performance measures, it is important to make sure that highlighting one mode does not come at the cost of penalizing another (Lasley, 2016). Moreover, agencies should consider performance measures that are easily understandable and interpretable. The measures should not be too complicated to communicate and perceive. Finally, agencies should set an expectation or expected outcome for each mode. Similar to how roadways are classified in a different manner, expectations for the travel speed we get from a freeway should be different than that of an urban arterial. We should not expect the same standards across different modes (e.g., when comparing auto delay to transit delay).

Elefteriadou et al. (2012) developed a framework to help agencies in selecting a set of useful performance measures, consistent with their overall goals and quality of life desired by their community. The implementation of this framework is in the following three steps:

1. Identify goals and objectives for the project and the transportation system of the region (e.g., reduce congestion, increase non-SOV travel, minimize environmental impact, enhance safety).
2. Select a set of measures appropriate for each goal from an extensive list of measures (this list is attached in the Appendix C).
3. Use evaluation criteria to assess each measure in light of the agency's goals, policies, and resources.

The framework uses five mobility dimensions: Measures of infrastructure and environment; measures of demand and system utilization; measures of user perceptions; measures of safety; and measures of sustainability (Elefteriadou et al., 2012). These are further categorized into the subdimensions shown in Figure 1. For each of the subdimensions, an extensive list of performance measures is identified (illustrated in the Appendix C).

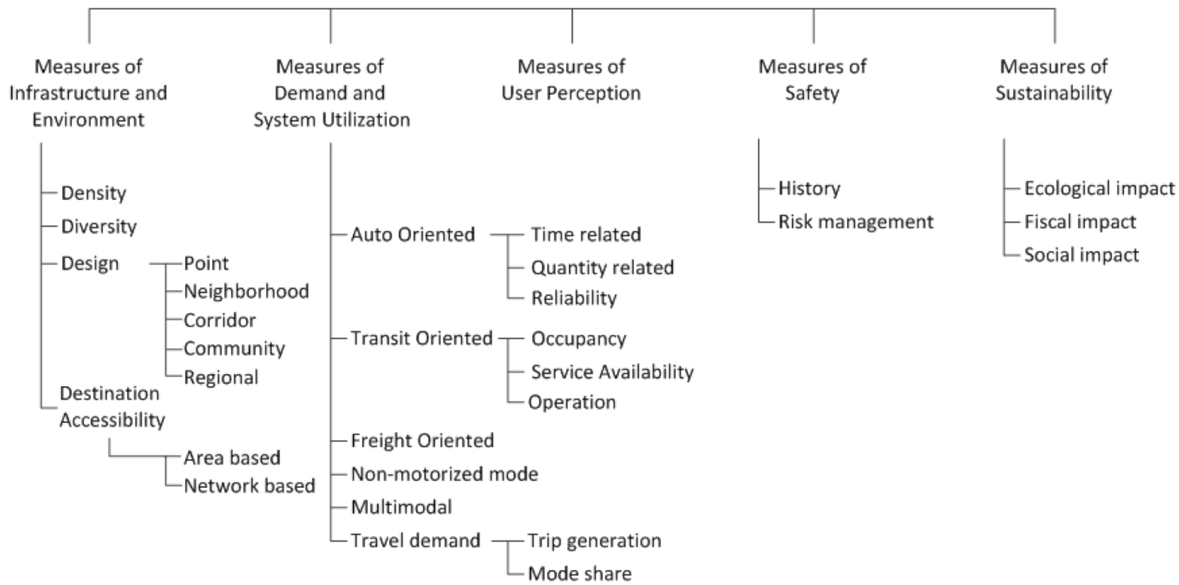

Figure 1: Classification of performance measures by mobility dimension (Elefteriadou et al., 2012)

The framework employs seven broad mobility-related planning objectives that are then linked to the performance measures. (For further information, refer to Table B.2 of their report, which provides performance measures by objectives and characteristics.) The planning objectives are (1) minimize ecological impact; (2) increase accessibility; (3) increase non-SOV travel; (4) reduce congestion; (5) optimize freight movement; (6) enhance safety; and (7) reduce air pollution. Finally, the data requirements for each indicator were assessed in the study, and those are available in Appendix D. This framework is among the most useful we found in our review of the literature, and we recommend it to those looking to extend performance-based design beyond what's described in the Highway Capacity Manual.

Dock et al. (2017) offered a different approach that emphasizes the importance of visualization tools for agencies to display how they are addressing multimodal mobility. The study provided a set of measures and a data visualization component for the District of Columbia DOT and for other agencies to use. The performance measures include a set of commute-related metrics, which are shown in Figure 2 based on their modal perspective and broad mobility category.

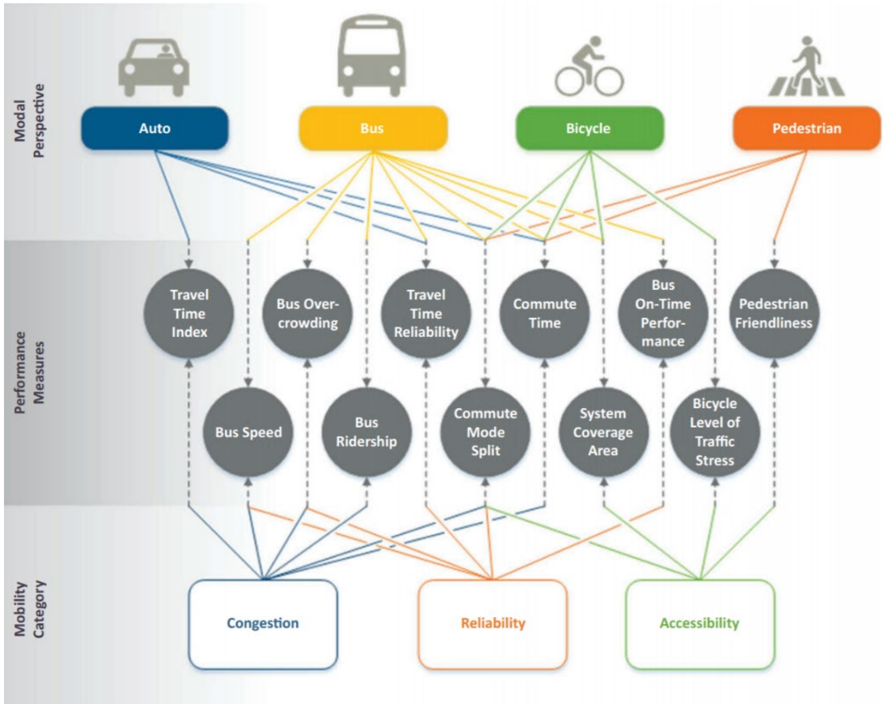

Figure 2: Performance measures by modal perspective and mobility category (Dock et al., 2017)

The study noted that "Washington State and Florida are leaders among states in performance measurement" and that both of these states used congestion measures that address multiple modes (Dock et al., 2017). The study specifically cited the Washington State DOT's Corridor Capacity Report, a web tool that evolved out of the Grey Notebook performance publication (Washington State Department of Transportation, 2014). Congestion on major Interstate corridors is described in The Corridor Capacity Report in terms of daily vehicle delay; vehicle throughput; length and duration of routine congestion; and transit, park-and-ride, and high-occupancy vehicle lane usage. Dock et al. (2017) concluded that this shift helps the department consider its performance "through the lens of economic productivity."

Similarly, the Florida DOT produces the Multimodal Mobility Performance Measures Source Book, an annual report of mobility performance measures (Transportation Statistics Office, Florida Department of Transportation, 2015) was discussed in Dock et al. (2017). A robust set of mobility and system coverage measures are mentioned in the source book that cover all modes (i.e., all surface modes, aviation, and seaports). System performance is divided into four broad categories: quantity, quality, accessibility, and utilization.

Another approach focuses on transportation accessibility as "the measure that truly represents the success of multimodal transportation systems from both the eyes of users and transportation practitioners" (Tasic & Bozic, 2017). The paper further presented spatio-temporal accessibility measures for pedestrians, bicyclists, and transit users, using the City of Chicago as a case study.

Sanders et al. (2010), similar to other named studies, recommended first identifying broad objectives and goals for the project, and then adopting performance measures to suit those goals. The study identified five broad goals for a public agency (the study was particularly making suggestions to CalTrans, but they noted that these can be adopted by other agencies as well), including safety, mobility, delivery, stewardship, and service. They also identified "complete and green street measures," which can measure progress towards the broad objective of multimodality. The measures they suggested are fully outlined in the appendix section of this document; however, some measures are also mentioned below.

For pedestrians and bicyclists, Sanders et al. (2010) proposed safety performance measures including pedestrian fatality rate per walking trip; pedestrian injury rate per walking trip; bicyclist fatality rate per bicycling trip; and the number of pedestrian/bicyclist collision hotspots on urban arterials. In addition, they suggested some key system mobility measures, including the ratio of sidewalk mileage to centerline roadway mileage, bidirectionally on urban arterials; the ratio of Class II bicycle facility mileage to centerline roadway mileage, bidirectionally on urban arterials, percentage of intersections that are ADA compliant, number of pedestrian trips on urban arterials, and number of bicycle trips on urban arterials.

Summary

This survey of some of the important studies that have worked to extend multimodal project analysis beyond what is included in the Highway Capacity Manual conveys some of the diversity of views on what performance measures to apply given the context of any particular planning or design decision. While we found the literature reflected a wide range of viewpoints on performance measures, the studies tended to converge on the steps involved in a good multimodal planning process.

Figure 3 compares the recommended processes for project evaluation and performance measure development, highlighting key themes mentioned by three of the most relevant and thorough studies (Elefteriadou et al., 2012; Lasley, 2016; Seskin et al., 2015). Table 1 compares the recommended goals and objectives, along with dimensions for characterizing performance measures, as found in a selection of the most relevant published papers.

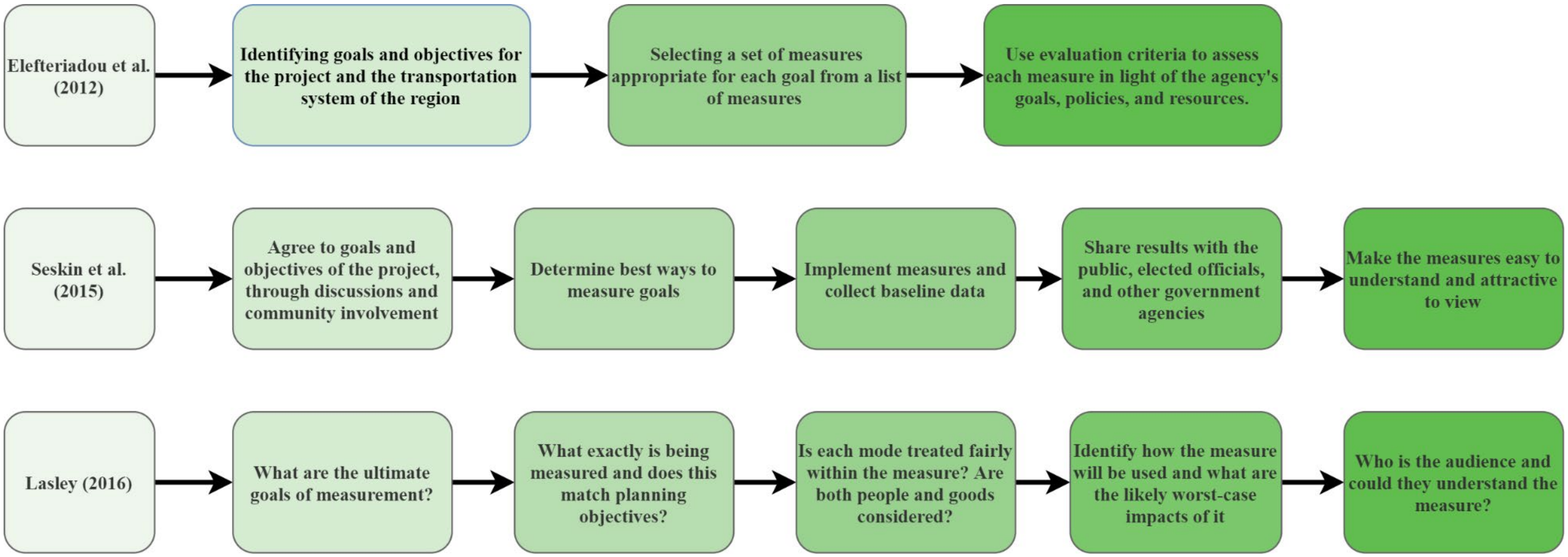

Figure 3: Processes for developing performance-based measures and evaluating projects

Table 1: Characterizing the literature by recommended goals for projects, dimension provided for the performance measures, and list of performance measures provided

Study	Recommended Goals and Objectives	Dimensions for Characterizing the Measures	List of Performance Measures
Elefteriadou et al. (2012)	(1) Minimize ecological impact, (2) Increase accessibility, (3) Increase non-SOV travel (4) Reduce congestion (5) Optimize freight movement, (6) Enhance safety, and (7) Reduce air pollution	1 Infrastructure and environment (Density, Diversity, Design, Destination, and Accessibility), 2 Demand and system utilization (Auto, Transit, Freight, Non-motorized, Multimodal, and Travel Demand), 3 User Perceptions (Time-Related, Quantity-Related, Reliability, Occupancy, Service Availability, Operation, Trip generation, and Mode share), 4 Safety (History and Risk management), and 5 Sustainability (Ecological, fiscal, and Social)	Appendix D (pages C-1 to C-36)
Seskin et al. (2015)	(1) Access, (2) Economy, (3) Environment, (4) Place, (5) Safety, (6) Equity, and (7) Public Health		Appendix B (pages B-1 to B-15)
Lasky (2016)		1 Quantity (volume or tonnage), 2 Effectiveness (person or vehicle throughput per hour), 3 Efficiency (travel time or delay), 4 Competitiveness (reliability or cost), 5 Connectivity (LOS measures or connectivity to other modes and/or facilities), and 6 Safety	
Sanders et al. (2010)	(1) Safety, (2) Mobility, (3) Delivery, (4) Stewardship, and (5) Service		Appendix A (pages A-31 to A 34)
Dock et al. (2017)		1 Congestion, 2 Reliability, and 3 Accessibility	

SUPPLY- VERSUS DEMAND-BASED PERFORMANCE MEASURES

A recurring theme in the literature is the difference between supply- and demand-based performance measures. Demand-based measures focus on how much a facility is serving users (e.g., the number of bicycle trips on the urban arterial per day, reductions in travel time). In contrast, supply-based measures emphasize the opportunities provided by facilities (e.g., ratio of bicycle facility mileage to roadway mileage).

