Assessing System Performance of the Michigan Trunkline: Measures and Analytical Procedures for Planning and Operations

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16. Abstract

The Moving Ahead for Progress in the 21st Century Act (MAP-21) required transportation agencies to use performance-based approaches, and there are federal guidelines and programs to help agencies develop performance management systems. For the performance management strategies to be effective, it is critical to establish performance measures that are practical and sensitive to planning and operational functions. Previously, the Michigan Department of Transportation (MDOT) provided the roadway inventory data in the Annual Sufficiency Report, which served as a planning tool and provided information that included the operational characteristics of the Michigan trunkline system. This report was retired in 2015. Given the lack of an up-to-date performance report, this study aims to identify and propose effective measures and analytical procedures for assessing the system performance of the Michigan trunkline system. To do so, first, the research team conducted a comprehensive review of literature regarding system planning performance management. Then, the research team explored the current state-of-the-practice by transportation agencies across the United States through a nationwide survey. Next, the research team performed a review of the MDOT current and historical practices regarding performance management. Subsequently, MDOT staff pertinent to performance management were interviewed to identify the current needs and gaps of the MDOT work areas in this regard. Then, the research team identified the potential system planning performance measures for the Michigan trunkline system, and a nationwide follow-up survey was carried out to determine the appropriate specifications (e.g., definition, calculation equations, thresholds, and targets) currently used by transportation agencies for the potential measures. Finally, the final recommendations and guidelines for the system planning performance management of the Michigan trunkline are provided. Based on the results of the study, total delay (and associated delay per mile for corridors), travel time index, planning time index, volume-to-capacity ratio, and level-of-service are the recommended measures for assessing the system performance of Michigan trunkline. The research team also presents the recommended specifications, data sources and tools to calculate the measures, as well as the reporting and communication methods for the selected measures are presented.

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FINAL REPORT

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EXECUTIVE SUMMARY

Assessing the operational performance of transportation systems is critical for transportation planners to identify mobility trends and prioritize improvement projects. The Moving Ahead for Progress in the 21st Century Act (MAP-21) required transportation agencies to use performance-based approaches, and there are federal guidelines and programs, which help agencies develop performance management systems. For the performance management strategies to be effective, it is critical to establish performance measures that are practical and sensitive to planning and operational functions. In this regard, one needs to determine associated targets, data needs, and proper tools and methodologies to calculate the measures. Previously, the Michigan Department of Transportation (MDOT) provided the roadway inventory data in the Annual Sufficiency Report, which served as a planning tool and provided information that included the operational characteristics of the Michigan trunkline system. This report was retired after the release of the 2015 Sufficiency Report. Recent MDOT activities regarding performance management include the Freeway Congestion and Reliability Report and the Arterial Performance Report.

The ultimate goal of this study was to identify and propose effective measures and analytical procedures for assessing the system performance of the Michigan trunkline system. This report involves a review of the literature regarding performance management (Task 1), a nationwide survey to identify the current practices of the agencies across the nation (Task 2), a review of the MDOT current and historical practices regarding performance management (Task 3), performing MDOT staff interviews (Task 4), identifying potential performance measures for the Michigan trunkline (Task 5), a needs assessment for the Michigan trunkline performance assessment system (Task 6), and final recommendations for Michigan trunkline performance measures (Task 7).

In this report, first, the project team presents a comprehensive review of literature regarding operational performance management in three sections. The first section provides a comprehensive review of the federal guidelines and resources for assessing the operational performance of the transportation systems. In the second section, the review of online resources regarding the performance management activities by different state Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) (across 34 states) are presented. Also, the project team identified the most commonly used performance measures and data sources. The third section provides a review of the journal articles and conference proceedings focusing on performance management, including developing the performance measures and their implementation in decision-making, evaluation of the effectiveness of the measures, their calculation methods, and data aggregation techniques for calculating the measures.