Lee & Miller (2017) emphasized the importance of differentiating between supply-based measures and demand-based measures. They also argued that some methodologies want to measure what level of multimodality their facility design is supplying to the user, while others measure the level of usage of their facility by different modes. For example, the "Complete Streets score" is a supply-based measure that evaluates how a facility serves pedestrian, transit, auto, and bicycle users, based on criteria established by the community (e.g., a street passing through town should serve both transit riders and bicyclists) (Kingsbury et al., 2011). A second example of a supply-based measure is Multimodal Level of Service (MMLOS), provided in Dowling et al. (2008), which is more operational-focused and evaluates auto drivers, bus passengers, bicyclists, and pedestrians. Criteria such as pavement conditions or lateral distance of bicyclist from drivers are considered in this methodology, among other mainly supply-based characteristics of the corridor. On the other hand, an example of a demand-based measure was indirectly implied in work by Grant et al. (2012), where the use of a facility by non-auto modes implied a greater level of multimodality.

Lee & Miller (2017) noted the lack of a suitable framework that can assess multimodality by looking at supply and demand simultaneously and so proposed an approach that combines probability theory and principal component analysis to create a new indicator based on both supply and demand (i.e., modal shares and monetary investment for each mode).

Phillips et al. (2001) also noted the difference between supply- and demand-side methodologies and implied that quality-of-service methodologies are considered "supply-side" assessments since they are an evaluation of existing facilities. A problem with supply-side assessments is that they do not predict or estimate future demand. They may, however, help decision-making regarding potential investments. On the other hand, quantitative estimates of demand for multi-modal facilities rely on methods that assess potential demand levels rather than actual demand, and such analysis may be biased by the incentives of project proponents. The study further encouraged the use of supply-side methodologies in coordination with some of the demand-side assessments, especially when demand is associated with the quality of existing facilities (Phillips et al., 2001).

For demand-based measures, a common theme mentioned in several studies was the lack of data for measuring the true performance of a system in terms of facility usage. A study by Barbeau et al. (2020) found a solution in applying big data for improving transportation measurement, particularly that of public transit using sources such as General Transit Feed Specification (GTFS) and automatic vehicle location (AVL) data. Another study (Sinclair et al., 2019) also indicated that the use of location data from smartphones could help make up for the lack of facility-based data in measuring multimodal network performance by using individual trip-based data from smartphones rather than data from facilities. While there are privacy concerns regarding the use of these data, companies such as Inrix have developed business models to that employ these data to create demand-based performance measures of particular facilities.

KEY INSIGHTS FROM THE LITERATURE ON MULTIMODAL PERFORMANCE MEASURES

Our review examined the history of multimodal approaches in transportation design and methods for multimodal performance-based design. We found that in reaction to decades of auto-centric design, transportation agencies have shifted towards multimodalism. A number of multimodal level of service methods and multimodal performance measures are available in the literature, but none of them may serve as an "ideal" performance measure since the needs of projects are inherently different from each other.

Several of the key studies recommended that agencies identify and define their own performance measures for each project by evaluating their broad and project-specific goals and the available data that they have. Key suggestions regarding performance-based design include the following:

- The goals and objectives of the project should be identified as a first step. These goals could be generic and use broad terms such as safety, reliability, utilization, etc., or they could be more specific, such as "reducing pedestrian fatality rate to amount X by year Z."

- An extensive list of performance measures is readily available for analysts to choose from. Two extensive lists of performance measures are provided in the appendices to this document: Seskin et al. (2015) in Appendix B and Elefteriadou et al. (2012) in Appendix C.
- Once performance measures have been selected, analysts should identify required data sources to reach those goals.
- One mode should not be sacrificed to serve another.
- Performance measures used for a project should be a combination of supply-based and demand-based measures, not focused on just one side in favor of the other.

CHAPTER 2
REVIEW OF THE STATE OF THE PRACTICE

To build an understanding of the state of the practice in multimodal and performance-based design we began by interviewing multimodal planning and design experts to see which state DOTs lead in this area and what documents are especially relevant to them. Then we summarized those documents and synthesized the best practices for finding performance measures and structuring the overall design processes.

PROCESS FOR IDENTIFYING LEADERS IN MULTIMODAL DESIGN

We identified multimodal planning and design experts from a list of participants in the Transportation Research Board 2021 Annual Conference's multimodal subcommittee virtual meeting. We sent 13 emails to a combination of USDOT (FHWA), state DOT, local DOT, and industry experts, asking for 15 minutes to talk about agencies and jurisdictions that are considered multimodal leaders and recommendations of state or local design manuals that are especially relevant to our research. We received nine responses that consisted of five state DOT officials and four industry experts.

The interviewees identified local or state jurisdictions that had done previous work regarding multimodal design, performance-based design, context-sensitive solutions, and Complete Streets, or had some level of documentation for these topics in their design manuals, handbooks, or guidebooks. All but one state DOT interviewee identified their own agency as having done some level of work in these fields. On average, each DOT representative identified seven jurisdictions as multimodal leaders (including themselves), whereas each industry expert identified eight leaders on average. One of the industry experts highlighted 19 jurisdictions leading to a higher average.

Our interview protocol began with a brief, two-minute introduction of the research project and then moved to five open-ended questions, although not every interview included all five questions. The discussion for some questions was more detailed and automatically led to the responses we were looking for to our other questions. We clarified that by “multimodal,” we meant active transportation (e.g., pedestrians, bicycles), freight (e.g., trucks, delivery vans, etc.), transit (e.g., buses, trains, paratransit), and single-occupant vehicles, and we asked them to incorporate information about all these modes in their responses to these questions:

- Are there any ongoing activities for expanding and pushing multimodal transportation forward in your own state? If so, could you elaborate on those efforts?
- Where could we learn more about these efforts in your state (i.e., online resources, particular design manual chapters, etc.)?
- Are there other design manuals or documents belonging to other states that could be identified as especially relevant to our research?
- In particular to performance measures, and data needs for different modes in multimodal transportation, what resources can be identified?
- Do you have examples in your community where this new multimodal approach was implemented? Has it made a difference and was it a helpful difference or not?

Table 2 shows the results of our interviews. The table shows the four jurisdictions that were ultimately chosen as multimodal practice leaders to compare to WSDOT, with their votes highlighted. Massachusetts received the highest number of votes with seven, Minnesota was next with six, Florida had five, and Michigan had four. However, we elected not to examine Michigan because Minnesota is in the same region and recieved more votes. Instead, we selected Oregon, which had three votes. Three other jurisdictions also received three votes, i.e., Wisconsin DOT, Washington DOT, and Portland, Oregon. Wisconsin was also not chosen because Minnesota had already been chosen from the Midwest. Washington was not chosen because this project was conducted for WSDOT, and we aimed to identify other jurisdictions. Although Portland, Oregon, was a viable choice, Oregon DOT was determined to be a better fit given its status as a neighboring state transportation department. Interview highlights included the following:

- At least two of interviewees pointed to Massachusetts DOT's (MassDOT) Bike Facilities Guide as a standout among other practical guidelines. One interviewee noted that Massachusetts adopted context-based design earlier than other jurisdictions, continues to improve its Project Development and Design Guide, and excels at the context-sensitive and multimodal aspects of design.
- Florida DOT (FDOT) was acknowledged as a leader for its efforts to transition to context-based design and context-sensitive guidelines. FDOT has a thorough context classification document and has held several workshops in recent years, including workshops for Complete Streets and context-based design.

- Minnesota was praised for its bike facility guidelines, its performance-based practical design guidelines, and its documentation efforts, and Oregon DOT was especially praised for its Blueprint for Urban Design (BUD).
- Interviewees identified two NCHRP reports as especially relevant. NCHRP Report 785 (Ray et al., 2014) provides a principles-focused approach that looks at the outcomes of design decisions as the primary measure of design effectiveness. The report presents methods to incorporate performance-based analysis into the project development process. NCHRP Report 839 recommends a new highway geometric design process that is more aligned with the current expectations of transportation agencies and communities by focusing on transportation performance rather than the selection of values from tables of dimensions.
- One interviewee noted that a particular county they know of is moving entirely away from functional classification of roadways towards context classification exclusively.
- Finally, one expert noted the decline in the incidence of performance measures in design manuals and greater emphasis on design processes and tailoring measures to projects.

Table 2: Results of informational interviews for identifying multimodal leaders

Region	Type	Jurisdiction Name	State DOT (A-E)					Industry Expert (F-I)				Total
			A	B	C	D	E	F	G	H	I	
West	State	California DOT	✓						✓			2
		Oregon DOT		✓						✓	✓	3
		Washington DOT	✓	✓						✓		3
	Local	Denver, CO	✓							✓		2
		Portland, OR	✓	✓						✓		3
		Seattle, WA								✓		1
Southwest	State	Arizona DOT			✓							1
	Local	Austin,TX								✓		1
		Dallas County, TX								✓		1
		Maricopa County, AZ								✓		1
Midwest	State	Illinois DOT					✓	✓				2
		Michigan DOT	✓			✓	✓			✓		4
		Minnesota DOT		✓	✓		✓	✓	✓	✓		6
		Ohio DOT								✓		1
		Wisconsin DOT					✓	✓	✓			3
	Local	Ann Arbor, MI	✓				✓					2
		Columbus, OH								✓		1
		Chicago, IL	✓					✓				2
		Grand Rapids, MI					✓					1
Southeast	State	Florida DOT	✓		✓	✓	✓		✓			5
		Georgia DOT						✓				1
		North Carolina DOT				✓	✓			✓		3
		Tennessee DOT								✓		1
		Virginia DOT	✓		✓							2
	Local	Charlotte, NC								✓		1
		Raleigh, NC								✓		1
		New Orleans, LA			✓							1
Northeast	State	District (DC) DOT	✓						✓			2
		Maryland DOT							✓	✓		2
		Massachusetts DOT	✓	✓	✓	✓	✓			✓	✓	7
		New Jersey DOT				✓						1
		Pennsylvania DOT								✓		1
	Local	Cambridge, MA	✓									1
		New York City, NY	✓						✓			2
		Somerville, MA	✓									1
		Total	14	5	6	5	9	5	7	19	2	

REVIEW OF MULTIMODAL PRACTICE LEADERS DESIGN GUIDANCE

Table 3 shows the key documents referenced in our interviews for each of the final four states.

Table 3: List of documents for four multimodal practice leaders

Document type	FDOT	MnDOT	MassDOT	ODOT
Main Design Manual	- FDOT Design Manual (FDOT, 2020a) - Florida Greenbook (FDOT, 2016)	- Road Design Manual (MnDOT, n.d.)	- Project Development and Design Guide (MassHighway, 2006)	- Highway Design Manual (ODOT, 2012)
Other Design Guidelines	- Context Classification Guidelines (FDOT, 2020b) - Transit Facilities Guideline (FDOT, 2017) - Context Classification Framework for Bus Transit (Kittelson & Associates, Inc., 2020)	- Performance-Based Practical Design Process and Design Guidance (MnDOT, 2018) - Bicycle Facility Design Manual (MnDOT, 2020)	- Separated Bike Lane Planning & Design Guide (MassDOT, 2015) - Guidelines for the Planning and Design of Roundabouts (MassDOT, 2020)	- Blueprint for Urban Design (BUD) Volumes 1 & 2 (ODOT, 2020a, 2020b)
Transportation Plans	- Complete Streets Implementation Plan. M2D2: Multimodal Development and Delivery (FDOT & Smart Growth America, 2015)	- Statewide Bicycle, Pedestrian, Multimodal, and other Transportation Plans		- Oregon Transportation Plan

Florida Department of Transportation

The FDOT Design Manual (FDM) serves as the main design guide for the State of Florida. Chapter 1 of the design manual covers project development, and Chapter 2 covers design criteria. The FDM replaced FDOT's Plans Preparation Manual (PPM) (circulated since 1998) in January 2018. The department has another important document titled FDOT Context Classification Guidelines (FDOT, 2020b) that classifies Florida's roads into eight different contexts. It also has policies, guidelines, and implementation plans for Complete Streets projects. The FDM also has subchapters on pedestrian facilities (222), bike facilities (223), shared-use paths (224), and public transit facilities (225). Intersections are in chapter (212) and modern roundabouts in chapter (213).

Florida DOT leads in its use of context classification and context-sensitive solutions (CSS) as well as its Complete Streets program. Interviewees noted that Florida moved to context classification earlier than several other states and that its detailed CSS guidelines provide state-of-the-art guidance for its engineers and practitioners in designing facilities that serve all modes according to the land context. The Florida Greenbook (FDOT, 2016) provides uniform minimum standards and criteria for the design, construction, and maintenance of all public streets and highways, including pedestrian and bicycle facilities, in the State of Florida.

FDOT was also able to fit its bike and transit guidelines within the CSS framework, according to one of our interviewees. Its public transit office has several documents that provide technical guidelines in transit facilities designed to facilitate transit operations on and off the roadway system. Its Context Classification Framework for Bus Transit (Kittelson & Associates, Inc., 2020) provides illustrations pointing out the basic and desired elements for transit facilities (i.e., bus lanes, bus stops, etc.) with respect to Florida's eight different contexts, shown in Figure 4. Figure 5 shows what modes to expect in each context. Furthermore, its Transit Facilities Guidelines (FDOT, 2017) provides design drawings for various transit facilities. FDOT updates its design manual frequently, bringing in newer guidance for all transportation modes, which is another reason it was identified as a multimodal leader.

FDOT CONTEXT CLASSIFICATIONS

C1-Natural
Lands preserved in a natural or wilderness condition, including lands unsuitable for settlement due to natural conditions.

C2-Rural
Sparsely settled lands; may include agricultural land, grassland, woodland, and wetlands.

C2T-Rural Town
Small concentrations of developed areas immediately surrounded by rural and natural areas; includes many historic towns.

C3R-Suburban Residential
Mostly residential uses within large blocks and a disconnected or sparse roadway network.

C3C-Suburban Commercial
Mostly non-residential uses with large building footprints and large parking lots within large blocks and a disconnected or sparse roadway network.

C4-Urban General
Mix of uses set within small blocks with a well-connected roadway network. May extend long distances. The roadway network usually connects to residential neighborhoods immediately along the corridor or behind the uses fronting the roadway.

C5-Urban Center
Mix of uses set within small blocks with a well-connected roadway network. Typically concentrated around a few blocks and identified as part of a civic or economic center of a community, town, or city.

C6-Urban Core
Areas with the highest densities and building heights, and within FDOT classified Large Urbanized Areas (population >1,000,000). Many are regional centers and destinations. Buildings have mixed uses, are built up to the roadway, and are within a well-connected roadway network.

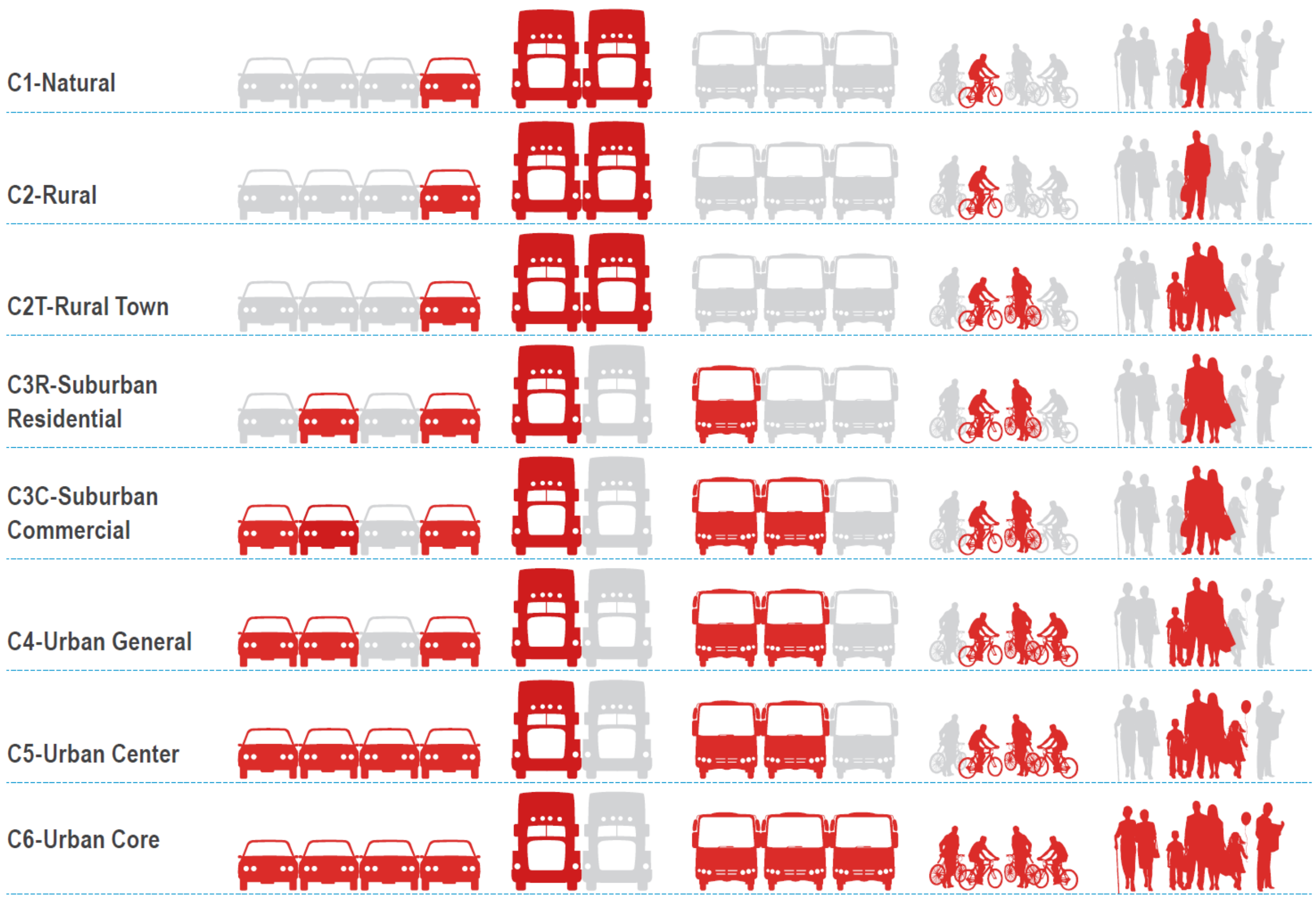

Figure 5: Expected user types in different contexts (FDOT, 2020b)

Minnesota Department of Transportation

MnDOT has a Road Design Manual (RDM) that is now being transitioned into its successor document, the Facility Design Guide (FDG). Both publications are now active on its website, and as new parts of the FDG are published, the corresponding RDM parts will be removed from the website, with a linked FDG reference substituting in its place. However, the FDG is not complete yet, and therefore, the RDM was used to characterize MnDOT's design processes. MnDOT also has a Performance-Based Practical Design Process and Design Guidance (MnDOT, 2018) document that provides information on what performance-based design and practical design are and what they are intended to do. This document addresses why these approaches are needed today and offers some details about how to implement this approach. However, it does not provide a full set of performance measures for project evaluation.

MnDOT also has a Bicycle Facility Design Manual (MnDOT, 2020), which complements the RDM with guidance on planning, designing, and maintaining bicycle facilities. The state also has dozens of two- to three-page "info sheets" on topics such as a paved shoulders and side paths, each providing concise guidance on a particular matter. Interviewees complimented MnDOT's effective documentation and practice of publishing this guidance on its website.

The department also has several statewide system plans, including a Statewide Bicycle System Plan, Pedestrian System Plan, Transit Plan, Freight Plan, ADA Transition Plan, and more importantly a Statewide Multimodal Transportation Plan. An overview of the DOT's plans is shown in Figure 6. All these plans provide some level of insight into the future and establish the visions and goals that the state has for the years ahead. In particular, the Statewide Multimodal Transportation Plan (MnDOT, 2017) is a 20-year plan based on the Minnesota Governor's Office vision, and it is the highest level policy plan for all transportation modes that aims to maximize the health of the people, the environment, and the economy. The document outlines the Minnesota GO Vision, discusses the current state of the state's transportation system, and reviews key trends in the state's economy, population, environment, and transportation plan. The document also provides guidance on how MnDOT plans to move forward by presenting objectives, performance measures, and strategies to move towards its two-decade vision. The performance measures provided in the document are mostly broad, state-level measures such as system reliability and delay measures for the Interstate and national highway system, average annual aircraft delay, annual transit on-time performance, percentage of state-owned sidewalk miles compliant with ADA standards, annual greenhouse gas emissions from the transportations sector, etc. All of these measures look at the transportation system as a whole, rather than serving as performance measures for one single project (MnDOT, 2017).

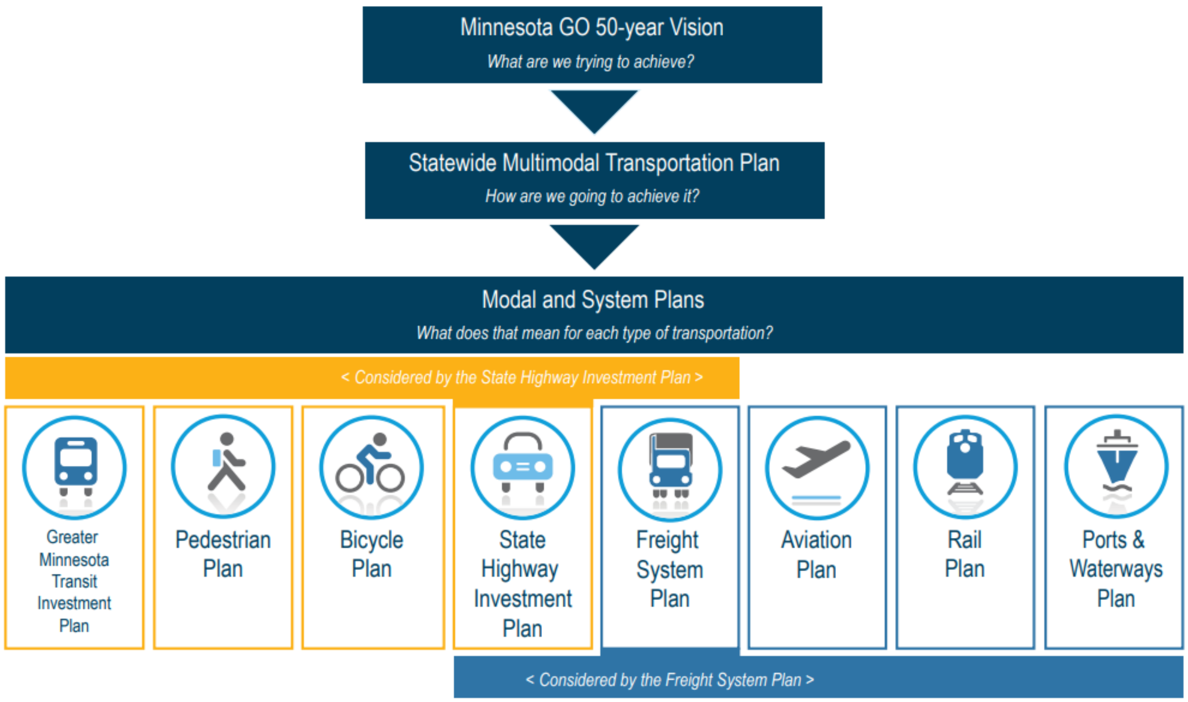

Figure 6: Minnesota DOT's family of transportation plans (MnDOT, 2017)

Massachusetts Department of Transporation

Massachusetts DOT was the jurisdiction with the most votes as a multimodal practice leader in our interviews. Several interviewees pointed to its innovative project development and design guidelines, which take both multimodal and context-based design into consideration. MassHighway's Project Development and Design Guide (MassHighway, 2006) sets several goals for the project development process from concept to construction, including: (1) to ensure context sensitivity through open dialog between project proponents, reviewers, the public, and other parties; (2) to think beyond the pavement to achieve the optimum accommodation for all modes; (3) to encourage early planning, public outreach, and evaluation to identify project needs, objectives, issues, and impacts before expanding significant resources; (4) to "achieve consistent expectations and understanding between project proponents and those entities who evaluate, prioritize, and fund projects"; and (5) to ensure resources are allocated to projects that address local, regional, and statewide priorities and needs.

MassDOT's Separated Bike Lane Planning & Design Guide (MassDOT, 2015) was also mentioned by several interviewees who noted the guide was ahead of its time when released in 2015. This document supplements the bicycle facility design advice in the Project Development & Design Guide (Chapters 5 and 6) by providing guidance on where to implement separated bike lanes as well as how to design them as part of a safe and comfortable network of bicycle facilities. In addition, MassDOT's Guidelines for the Planning and Design of Roundabouts was referred to several times by our interviewees.

MassDOT's design manual, titled "Project Development and Design Guide", essentially divides a project into two parts: project development and design. Chapter 1 of the book has some general introductions, and Chapter 2 talks about the project development step, whereas chapters 3 to 14 are basic design chapters. Chapter 3 talks about basic design controls, while Chapter 4 establishes parameters for designing horizontal and vertical alignments of streets and highways. Chapter 11 has information on shared-use paths and greenways. Chapter 12 has information on intermodal facilities and rest areas, including park and ride facilities and transit centers. Other chapters include intersection design, interchanges, bridges, access management, etc. The document develops an eight-step project development process to move a project from problem identification to completion, which can be seen in Figure 7.

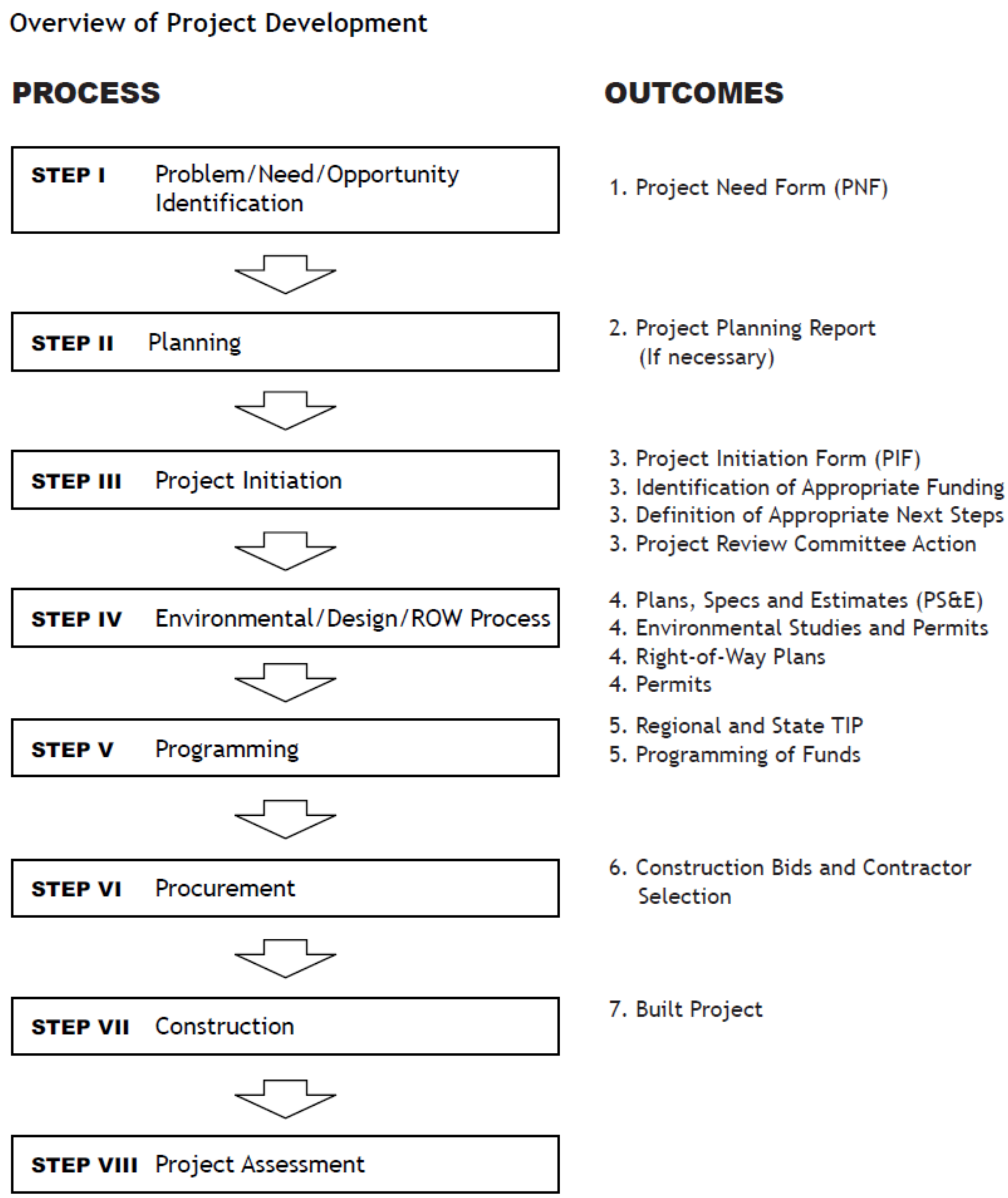

Figure 7: Overview of MassDOT's project development steps (MassHighway, 2006)

Oregon Department of Transportation

ODOT uses two primary sources for its design: 1) the ODOT Highway Design Manual and 2) the Blueprint for Urban Design (Volumes 1 and 2). These two documents complement each other and are used by all ODOT engineers for designing facilities. Our interviewees appreciated the Blueprint for Urban Design for having innovative guidance on urban contexts and roadway classification, design flexibility, and a multimodal decision-making framework. ODOT also uses its Project Delivery Guide (ODOT, 2017) to provide step-by-step guidance in the development and delivery of projects from transportation planning to constructing management transition. Figure 6 displays the ODOT Transportation System Lifecycle.