Then, the project team assessed the current state-of-the-practice regarding performance management across the United States through a comprehensive survey of state DOTs and MPOs. In this survey, agencies were asked to provide the set of performance measures that are used and their pertinent applications, assessment frequency, measurement time period, vehicle type, threshold, and data sources. In addition, researchers also collected state agencies' current practices regarding reporting the performance measures. The provided information in this survey revealed the state-of-the-practice, which was used in defining the performance measures for the Michigan trunkline system. The results indicated that agencies tend to use a small set of measures that can be easily used and understood and do not have overlap with each other. Also, it was found that incorporating multimodal measures into the performance management is critical to assess the system performance thoroughly. In addition, it was concluded that evolving the measures and tools is important due to adaption of the operational practices, particularly data availability. In terms of the data sources used for calculating the measures, the results showed that the agencies use in-house traffic count data and INRIX data sources most frequently. Also, it was found that moving from printed reports to an online performance dashboard is effective in improving the communication and transparency of the performance measurement to the public and promotes the application of the performance measures. Finally, it was suggested that measures such as volume-to-capacity ratio no longer serve the needs of state DOTs and MPOs as the congestion level grows in transportation networks, which calls for using more informative complementary measures that capture various aspects of congestion and reliability.

A comprehensive review of MDOT current and historical practices regarding the operational performance measurement is presented in the next section that included the operational performance management studies in Michigan: Annual Sufficiency Reports, Annual PM3 Reports, Annual Freeway Congestion and Reliability Reports, Annual Arterial Performance Reports, and the Regional Integrated Transportation Information System (RITIS) tool. It was found that there is a need for a comprehensive evaluation and assessment of the performance measurement system in Michigan. In addition, an interactive performance dashboard to communicate the system planning performance measure of the Michigan trunkline needs to be provided to the public, and different MDOT work areas, to promote application of the performance measures.

Then, the current needs and practices regarding performance management among MDOT work areas were identified from interviews of pertinent MDOT staff. In this survey, the interviewees were asked to provide the set of performance measures that they use and their related applications, critical concerns regarding the use of the performance measures, use of the measures reported in MDOT freeway and arterial performance reports, data sources, and their current practices for publishing and reporting the measures. The results indicated that level-of-service and volume-to-capacity ratio measures, which were reported in the Sufficiency Reports are among the most frequently used measures and are still used by most of the MDOT work areas. This is typically because some work areas are holding onto traditional measures to maintain consistency in their historical reports. Level-of-service and volume-to-capacity ratio measures are also highly used as they are mentioned by the MDOT work areas due to lack of system-wide data and/or resources to compute the more informative measures (e.g., delay-based measures) at the system level. Complementary measures for level-of-service and volume-to-capacity ratio are suggested to promote a transition period from these historical measures. The project team also found that determining how the thresholds for the performance measures are calculated is a critical consideration. Also, a report similar to the previous Sufficiency Report, along with GIS maps, can be a useful approach for reporting and disseminating the measures. The needs and gaps of the MDOT performance measurement system are presented based on the outcomes of previous tasks.

Researchers present the procedures for identifying the potential performance measures for the Michigan trunkline in the next section. First, the set of potential measures was determined by assigning equal weights on the importance and relevance of the performance measures for different application categories of operational evaluation, prioritizing projects, and short/long-range transportation planning. In this regard, researchers used the provided rankings for the measures based on the results of the MDOT staff interviews. The top 6 measures provided by overall MDOT work areas and Bureau of Transportation Planning were selected and combined to form the set of 7 unique potential measures. This set included total delay (total delay for areawide measurement and total delay per mile for corridor-level comparison), travel time index, planning time index, percent of miles congested, volume-to-capacity ratio, level-of-service, and level of travel time reliability index. The project team then designed and distributed a follow-up nationwide agencies survey to finalize the set of performance measures for the Michigan trunkline and set the specifications of these measures. Researchers used the results of this survey to identify the selected performance measures for the Michigan trunkline, and also to determine the specifications of these measures, including definition, calculation equation, thresholds, and target values. Note that the threshold values are the ones that are included in the definition of the measures and targets are the values that the agencies aim to achieve for the performance measure.