ODOT also relies on the Oregon Transportation Plan (OTP) to provide a system-wide context for project selection and design. There is an OTP amendment on performance measures that has guidance on performance-based statewide transportation planning processes. In addition, the Oregon Highway Plan includes federal requirements for tracking certain performance measures.

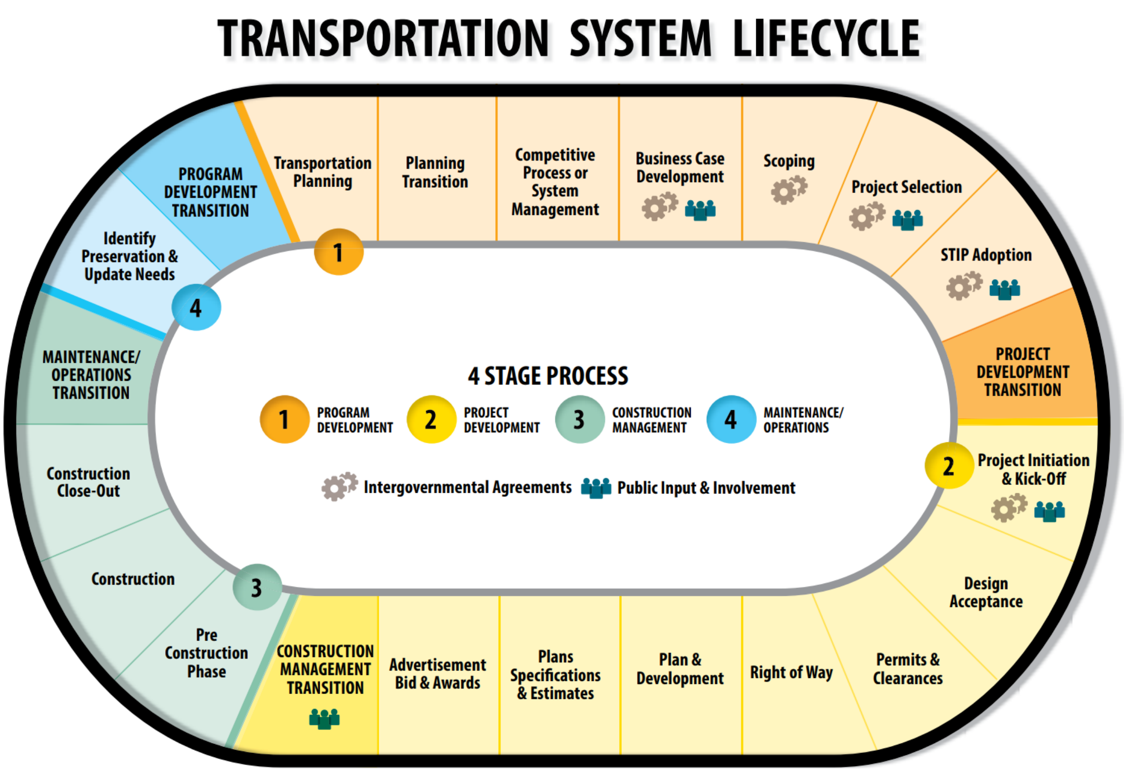

Figure 8. ODOT's Transportation System Lifecycle (ODOT, 2017)

NCHRP REPORT 839

NCRHP Report 839: A Performance-Based Highway Geometric Design Process provides a geometric design process for highways that focuses on the transportation performance of facilities rather than design dimensions. The report starts by reviewing a history of highway design from the 1940s up until the 2010s and shifts in project needs and design processes for ten-year periods. The report describes a movement towards more flexibility in design to help transportation projects meet the needs of multiple stakeholders, and due to these shifts, the emergence of alternative design concepts that have become part of the practice (Neuman et al., 2016). These emerging concepts include the following: (1) the Complete Streets concept; (2) the concept of Context Sensitive Design (CSD) (now often referred to as Context Sensitive Solutions (CSS)); (3) the concept of performance-based design; (4) the concept of practical design; (5) the design matrix approach; (6) the safe systems approach; (7) the concept of travel time reliability; (8) the concept of Value Engineering (VE); (9) the concept of designing for 3R (reconstruction, rehabilitation, resurfacing) projects; and (10) the concept of design for very low-volume local roads (VLVLR) (roads with ADT $\leq$ 400) (Neuman et al., 2016). Each of these alternative design concepts and how they achieve their goals are briefly described in the report. Table 4 lists important insights from these design processes and illustrates how they compare and overlap across these various initiatives. The report describes a new geometric design approach informed by these various concepts that focuses on transportation performance.

Table 4: Alternative design processes and initiatives overlaps (Neuman et al., 2016)

Important Insights for the Geometric Design Process	Alternative Design Processes and Initiatives										
	Complete Streets	CSD	Performance-Based Design	Practical Design	Design Matrix	Safe Systems	Travel Time Reliability	Value Engineering	Designing for 3R	Designing for VLVLR	Systemic Safety
Roads serve more than just motor vehicles	●	●									
Road design involves many different disciplines	●	●	●			●		●	○		
Context matters and it varies	●	●	○	○	●	○	○	○		●	●
Performance (operational, safety) is important		○	●	●	●	●	●	○			●
Performance may have many dimensions	●	●	●	●	●		●	○	○		
Safety performance should focus on elimination or mitigation of severe crashes			○	○	○	●		○		○	●
Speed and crash severity are closely linked			●			●					
Existing roads with known problems are different from new roads				●	●				●	○	●
Traditional design approaches are believed by professionals to yield suboptimal results	●	●		●	●			○			○
Focusing on identifying and addressing the problem(s) should be central to developing design solutions	○	○	●	●	●		○	●	○		●
Safety risk and cost effectiveness are related to traffic volume			●		●				○	●	●

Note: ● Fully applies ○ Partially applies

<u>COMPARISON OF PROJECT DEVELOPMENT AND DESIGN PROCESSES THROUGH KEY DESIGN STEPS AND ELEMENTS</u>

The design processes for the four multimodal practice leaders, WSDOT’s process, and the design process identified in NCHRP Report 839 have much in common. Table 5 gives a summary of the project development and design processes, with the left-most column showing the 11-step process from NCHRP 839 and the remaining columns showing how the states map to this framework. The table shows that the design processes for all jurisdictions share common traits, while some have more details than others. Table 6 shows a summary of which jurisdictions follow which steps, including two more steps for a total of 13. Table 7 shows a comparison of the various context classifications that these states describe. Lastly, Table 8 compares the design controls of the various jurisdictions.

All the jurisdictions start their design by identifying a need or problem. They work to clearly develop a need statement in the first step without prescribing a solution at the start. In the next step, the design lead identifies and charters a group of project stakeholders, including those internal and external to the agency. This step also involves public outreach for some of the jurisdictions.

The project team refines and confirms the problem or need statement to then inform the development of alternatives and the selection of the preferred project scope. The scope will establish the project type, such as a new road, reconstruction, or 3R (reconstruction, rehabilitation, and resurfacing). Next, the team evaluates the project context and geometric design criteria using a context-based or context-sensitive classification. The team identifies design controls such as target speed, traffic volumes, LOS, and road user attributes. Next, the team applies the appropriate geometric design process and criteria to the project.

Once the geometric design is complete, an inclusive and interdisciplinary team evaluates geometric alternatives that address the need or solve the problem, within the context conditions and constraints. The team then makes key design decisions and generates documentation to inform the final design decisions before transitioning to final engineering. In the aftermath of the project, continuous monitoring and feedback allow the responsible agencies to evaluate the project's performance relative to the design goals.

Table 5: Summary of the design processes for WSDOT, FDOT, MnDOT, ODOT, and MassDOT, all compared to NCHRP 839's design processes guidelines

No.	NCHRP 839	WSDOT	FDOT	MnDOT	ODOT	Mass DOT
1	Define the Transportation Problem or Need	• Clearly identify the baseline need. Define it in terms of performance, contributing factors, and underlying reasons for the baseline need (Chapter 1101). • Identify the objective, in simple, direct terms. • Identify the performance metric(s) involved. • Include one or more quantifiable statements. • Exclude any description or discussion of potential solutions.	Fully define and document the objectives of the project and the scope of activities to accomplish them (FDM 110.2)	The earliest step in the design process is determining project purpose, need and problems followed by establishing desired outcomes and goals. (MnDOT PBPD) Some key principles that MnDOT highlights for successful project development are: • Balance safety, mobility, community, and environmental goals in all projects. • Involve the public and affected agencies • Address all modes of travel • Apply flexibility inherent in design standards (MnDOT RDM p. 2-1(1))	Identify the problem and need for the project	Step I: Problem/Need/Opportunity Identification "The proponent completes a Project Need Form (PNF). This form is then reviewed by the MassHighway District office which provides guidance to the proponent on the subsequent steps of the process" (MassHighway PDDG Exhibit 2-11)
2	Identify and Charter All Project Stakeholders • Internal Agency Stakeholders • External Agency Stakeholders • Other External Stakeholder Groups or Agencies • Directly Affected Stakeholders • Stakeholder Chartering	Engage local partners and stakeholders at the earliest stages of scope definition to account for their input at the right stage of the development process. Engage with the community to fully understand: • Performance gaps • Context identity • Local environmental issues • Modal priorities and needs (Chapter 1100)	Public Information and Outreach (FDM 104.2) and Community Awareness Plan (FDM 104.3): • Identify partners • Identify project stakeholders • Identify target audiences • Develop the message(s) • Determine communication strategies (more in the Florida Public Involvement Handbook) • Determine communication timing	Understand the classification of various highways according to who has responsibility for its maintenance, improvement, and traffic regulation (MnDOT RDM p. 2-2(1)): • Jurisdictional systems: Trunk highway system, County Highway system, township road system, Municipal city street system • State aid systems: County State Aid Highways (CSAH) and Municipal State Aid Streets (MSAS).		

No.	NCHRP 839	WSDOT	FDOT	MnDOT	ODOT	Mass DOT
3	Develop the Project Scope: Refinement and Confirmation of Problem or Needs Statement	Translate the need into specific performance metrics and select targets in accordance to what the design shall achieve. A contributing factors analysis (in Chapter 1101) refines focus in order to resolve the specific performance problems and helps define the potential scope of project alternatives.	The Department's project manager is responsible for the development, review and approval of the project objectives, scope of work, and schedule in accordance with the Project Management Guide. They must also verify that required funds are in the work program.	• Project scoping: Identify system deficiencies and needs through operation monitoring, data from management systems (bridge, pavement, safety, etc.), maintenance problems, and public comments. (MnDOT RDM p. 2-4 (1)). • Consider (1) Project programming; (2) Cost-effectiveness policy; and (3) Value engineering		Step II: Planning "Project planning can range from agreement that the problem should be addressed through a clear solution to a detailed analysis of alternatives and their impacts." (MassHighway PDDG Exhibit 2-11) Step III: Project Initiation "The proponent prepares and submits a Project Initiation Form (PIF) and a Transportation Evaluation Criteria (TEC) form in this step. The PIF and TEC are informally reviewed by the Metropolitan Planning Organization (MPO) and MassHighway District office, and formally reviewed by the PRC." (MassHighway PDDG Exhibit 2-11)
4	Determine the Project Type and Design Development Parameters. Project types are: • New Roads • Reconstruction Projects • 3R (Reconstruction, Rehabilitation, and Resurfacing) Projects		Three basic types of projects: • New Construction • Add Lanes and Reconstruction • Other Projects (RRR, operational improvements, safety enhancements, etc.)	• The objectives and available funding for the project must be balanced early in the scoping process. There are three investment categories: (1) New construction / reconstruction, (2) Preservations, and (3) Preventive maintenance (MnDOT RDM p. 2-5 (2))	Types of Projects: • Modernization [New Construction/Reconstruction (4R)] • Preservation [Interstate Maintenance/Resurfacing, Restoration, and Rehabilitation (3R)] • Bridge • Safety • Operations • Maintenance • Miscellaneous/Special Programs • Single Function • ODOT Resurfacing 1R (ODOT HDM 1-15)	

No.	NCHRP 839	WSDOT	FDOT	MnDOT	ODOT	Mass DOT
5	Establish the Project's Context and Geometric Design Framework • Develop Project Evaluation Criteria Within the Context Framework • Establish Decision-making Roles and Responsibilities • Determine Basic Geometric Design Controls: • Design or Target Speed • Design Traffic Volumes • Design LOS • Road User Attributes	Identify the land use and transportation context (which includes environmental use and constraints) for the location (Chapter 1102). • Land Use Categories: (1) Rural, (2) Suburban, (3) Urban, and (4) Urban Core • Transportation Context: (1) Roadway type, (2) Bicycle route type, (3) Pedestrian route type, (4) Freight route type, (5) Transit use considerations, (6) Complete Streets and Main Street highways	• Establish and document the project's surrounding context: • Functional Class: (1) Limited Access Facilities, (2) Principal Arterial, (3) Minor Arterial, (4) Collector, (5) Local Roads • Context Class: C1: Natural, C2: Rural, C2T: Rural Town, C3R: Suburban Residential, C3C: Suburban Commercial, C4: Urban General, C5: Urban Center, C6: Urban Core	• Functional classification: (1) Arterials, (2) Collectors, and (3) Local roads and streets (MnDOT RDM p. 2-5(1)) • Types of highways: (1) Two-lane, (2) multi-lane highways, and (3) scenic byways (MnDOT RDM p. 2-5(3))	Roadway Classification: (1) Statewide Highways, (2) Regional Highways, (3) District Highways, (4) Local Interest Roads (ODOT BUD) Context classifications: (1) Traditional Downtown/ Central Business District (CBD), (2) Urban Mix, (3) Commercial Corridor, (4) Residential Corridor, (5) Suburban Fringe, (6) Rural Community (ODOT BUD)	• Roadway Context (Section 3.2): Area types: Rural, Suburban, Urban & Roadway types: Freeways, major arterials, minor arterials, major collectors, minor collectors, local roads and streets

No.	NCHRP 839	WSDOT	FDOT	MnDOT	ODOT	Mass DOT
6	Apply the Appropriate Geometric Design Process and Criteria	• Select design controls compatible with the context (Chapter 1103). • Design controls create significant boundaries and have significant influence on design. WSDOT uses five primary design controls: (1) **Design Year**, (2) **Modal Priority**, (3) **Access Control**, (4) **Design Speed**, and (5) **Terrain Classification**	• The design controls addressed in this manual include: • **Context Classification**: Determines key design criteria elements for arterials and collectors. • **Functional classification** • **Level of service** • **Traffic and Design Year**: Satisfy capacity needs at an acceptable level of service through the design year. • **Access Management**: Regulation of access is necessary to preserve the functional integrity of the State Highway System and to promote the safe and efficient movement of people and goods within the state. • **Design Speed**: (1) High: 50 mph and greater, (2) Low: 45 mph and less, and (3) Very Low: 35 mph and less. • **Design Vehicle**: The largest vehicle that is accommodated without encroachment on to curbs (when present) or into adjacent travel lanes.	Fundamental Design Controls (from PBPD) • **Level of Service**: PLOS, BLOS, and TPLOS. • **Design Speed** • **Design Vehicle** Other design parameters: • **Functional classification** (MnDOT RDM p. 2-5(1)) • **Types of highways** (MnDOT RDM p. 2-5(3)) • **Traffic characteristics**: (1) Volume, (2) Direction, (3) Distribution, (4) Composition, and (5) Traffic flow. (MnDOT RDM p. 2-5(5)) • **Speed** (MnDOT RDM p. 2-5(7)) • **Capacity** (MnDOT RDM p. 2-5(8)) • **Sight Distance**: Stopping sight distance, Passing sight distance, Decision sight distance should be considered. (MnDOT RDM p. 2-5(11)) • **Terrain**: (1) level, (2) rolling, and (3) mountainous. (MnDOT RDM p. 2-5(15)) • **Crash data**: Review crash history within project limits (MnDOT RDM p. 2-5(16))	Design control and criteria: • **Design vehicles**: the number and type of trucks, functional classification of the highway, freight route designation, and the effect on other modes including pedestrians and bicycles, should all be considered. • **Design speed**: The selection of a design speed is dependent on traffic volume, geographic characteristics, functional classification, number of travel lanes, 85th percentile speed, roadway environment, adjacent land use, and type of project . • **Access management**: Good access management will reduce the overall number of crashes and increase the highway's capacity (ODOT BUD) • **Traffic Characteristics**: Four major components affect traffic characteristics: (1) Vehicles, (2) Facility character and functional requirements, (3) Drivers/users, and (4) Traffic demand	Basic design controls: • **Roadway Context** (Section 3.2) • **Roadway Users** (Section 3.3): Pedestrian, bicyclists, and drive • **Transportation Demand** (Section 3.4): Design year, volume and composition of the demand, • **Measures of Effectiveness** (Section 3.5): facility condition, safety, mode choice, network connectivity, level of service • **Speed** (Section 3.6): selecting vehicle, pedestrian, and bicycle design speed • **Sight Distance** (Section 3.7): recognizing sight distance for motor vehicles, bicyclists, and pedestrians

No.	NCHRP 839	WSDOT	FDOT	MnDOT	ODOT	Mass DOT
7	Designing the Geometric Alternatives • Assemble an Inclusive and Interdisciplinary Team • Focus on and Address the Need or Solve the Problem(s) Within the Context Conditions and Constraints	• Formulate and evaluate potential alternatives that resolve the baseline need for the selected context and design controls (Chapter 1104). • Alternative Solution Formulation • Alternative Solution Evaluation	• Establish geometry, grades, and cross sections and evaluate alternatives	Use value engineering principles to design alternatives: • Use creative thinking to speculate on alternatives that can provide the required functions. • Evaluate the best and lowest life-cycle cost alternatives. • Develop acceptable alternatives into fully supported recommendations. • Present/formally report all recommendations to management for review, approval, and implementation. (MnDOT RDM p. 2-4(2))	Work with different project team members to refine the selected alternative design	Document all considered alternatives
8	Design Decision Making and Documentation • Independent Quality and Risk Management Processes	Select design elements that will be included in the alternatives (Chapter 1105).	✓	Document design decisions	Document design decisions	Document design decisions
9	Transition to Preliminary and Final Engineering	Determine design element dimensions consistent with performance needs, context, and design controls (Chapter 1106).	✓	✓	✓	✓
10	Agency Operations and Maintenance Database Assembly					
11	Continuous Monitoring and Feedback to Agency Processes and Database					

Table 6: Summary of design processes

Step	Tasks	NCHRP 839	WSDOT	FDOT	MnDOT	ODOT	Mass DOT
1	Define the transportation problem or need. Identify the objective, in simple, direct terms.	✓	✓	✓	✓	✓	✓
2	Include at least one quantifiable statement by identifying performance metric(s) involved		✓	✓			✓
3	Identify and charter all project stakeholders, including general public	✓	✓	✓	✓		
4	Prepare a community awareness plan, reaching out to the target audience			✓			
5	Develop the project scope: refinement and confirmation of problem or needs statement	✓	✓	✓	✓		✓
6	Determine the project type	✓		✓	✓	✓	
7	Identify the land use and transportation context for each mode	✓	✓	✓	✓	✓	✓
8	Select design controls compatible with the project context	✓	✓	✓	✓	✓	✓
9	Formulate and assemble other geometric alternatives that resolve the baseline need	✓	✓	✓	✓	✓	✓
10	Design decision making and documentation	✓	✓	✓	✓	✓	✓
11	Transition to preliminary and final engineering	✓	✓	✓	✓	✓	✓
12	Input core data into O&M databases for agency operations	✓					
13	Continuously monitor and fully utilize data coming in from the projects (e.g., ITS data)	✓					

Table 7: Context classification comparison across jurisdictions

<table>
<tr><th>No.</th><th>FDOT (Reference)</th><th>ODOT</th><th>WSDOT</th><th>MassDOT</th><th>MnDOT</th></tr>
<tr><td>1</td><td>C1: Natural</td><td>×</td><td>×</td><td>×</td><td rowspan="8">Even though they mention context-sensitive solutions and talk about rural vs. urban vs. suburban highways and streets several times, none of their documents explicitly mentioned context classification</td></tr>
<tr><td>2</td><td>C2: Rural</td><td>Rural Community</td><td rowspan="2">Rural</td><td rowspan="2">Rural</td></tr>
<tr><td>3</td><td>C2T: Rural Town</td><td>Suburban Fringe</td></tr>
<tr><td>4</td><td>C3R: Suburban Residential</td><td>Residential Corridor</td><td rowspan="2">Suburban</td><td rowspan="2">Suburban</td></tr>
<tr><td>5</td><td>C3C: Suburban Commercial</td><td>Commercial Corridor</td></tr>
<tr><td>6</td><td>C4: Urban General</td><td>Urban Mix</td><td rowspan="2">Urban</td><td rowspan="3">Urban</td></tr>
<tr><td>7</td><td>C5: Urban Center</td><td rowspan="2">Traditional Downtown / Central Business District (CBD)</td></tr>
<tr><td>8</td><td>C6: Urban Core</td><td>Urban Core</td></tr>
<tr><td>No. of Classes</td><td>8</td><td>6</td><td>4</td><td>3</td><td>N/A</td></tr>
</table>

Table 8: Design control comparison across jurisdictions

Design Controls	WSDOT	FDOT	MnDOT	ODOT	MassDOT
Design speed	✓	✓	✓	✓	✓
Access classification, control, or management	✓	✓	✓	✓	
Design vehicle		✓	✓	✓	
Level of service		✓	✓		
Design period or year	✓	✓			
Functional classification		✓			✓
Context classification		✓			✓
Traffic volumes		✓			
Modal priority	✓				✓
Roadway users			✓ (drivers)		✓ (drivers, peds, and bikes)
Transportation demand					✓
Sight distance					✓
Measure of effectiveness (e.g., LOS, Safety, etc.)					✓
Terrain classification	✓				
Pedestrian and bicyclist traffic			✓		
Mass transit			✓		
Safety			✓		
Traffic characteristics (vehicles, modes, volumes)				✓	

After reviewing the design manuals and handbooks of the multimodal practice leaders, we also worked to identify documents that address performance measures and data sources recommended for project development. Two documents stood out. First is the ODOT Blueprint for Urban Design, which includes a table that lists some performance measures that are useful for project evaluation across different modes, shown in Table 9.

Table 9: Example of project-level performance measures by mode (ODOT, 2020b)

Vehicular	Freight	Bicycle	Pedestrian	Transit
• Volume-to-capacity ratio • Travel-time reliability • Peak and off-peak travel time • Estimated potential reduction in crashes using crash reduction factors • Length of vehicle queues • Average or 85th percentile travel speed	• Volume-to-capacity ratio • Travel-time reliability • Peak and off-peak travel time • Ability to serve freight origins and destinations • Availability of loading zones • Average and 85th percentile travel speed	• Bicycle Level of Traffic Stress • Multimodal level of service (simplified or full calculation) • Percent of roadway served by an exclusive bicycle facility • Percent of roadway with bicycle facilities meeting current standards • Estimated potential reduction in crashes using crash reduction factors • Forecast volumes of bicyclist (various methods available)	• Pedestrian Level of Traffic Stress • Multimodal level of service (simplified or full calculation) • Sidewalk coverage and connectivity • Sidewalk width • Average distance between marked crossings • Percent of ADA-compliant pedestrian crossings • Average pedestrian delay at intersections • Presence of pedestrian refuge islands • Degree of street trees and shade • Level of pedestrian-scale street lighting • Estimated potential reduction in crashes using crash reduction factors	• Number/percent of ADA-compliant transit stops • Number of residents/jobs within ¼ mile of stop locations (or ½ mile of high frequency transit) • Anticipated transit delay due to stop location (In-lane stops and far-side stops typically reduce delay.) • Presence or degree of transit priority treatments (where appropriate) • Sidewalk width • Proximity of marked street crossings to transit stop locations • Average travel speed

Second, MassDOT's guidelines on Complete Streets also established a set of performance measures used for the development of Complete Streets projects. These performance measures are listed by mode in Table 10:

Table 10: List of performance measures for MassDOT by mode (Lovas et al., 2015)

Mode	Performance Measures
Pedestrian	Linear feet of new or reconstructed sidewalks
	Number of new or reconstructed curb ramps
	Number of new or repainted crosswalks
	Number and type of crosswalk and intersection improvements
Bicycle	Miles of new or restriped on-street bicycle facilities
Transit	Efficiency or reliability of transit vehicles on routes
	Change in percentage of transit stops with shelters
	Change in percentage of transit stops accessible via sidewalks and curb ramps
Auto	Vehicle Miles Traveled (VMT) or Single Occupancy Vehicle (SOV) trip reduction
	Auto Trips Generated (ATG)
	Decrease in rate of crashes, injuries, and fatalities by mode
Multimodal	Transportation mode shift: more people walking, bicycling, and taking transit
	Percentage completion of bicycle and pedestrian networks as envisioned by municipal plans
	Increase in Bicycle, Pedestrian, and Multimodal levels of service (LOS)
Other	Rate of children walking or bicycling to school
	Number of new street trees/percentage of streets with tree canopy
	Economic impacts in business districts
	Satisfaction levels as expressed on customer preference surveys
	Number of approved exemptions from municipal Complete Streets Policy

KEY INSIGHTS FROM MULTIMODAL PRACTICE LEADERS

Our interviews with experts and a review of design documents and guidelines from four leading state transportation departments, along with recent reports from NCHRP, offer a snapshot of the "state of the practice" for multimodal design. Broadly speaking, relative to the past, best practice now eschews imposing a "one size fits all" solution that focuses on optimizing for automobile travel time. Instead, multimodal practice leaders favor solutions tailored to a particular geographic and social context that balance the transportation interests of car drivers, truck drivers, pedestrians, cyclists, and transit users. Best practice solutions also consider other important social goals such as increased safety and reduced noise, air, and water pollution. This shift in emphasis from one performance measure (level of service as a proxy for travel time and reliability) to many performance measures adds complexity and time to project design.

To address this complexity, modern best practice engages a broader range of stakeholders in project design, considers a wider range of alternatives, and allows for more design flexibility to match a solution to its specific context and potentially deliver more value for the project dollar. Ideally, a multimodal design process employs a suite of performance measures that address the competing stakeholder interests involved in a solution and allow stakeholders to see the tradeoffs among competing goals. The current state of the practice does not have clear guidance on an appropriate set of robust and cost-effective performance measures that a project designer should apply to a project of a given type. Indeed, tailoring performance measures to the particular project context is viewed by many as best practice.

CHAPTER 3
SIX CASE STUDIES OF MULTIMODAL DESIGN IN WASHINGTON STATE

Our review of WSDOT's planning and design documents showed that they compare favorably to those of multimodal practice leaders in other transportation departments across the country. In this section, we explore how WSDOT engineering staff implement that design guidance by reviewing six projects in districts across the state with an eye for opportunities to improve the practial implementation of multimodal planning and design on typical agency projects.

METHOD FOR SELECTING CASE STUDIES

With the assistance of the sponsors of this research project within WSDOT, we emailed 47 project engineers in every WSDOT region and asked them to complete an online survey with recommendations on multimodal projects for study. The survey asked them to identify projects that they thought represented good models of multimodal design as well as projects that represented opportunities for improvement. The survey netted 22 projects recommended for study, nearly all of which the project engineers thought represented good examples of multimodal design.

After reviewing the project list, we screened out megaprojects like the upgrades to Colman Dock in downtown Seattle and the addition of HOV/toll lanes to I-405, as these projects had unique attributes and a large number of informed stakeholders who would advocate for transit, bicycle, and pedestrian modes. We also excluded projects that were overtly focused on transit integration, such as facilities to integrate with the LINK light rail station in Lynnwood. Instead we selected a mix of projects from across the state that involved different highway classifications and could offer lessons that might be generalizeable to many typical WSDOT projects. The projects ranged from an intersection study in North Wenatchee that was in the early planning stages to completed projects like the diverging diamond interchange at I-5 and SR 510 in Lacey. All of the projects involved improvements to highway intersections, and all of them used alternatives to traditional traffic signals. See Figure 9 for the project locations and summary descriptions.

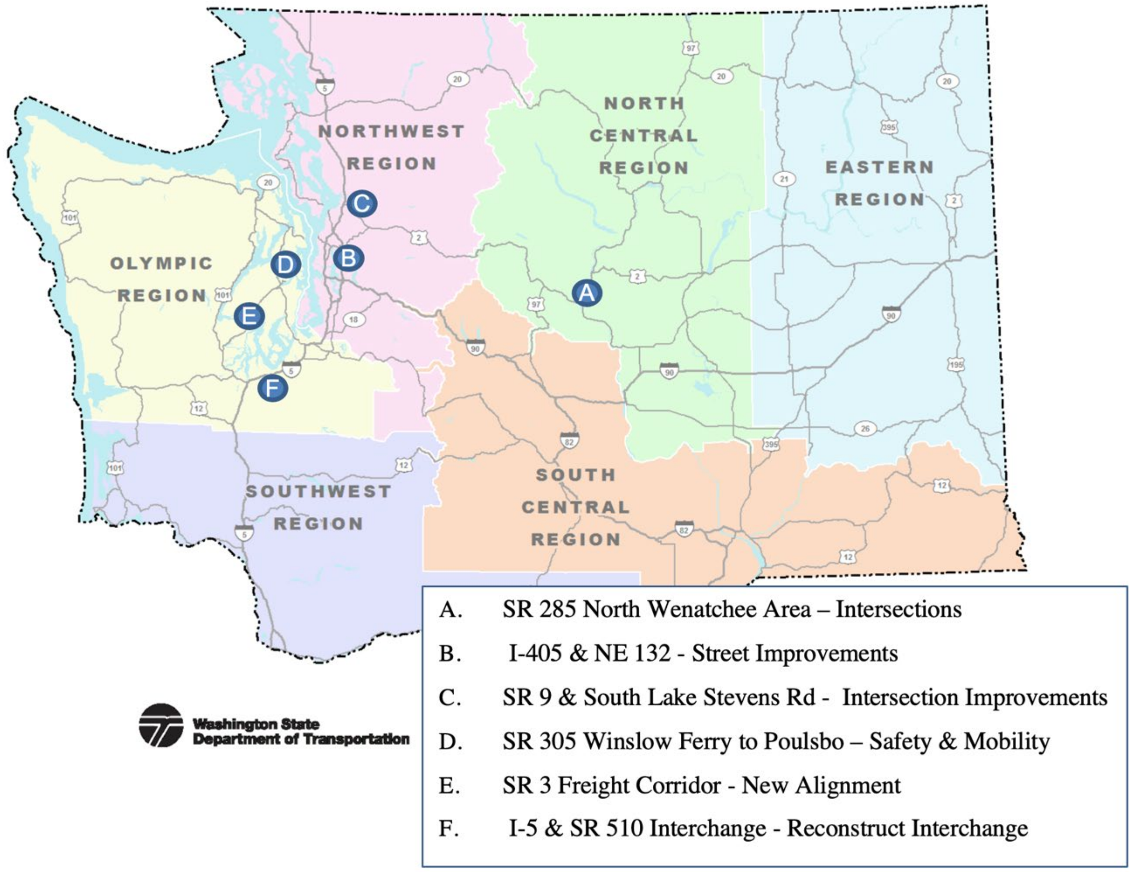

Figure 9. Project locations for multimodal case studies

For each of the projects, we interviewed the design manager and one or two other people who worked on the project design. Our questions included the following:

1. What problems is the project trying to solve?
2. What documents do you use for guidance when designing a project like this?
3. How did you consider the interests of different categories of users such as auto drivers, freight delivery drivers, transit users, pedestrians, and bicyclists in the design process?
4. How did multimodal considerations alter your design?
5. Did you use any non-automotive performance measures in the design process?
6. Did the framing of the project funding by the legislature (or others) constrain the range of multimodal design alternatives?

7. Is there guidance that you think is missing from the WSDOT design manual when undertaking a project like this?

After the initial interview, we collected the relevant design documents recommended by the project engineer, including the Basis of Design and stakeholder involvement materials that framed key design decisions. We then reviewed the documents and made follow-up calls when we needed further clarification on the design process.

OVERVIEW OF THE SIX CASE STUDIES

SR 285 North Wenatchee Area – Intersections

The state highway north of Wenatchee on N. Wenatchee Avenue was frequently congested with long delays at the traffic lights adjacent to the Walmart retail center there (see Figure 10). Long delays at the traffic lights also caused some pedestrians to cross against the lights, creating safety concerns. The project was in the early planning stages and had not settled on a design solution. Options included widening the highway, developing a frontage road to absorb some of the local traffic, and installing roundabouts, although the volumes may have been too high for roundabouts to work. WSDOT engineers had been working with local stakeholders, including the city, the local transit agency, and adjacent property owners. The design focus was on improved mobility and pedestrian safety.

Figure 10. SR 285 in North Wenatchee (Google Maps)

<u>**SR 9 and South Lake Stevens Rd – Intersection Improvements**</u>

A new Costco retail center was planned for the intersection of SR 9 and Lake Stevens Road, and the projected traffic would overwhelm the existing intersection (see Figure 11). The design options included adding a signalized intersection and converting the intersection to a roundabout with a bike/pedestrian pathway. With the engagement of the City of Lake Stevens, WSDOT selected the roundabout option to serve the automotive traffic and also allow pedestrian and bicycle access to the retail area from the adjacent neighborhood on pathways that encircle the roundabout.

Figure 11. Roundabout location planned next to new Costco at SR 9 and S. Lake Stevens Road (Google Maps)

I-405 and NE 132nd St. – Freeway On-Ramps and Roundabouts

Congestion at this intersection on I-405 motivated the addition of new on- and off-ramps in the City of Kirkland (see Figure 12). The project team considered different configurations of signalized intersections and roundabouts, along with different designs for the associated bike and pedestrian pathways. The project team hosted a "Practical Solutions" workshop that involved stakeholders from the FHWA, City of Kirkland, Muckleshoot Indian Tribe, Sound Transit, and local citizens. The roundabout solution allowed for sidewalks and bike lanes on both sides of the new intersection, added fish passage, and was lower cost. The design team had to overcome community reluctance to roundabouts and conflicts with the city's design standards for bike lanes. The "Practical Solution" that was ultimately selected put sidewalks and bike paths right next to each other, above the grade of the roadway, and with different surface types to help minimize conflicts between cyclists and pedestrians. This design solution allowed for inclusion of fish passage and lowered the cost relative to other alternatives.

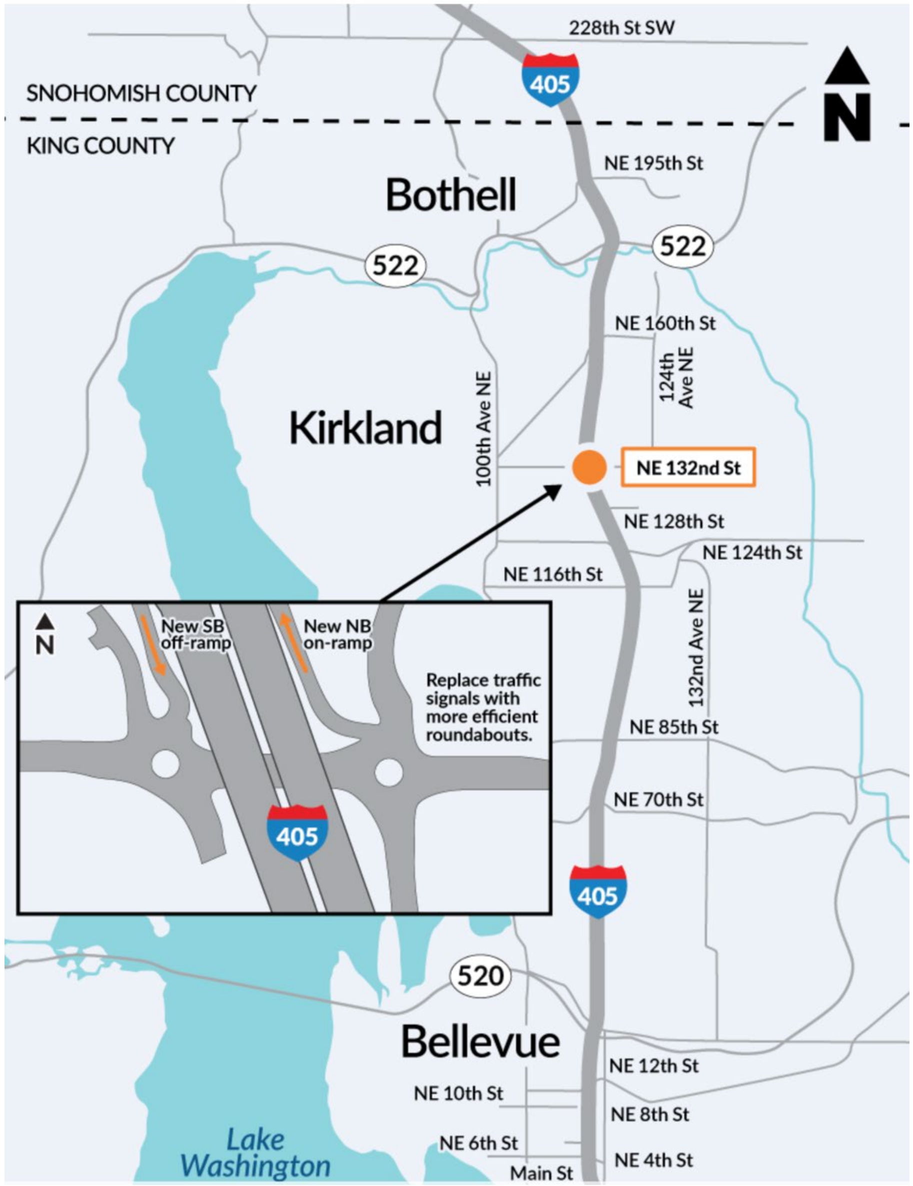

Figure 12. New roundabouts and freeway on- and off-ramps at I-405 and NE 132 St. (WSDOT map)

SR 305 Winslow Ferry to Poulsbo – Safety and Mobility

Heavy vehicle traffic to and from the ferry terminal at Winslow along SR 305 cause increased travel times, a high rate of accidents, and constraints on local business activity. The project was intended to improve corridor safety and mobility; address constraints on the Agate Pass bridge; improve service for cyclists, pedestrians and transit users; improve access for adjacent property owners; and enhance environmental outcomes (see Figure 13). The solution that emerged from the evaluation of alternatives would include adding roundabouts at the key intersections and widening the shoulders to allow for a 10-foot-wide bike lane. Stakeholder engagement included the City of Bainbridge Island, Kitsap Transit, local businesses, and bicycle and pedestrian advocates.

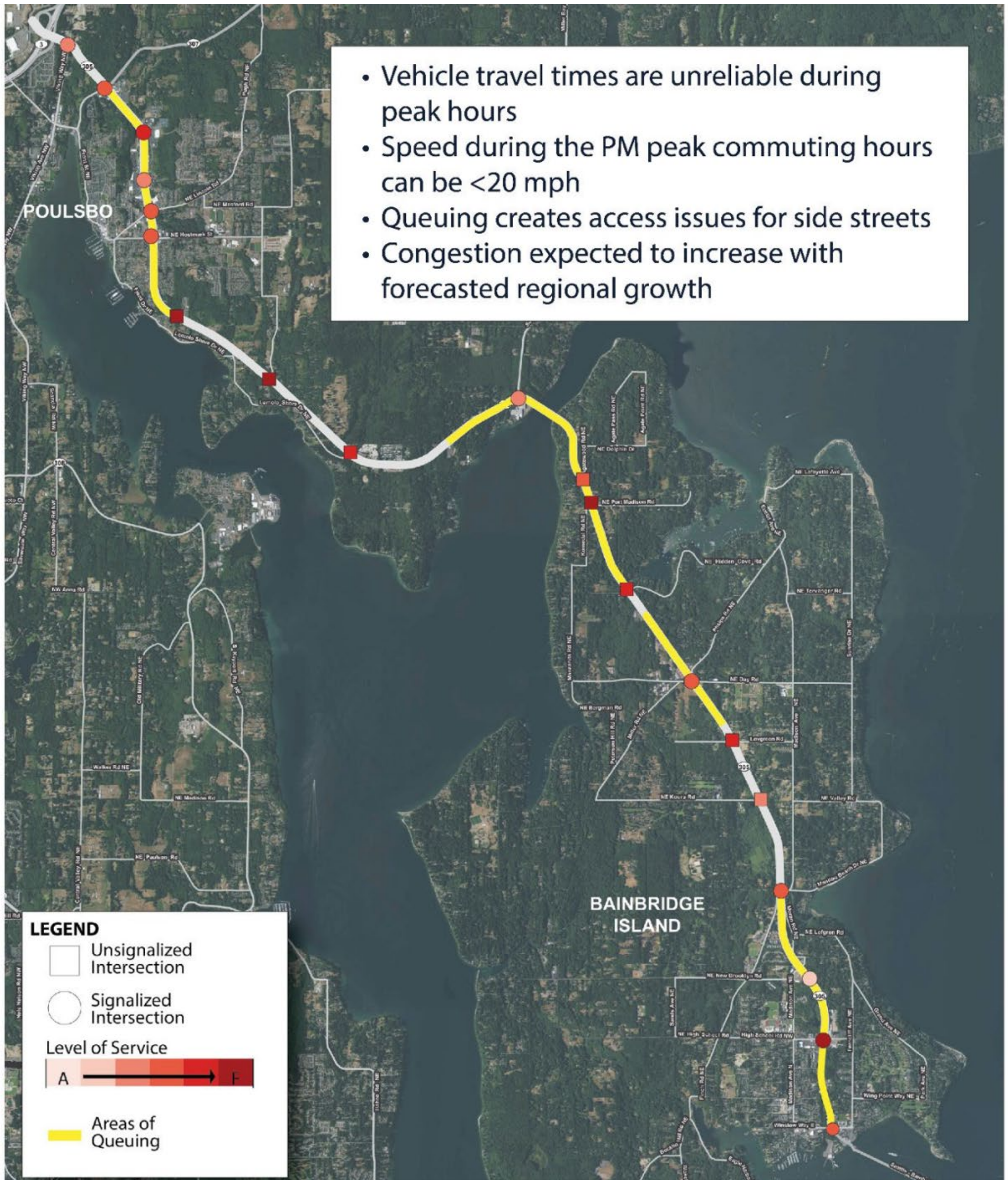

Figure 13. Congested intersections on SR 305 from Winslow to Poulsbo (Map from Parametrix for Kitsap Transit)

SR 3 Freight Corridor – New Alignment

The City of Belfair experienced significant congestion along SR 3 in the town center and preferred that freight traffic traveling through the city move to a new alignment that would bypass the city to improve safety and mobility for travelers using the existing alignment and for freight vehicles using the new alignment. The project anticipated using roundabouts along the new alignment instead of traffic lights and adding grade-separated, multi-use pathways to allow access under the new highways for local residents (Figure 14).

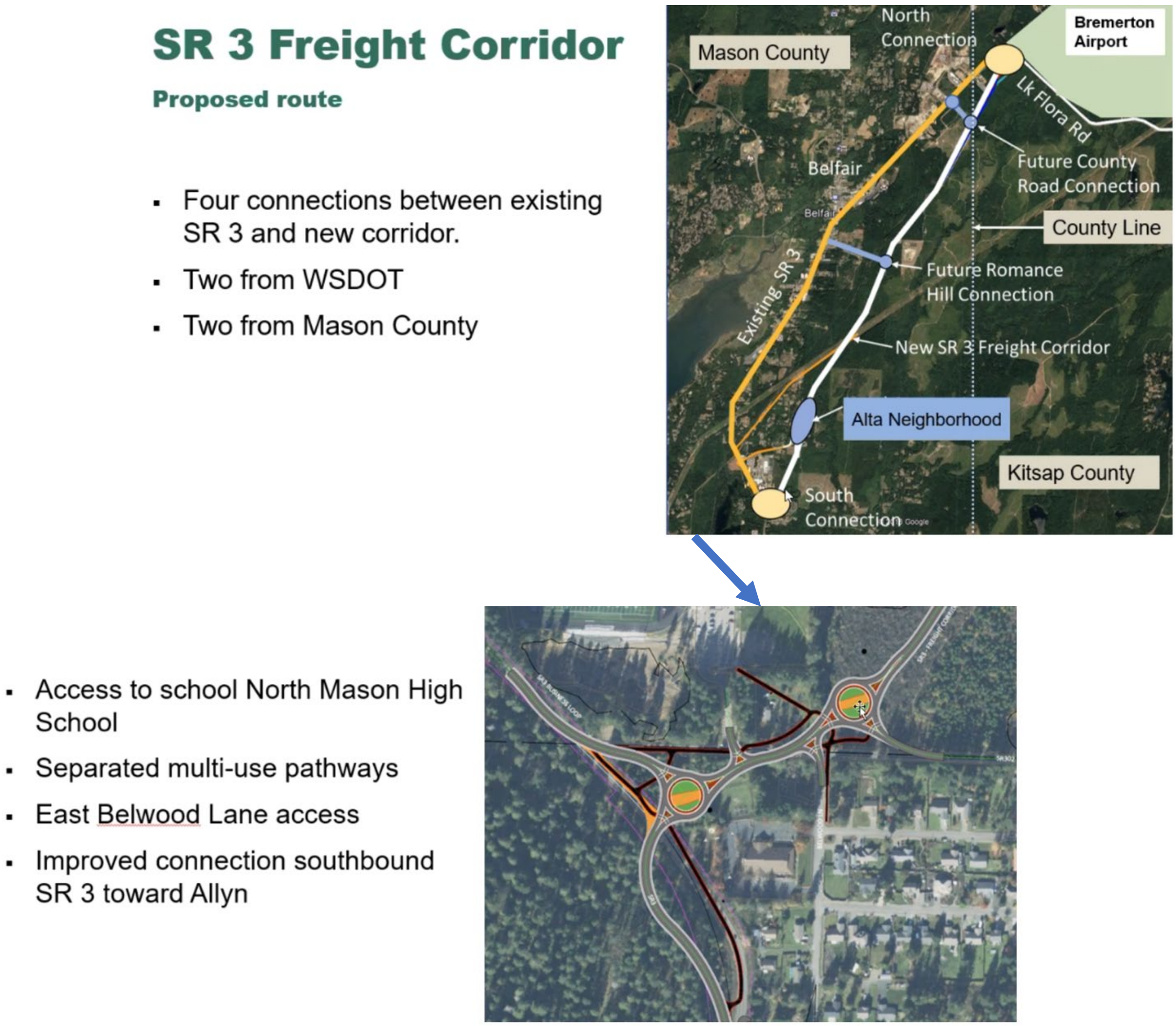

Figure 14. Proposed freight corridor on SR 3 near the City of Belfair (WSDOT)

<u>I-5 and SR 510 Interchange – Reconstruct Interchange</u>

The intersection of I-5 and Marvin Road NE (SR 510) experienced long queues, especially for the high volume of motorists leaving Lacey's large commercial center, shown at the right of Figure 15, and turning to enter I-5 South, shown in the lower left corner of the figure. The solution depicted in Figure 15 was the first diverging diamond interchange (DDI) in Washington state. In comparison to the conventional alternatives considered, the DDI would increase vehicle throughput, would lower the number of potential conflict points to increase safety, and would be $20 to $30 million less expensive than other alternatives. WSDOT engaged a large number of community stakeholders and, after designing the DDI solution, undertook a significant community outreach effort to explain how DDIs work and why motorists would not be confused or imperiled by a solution that swapped the traditional travel direction on adjacent divided roadways. The project's multimodal elements included a combined pedestrian-bike way and faster travel time for trucks serving the large commercial areas that included Walmart, Home Depot, Costco, restaurants, and hotels. Stakeholders included the city, local transit agency, and businesses from the commercial district.

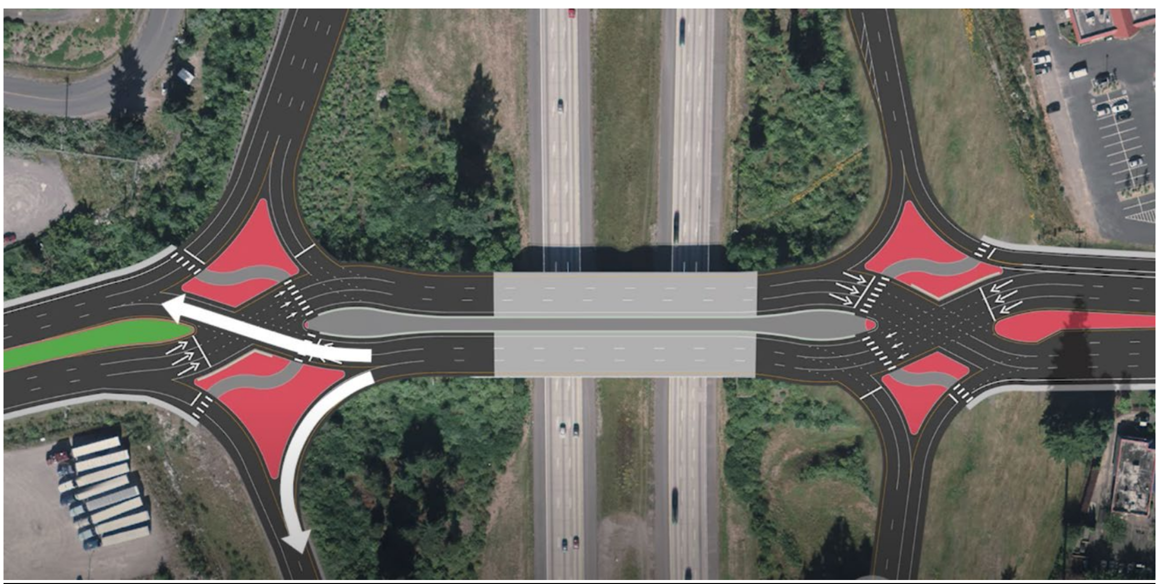

Figure 15. Diverging diamond interchange at I-5 and SR 510 in Lacey (WSDOT)

FINDINGS FROM CASE STUDIES

Several consistent themes emerged from our interviews and review of the design documents for the six projects. First, all of the engineers relied on the WSDOT Design Manual to guide their process. Second, the principles of Practical Solutions were embedded in all of the engineers' approaches to design; nearly all of the interviewees brought up the term Practical Solutions unbidden and discussed how the approach shaped their design process and decisions. Third, the engineers did not view performanced-based design as a top-down compliance exercise forced on them or just another box to check in a bureaucratic process, but rather as a guiding philosophy to inform their engineering decisions.

Every project evaluated the relevant alternatives for their impacts on transit users, cyclists, pedestrians, and freight because the Basis of Design document requires it. The Basis of Design documents we reviewed included comparison tables that score all of the alternatives for their performance on mobility and safety for the relevant modes. Designers must provide a narrative that discusses the trade-offs of the different choices and makes the case for the preferred alternatives. Some project engineers acknowledged that by the time came to fill out the forms to justify the preferred alternative, the paperwork had become a compliance exercise to meet requirements in the Design Manual. Nevertheless, the underlying approach of setting project objectives and then working with an open mind toward solutions with the involvement of key stakeholders and consideration of all modes was a part of every project.

In four of the six projects, the alternatives selection process resulted in a decision to implement roundabouts, so it's worth considering why this solution emerged so frequently as a solution for improvements at highway intersections. Project engineers cited several reasons for why roundabouts emerged as the preferred alternatives. Roundabouts can reduce crashes by lowering approach speeds, and they virtually eliminate the possibility of T-bone crashes. Roundabouts also don't induce some drivers to speed up the way that yellow lights at signalized intersections sometimes do. By reducing the amount of starting, stopping, and idling, roundabouts also reduce vehicle emissions. Roundabouts are also generally safer for pedestrians because of the slower vehicle speeds and a geometry that has sidewalks that cross only one direction of traffic at time. Finally, roundabouts can increase the throughput of an intersection, often at lower cost than traffic signals. The engineers reported that working through all of these attributes in developing the Basis of Design has contributed to the ascendance of roundabouts as a practical solution for intersections.

Every project we evaluated included sidewalks and pathways for bicycles and pedestrians. These multimodal features have become *de facto* standards for many WSDOT projects. While pedestrian and cycling elements are not always able to connect to existing non-motorized pathway networks, they do represent new links that could eventually connect into a more comprehensive network of pathways. Non-motorized travelers prefer routes that are not next to highways with vehicles moving at high speed, even when there is a barrier or a difference in grade. Because WSDOT project managers typically focus their design efforts within the state's right of way, they may miss opportunities to support new, lower-cost pathways that pedestrians and cyclists would prefer because the right-of-way for such pathways is owned by a different jurisdiction. In principle, a Practical Solutions approach would consider alternative pathways, but in practice we observed engineers focusing their alternative development within the WSDOT right-of-way; however, constraining WSDOT's designs to existing state right of way may be leading to suboptimal solutions. The possibility of finding other right-of-way for cyclists and pedestrians may not have existed in any of the case studies we examined, but other projects of similar scope might find better alternatives if the solution set was expanded to include such potential alternatives.

WSDOT engineers may be missing opportunities to employ quantitative methods for evaluating multimodal performance. As the owner of the state highway system, WSDOT typically confronts mobility and safety challenges that are associated with motorized vehicles. The tools and practices for evaluating travel speed, queuing, and delay for private vehicles and public transit for different geometries and for different levels of demand are well-developed and ready to apply on any project. However, the analytic tools to evaluate bicycle and pedestrian alternatives are less familiar, and those that exist may not be especially useful in the context of a typical WSDOT project. WSDOT's design manual directs engineers to the Highway Capacity Manual to calculate bicycle and pedestrian level of service, but in none of the six case studies did engineers employee the HCM methods to help inform design choices about the non-motorized elements.

Instead, project engineers reasonably focused their analytic tools on the main problems associated with motorized vehicles and then incorporated the non-motorized elements in ways that complemented the main motorized solution. Often, instead of using analytic tools to make decisions about the bicycle and pedestrian elements, WSDOT engineers relied on stakeholders, especially cities, to represent the interests of the non-motorized modes and negotiate the designs of sidewalks and pathways. This is entirely reasonable because cities often have their own standards, and WSDOT wants to work as a good partner with local jurisdictions. We did not find any evidence that the local partners had employed quantitative, performance-based design any more than WSDOT engineers did in evaluating alternatives for non-motorized users.

The project at the intersection at I-405 in Kirkland offers an example of a better way. The city's policy and standard was to put 4-foot-wide painted bike lanes on the same grade as the road and to use the curb height and planter strip to separate pedestrians from cyclists and motorized vehicles. WSDOT engineers argued for a different, more "practical" solution, which was to put the bike lane up at the curb height and use different surface finishes to distinguish the directly adjacent bicycle and pedestrian paths. This solution yielded a wider bike path at curb height that completely avoided crossing drain grates required at the street level and also created separation and safety for pedestrians. This design also allowed for a narrower street width, which was used to accommodate infrastructure for fish passage. WSDOTs engineering team had a design analysis and an argument for a different bike and pedestrian pathway design that ultimately persuaded the city to endorse the solution. The improvement in outcomes for the non-motorized modes resulted from the creativity of WSDOT engineers and a willingness to develop a better alternative that was not standard practice. The analytic methods employed to develop and evaluate this alternative involved construction geometry, cost estimation, and the design's utility for a broad spectrum of users. Calculating the bicycle level of service from the HCM would not have helped inform this decision. The team tailored their analysis to the key decisions they needed to make, which on this project directly involved the design and placement of the non-motorized lanes.

RECOMMENDATIONS TO CONSIDER FOR IMPROVING MULTIMODAL DESIGN AND PERFORMANCE MEASURES

The findings from the case studies point toward a number of steps that WSDOT could take to advance its multimodal goals:

- Continue to support the culture, attitudes, and practices that enable the application of Practical Solutions to transportation problems. WSDOT engineers and their engineering contractors have absorbed the message of performance-based design. By continuing to reinforce it and holding up examples of its successful application, the organization's culture will continue to improve the design solutions that WSDOT engineers develop to serve a broad cross-section of the traveling public.
- Continue to share information and performance outcomes from novel design solutions that meet multimodal needs. Roundabouts often represent a better solution for many intersections on state highways. A Practical Solutions approach will consider novel geometries, whether in the form of roundabouts, diverging diamonds, or other configurations that were uncommon in Washington twenty or thirty years ago.
- During the alternatives development phase, look for opportunities to include a variety of configurations for sidewalks and bicycle lanes, including some that offer more separation from auto and truck traffic by utilizing different right-of-way than that used by the main project.
- Offer training to project engineers on the analytic methods available to evaluate the transit and non-motorized elements of project design. Chapter 1 of this report provides a guide to the best approaches that have been developed for analyzing these design elements at the project, corridor, and network levels. By expanding the set of analytic tools with which they are familiar, project engineers will have more options to develop and apply relevant performance measures for the transit and non-motorized elements of a particular project.
- Develop guidance on when engineers should conduct quantitative analysis using HCM LOS methods or other analytic approaches to inform design decisions for the non-motorized and transit elements in their Basis of Design document. Project managers may reasonably choose to let the preferences of stakeholders, including local cities and transit agencies, serve as a proxy for analysis of alternatives for the non-motorized and transit elements of a project, but they should do so

consciously and have the analytic tools on hand to challenge those stakeholder preferences when doing so will advance Practical Solutions.

CONCLUSION

Over the last thirty years, transportation planning and design have evolved from an emphasis on standards-based design, which is focused on improving safety and travel time for trucks and automobiles, to performance-based design, which balances the interests of truck and car users with those of local communities and other transportation modes such as transit, bicycling, and walking. Analysts have developed lists of potential multimodal performance measures to support this shift in the approach to project design, but there is no consistent and comparable set of multimodal performance measures for project evaluation and decision-making. While the community of researchers and project engineers has not settled upon a single set of multimodal performance measures, there has been some convergence in the process of multimodal planning and design to help aid the selection of measures appropriate to a specific project.

WSDOT's approach to project planning and design aligns with that of practice leaders among other state transportation departments that have adopted multimodal planning and design. These approaches generally follow the recommendations in the National Cooperative Highway Research Program's publication on performance-based highway design (NCHRP 839). These practice leaders in other states tailor performance measures to individual projects and typically include both supply-side and demand-side measures.

WSDOT refers to its approach as "Practical Solutions" and uses it as a means to balance stakeholder interests and improve cost-effectiveness by not following rigid design standards. The WSDOT Design Manual is the key resource for project planning, and the Manual's process includes the use of a Basis of Design document that requires engineers to address all modes when evaluating design alternatives.

Opportunities for improving multimodal design and planning include ensuring that the alternatives development phase includes different configurations for sidewalks and bicycle lanes, including some that offer more separation from auto and truck traffic; offering training on the analytic tools available to evaluate non-motorized performance; and developing guidance on when engineers should conduct quantitative analysis using

HCM LOS methods or other analytic approaches to inform design decisions for the non-motorized elements in their Basis of Design documents.

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REFERENCES

REVIEW OF LITERATURE

Barbeau, S. J., Pham, M., Nieves, J. A., Bertini, R. L., University of South Florida, T., Center for Transportation Equity, D. & D. (CTEDD), & Office of the Assistant Secretary for Research and Technology. (2020). Improving Transportation Performance Measurement via Open "Big Data" Systems – Phase 1 Transit (01727573; p. 37p). https://ctedd.uta.edu/wp-content/uploads/2019/07/ImprovingTransportationPerformance_Barbeau_CTEDD_2019.pdf

Cambridge Systematics, I. (2010). Measuring Transportation Network Performance (01173400; Issue 664). Transportation Research Board. http://www.trb.org/Publications/Blurbs/164141.aspx

Dock, S., Westrom, R., Lee, K., & Cesme, B. (2017). Advancing Urban Multimodal Transportation System Performance Management. Transportation Research Record: Journal of the Transportation Research Board, 2646, pp 17-27.

Dowling, R. G., McLeod, D. S., Guttenplan, M., & Zegeer, J. D. (2002). Multimodal Corridor Level-of-Service Analysis. Transportation Research Record: Journal of the Transportation Research Board, 1802, 1–6.

Dowling, R. G., Reinke, D. B., Flannery, A., Ryus, P., Vandehey, M., Petritsch, T. A., Landis, B. W., Rouphail, N. M., & Bonneson, J. A. (2008). Multimodal Level of Service Analysis for Urban Streets (NCHRP Report 616). ISSN 0077-5614. https://trid.trb.org/View/870308

Elefteriadou, L. (2016). New TRB Publication: The Highway Capacity Manual, 6th Edition: A Guide for Multimodal Mobility Analysis. Transportation Research Board, 306, 16–21.

Elefteriadou, L., Dowling, R. G., & Ryus, P. (2015). Exploring Multimodal Analysis in the Highway Capacity Manual 2010. ITE Journal, 85(2). https://trid.trb.org/View/1356820

Elefteriadou, L., Srinivasan, S., Steiner, R. L., Tice, P. C., Lim, K., University of Florida, G., & Florida Department of Transportation. (2012). Expanded Transportation Performance Measures to Supplement Level of Service (LOS) for Growth Management and Transportation Impact Analysis (01454384; p. 203p). http://ftp.fdot.gov/file/d/FTP/FDOT%20LTS/CO/research/Completed_Proj/Summary_PL/FDOT_BDK77_977-14_rpt.pdf

Grant, M., Rue, H., Trainor, S., Bauer, J., Parks, J., Raulerson, M., Rooney, K., & Suter, S. (2012). The Role of Transportation Systems Management & Operations in Supporting Livability and Sustainability: A Primer. United States. Federal

Highway Administration. https://ops.fhwa.dot.gov/publications/fhwahop12004/fhwahop12004.pdf

Guttenplan, M., Landis, B. W., Crider, L. B., & McLeod, D. S. (2001). Multimodal Level-of-Service Analysis at Planning Level. *Transportation Research Record: Journal of the Transportation Research Board*, *1776*, 151–158.

Harvey, J. T., Saboori, A., Butt, A. A., Kendall, A., Ostovar, M., Hernandez, J., Haynes, B., National Center for Sustainable Transportation, University of California, D., JCH Research, California Department of Transportation, & Office of the Assistant Secretary for Research and Technology. (2018). *Framework for Life Cycle Assessment of Complete Streets Projects* (01690028; p. 200p). https://escholarship.org/uc/item/0vw335dp

Heller, D. S. (2014). Performance Measurement for Transportation Infrastructure: The Paradigm for Transportation Planning in the 21st Century. 669–681. https://doi.org/10.1061/9780784413586.064

Kanafani, A., Wang, R., University of California Transportation Center (UCTC), & Research and Innovative Technology Administration. (2010). Measuring Multimodal Transport Level of Service. In *UCTC Research Paper* (01330098). http://www.uctc.net/research/papers/UCTC-FR-2010-26.pdf

Kingsbury, K., Lowry, M., & Dixon, M. (2011). What makes a “Complete Street” complete? *Transportation Research Record: Journal of the Transportation Research Board*, *2245*, 103–110. https://doi.org/10.3141/2245-13

Kittelson & Associates, Inc., Texas Transportation Institute, & Transport Consulting Limited. (1999). *Transit Capacity and Quality of Service Manual*. Transit Cooperative Research Program, Transportation Research Board of the National Research Council.

Lasley, P. (2016). Developing Multimodal Performance Measures: Understanding What They Are and How to Develop Them. *Transportation Research Board Annual Meeting*, 12p. https://trid.trb.org/view/1393472

Lee, C., & Miller, J. S. (2017). A probability-based indicator for measuring the degree of multimodality in transportation investments. *Transportation Research Part A: Policy and Practice*, *103*, pp 377-390.

Ni, Y., Ling, Z., & Li, K. (2013). A New Evaluation Method Combining Efficiency and Safety: Multimodal Comprehensive Level of Service of Signalized Intersections. 1447–1455. https://doi.org/10.1061/9780784413036.193

Phillips, R., Karachepone, J., Landis, B., University of Florida, G., & Florida Department of Transportation. (2001). *Multi-Modal Quality of Service Project* (00808643; p. 117 p.). https://rosap.ntl.bts.gov/view/dot/15408

Sanders, R., Macdonald, E., & Anderson, A. (2010). Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California. *Transportation Research Board Annual Meeting*, 17p. https://escholarship.org/uc/item/54h8k27x. https://trid.trb.org/view/910237

Seskin, S., Kite, H., Searfoss, L., AARP, & Smart Growth America. (2015). *Evaluating Complete Streets Projects: A Guide for Practitioners* (01567388; p. 49p). http://www.smartgrowthamerica.org/documents/evaluating-complete-streets-projects.pdf

Sinclair, C., Schaefer, R., & others. (2019). *Multimodal System Performance Measures Research and Application: Innovation and Research Plan*. United States. Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/43579

Tasic, I., & Bozic, C. (2017). Toward True Multimodal Transportation Accessibility: Data, Measures, and Methods. *Transportation Research Board Annual Meeting*. https://trid.trb.org/view/1438514

Transportation Statistics Office, Florida Department of Transportation. (2015). *Florida Multimodal Mobility Performance Measures Source Book*.

Wang, L., Liu, J., Portland State University, Oregon Department of Transportation, & Federal Highway Administration. (2016). Multi-Modal Performance Measures in Oregon: Developing a Transportation Cost Index Based Upon Multi-Modal Network and Land Use Information (01593722; p. 132p). http://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR760_TCIFinalReport.pdf

Washington State Department of Transportation. (2014). *WSDOT's Handbook for Corridor Capacity Evaluation* (01544655; p. 48p). http://wsdot.wa.gov/publications/fulltext/graynotebook/CCR14_methodology.pdf

Zuniga-Garcia, N., Ross, H. W., & Machemehl, R. B. (2018). Multimodal Level of Service Methodologies: Evaluation of the Multimodal Performance of Arterial Corridors. *Transportation Research Record: Journal of the Transportation Research Board*, *2672*(15), 142–154. https://doi.org/10.1177/0361198118776112

STATE OF MULTIMODAL PRACTICE

Cambridge Systematics, Inc. (1999). *Multimodal transportation: Development of a performance-based planning process*. NCHRP Research Results Digest. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=900

FDOT. (2016). *Manual on Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways*. Florida Department of Transportation. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/floridagreenbook/2016floridagreenbookfinal-982972170.pdf?sfvrsn=946ed802_2

FDOT. (2017). *Transit Facilities Guidelines*. Florida Department of Transportation. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/transit/documents/transitfacilityguidelines-8-4-2017.pdf?sfvrsn=6d929e38_2

FDOT. (2020a). *FDOT Design Manual; Development and Processes*. Florida Department of Transportation. https://www.fdot.gov/roadway/fdm/2020-fdot-design-manual

FDOT. (2020b). *FDOT Context Classification Guide*. Florida Department of Transportation. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/completestreets/files/fdot-context-classification.pdf?sfvrsn=12be90da_2

FDOT & Smart Growth America. (2015). *Complete Streets Implementation Plan; M2D2: Multimodal Development and Delivery*. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/completestreets/files/final-csi-implementation-plan.pdf?sfvrsn=96979438_2

Kittelson & Associates, Inc. (2020). *Context Classification Framework For Bus Transit*. Florida Department of Transportation. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/transit/documents/context-classification-framework-for-bus-transit-final.pdf?sfvrsn=a53e4325_2

Lovas, D., Nabors, D., Goughnour, E., & Rabito, L. (2015). Massachusetts Department of Transportation Complete Streets Pedestrian and Bicycle Level of Service Study. *Transportation Research Board Annual Meeting*, Article 15–4803. https://trid.trb.org/View/1338857

MassDOT. (2015). *Separated Bike Lane Planning and Design Guide*. Massachusetts Department of Transportation. https://www.mass.gov/lists/separated-bike-lane-planning-design-guide

MassDOT. (2020). *Guidelines for the Planning and Design of Roundabouts*. Massachusetts Department of Transportation.

https://www.mass.gov/doc/massdot-guidelines-for-the-planning-and-design-of-roundabouts/download

MassHighway. (2006). *Project Development and Design Guide*. Massachusetts Department of Transportation.

MnDOT. (n.d.). *Road Design Manual*. Minnesota Department of Transportation. https://edocs-public.dot.state.mn.us/edocs_public/DMResultSet/download?docId=12772885

MnDOT. (2017). *Statewide Multimodal Transportation Plan: 2017 to 2036*. Minnesota Department of Transportation. https://minnesotago.org/final-plans/smtp-final-plan

MnDOT. (2018). *Performane-Based Practical Design (PBPD) Process and Design Guidance*. Minnesota Department of Transportation. https://edocs-public.dot.state.mn.us/edocs_public/DMResultSet/download?docId=2156389

MnDOT. (2020). *Bicycle Facility Design Manual*. Minnesota Department of Transportation. https://edocs-public.dot.state.mn.us/edocs_public/DMResultSet/download?docId=6976095

Neuman, T. R., Coakley, R. C., Panguluri, S., Harwood, D. W., National Cooperative Highway Research Program, Transportation Research Board, & National Academies of Sciences, Engineering, and Medicine. (2016). *A Performance-Based Highway Geometric Design Process* (p. 24626). Transportation Research Board. https://doi.org/10.17226/24626

ODOT. (2012). *Highway Design Manual*. Oregon Department of Transportation. https://www.oregon.gov/odot/Engineering/Documents_RoadwayEng/HDM_00-Full-Report.pdf

ODOT. (2017). *Project Delivery Guide*. Oregon Department of Transportation. https://www.oregon.gov/odot/ProjectDel/Documents/SBS-Guidebook.pdf

ODOT. (2020a). *Blueprint for Urban Design (BUD)—Vol 1* (Vol. 1). Oregon Department of Transportation. https://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/Blueprint-for-Urban-Design_v1.pdf

ODOT. (2020b). *Blueprint for Urban Design (BUD)—Vol 2* (Vol. 2). Oregon Department of Transportation. https://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/Blueprint-for-Urban-Design_v2.pdf

Ray, B. L., Ferguson, E. M., Knudsen, J. K., Porter, R. J., Mason, J., National Cooperative Highway Research Program, Transportation Research Board, & National Academies of Sciences, Engineering, and Medicine. (2014).

Performance-Based Analysis of Geometric Design of Highways and Streets (p. 22285). Transportation Research Board. https://doi.org/10.17226/22285

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