Finally, project team utilized the collective results of the literature review, nationwide agencies survey, MDOT state-of-the-practice review, MDOT staff interviews, and needs assessment to develop recommendations and guidelines for the assessment of the Michigan trunkline system. In this task, first a summary of findings of the previous tasks of the project is presented. Then, the final recommended performance measures are presented, including the set of selected performance measures and their specifications, data sources that are recommended for calculating/estimating the measures, and the recommended approach for communicating and reporting the measures. Specific recommendation are provided to the following items:

- Selected system planning performance measures for the Michigan trunkline system;
- Recommended data sources to estimate/calculate the selected performance measures;
- Recommended resources for threshold and target values for the selected performance measures;
- Recommended reporting and communication methods for the measures to meet the needs of varied audiences.

CHAPTER 1 – INTRODUCTION

1-1 Statement of the Problem

Mobility-related issues are critical concerns to the Michigan Department of Transportation (MDOT) and, particularly, to travelers throughout the state. The *2021 Urban Mobility Report* ranks Detroit as the 14th most congested urban area in the United States with an estimated total congestion cost of $21 billion in 2020, wasting 35 hours annually per auto commuter (Texas A&M Transportation Institute, 2021). While Metro Detroit is subject to severe levels of congestion, significant levels of delay are also experienced in urban and suburban areas throughout the state. In turn, this congestion leads to traffic crashes, increased levels of pollution, and various other adverse impacts. Given resource constraints, MDOT is tasked with investing in projects that improve safety, accessibility, and mobility. To optimize these investment decisions, it is critical to be able to forecast both short-term and long-term impacts of these projects on trunkline performance.

These same concerns are critical nationwide, providing motivation for the Moving Ahead for Progress in the 21st Century Act (MAP-21), which established a performance-based approach for decision-making in different aspects of the transportation sector (FHWA, 2012). Performance-based management uses statistical evidence to assess progress toward objectives of a transportation agency in providing services to the public. This approach enables agencies to identify emerging mobility trends, prioritize improvement projects, and determine performance targets that provide satisfactory levels of mobility for trunkline users. This approach not only improves the decision-making process and leads to more efficient investment of federal and state transportation funds, but it also enhances the communication between transportation agencies and the public.

For these management strategies to be effective, it is critical to establish tangible performance measures that are practical and sensitive to operational functions, including congestion and travel time reliability. Properly assessing the system performance of the Michigan trunkline includes identifying proper performance measures, determining associated threshold and target values for these measures, exploring estimation approaches and data needs, and using proper tools and methodologies to estimate and predict impacts of various improvement projects on the selected measures.

Beginning in 1961, MDOT conducted annual systematic evaluations of the condition and operational performance of individual highway segments on the trunkline system, culminating in an Annual Sufficiency Report. The Sufficiency Report served as an important planning tool, providing critical information as to geometric, safety, and operational characteristics of the trunkline network to facilitate planning, design, and operational analysis. The Sufficiency Program was retired after the release of the 2015 Sufficiency Report. While most of the data elements continue to be maintained annually through other MDOT programs, data characterizing trunkline operational performance, specifically capacity and level-of-service (LOS), has not been updated. Thus, the LOS values from the 2015 Sufficiency Report are still in use and are quickly becoming outdated. Recent MDOT initiatives regarding performance measures include the Freeway Congestion and Reliability Report and the Arterial Performance Report. Identifying key performance measures, their associated thresholds and target values, required data sources, and tools to calculate and report appropriate measures for reporting and decision-making needs to be investigated thoroughly.

1-2 Study Objectives

Given the lack of an up-to-date performance report, there is an urgent need to update performance measurement guidelines for the Michigan trunkline system with particular consideration of MDOT needs and the availability of emerging mobility datasets. This study will also result in a comprehensive evaluation of the performance measures used by MDOT and other agencies for the purposes of assessing system performance. In effect, while capacity and LOS have long served as key operational performance measures, delay-based mobility measures and travel time reliability related measures have emerged as attractive alternatives that allow for comparative evaluation both within and across different roadways. In addition, new opportunities have emerged with the introduction of alternative data sources, such as crowdsourced probe vehicles, creating opportunities to define and use performance measures in a manner that is more robust, timely, and cost-effective. Therefore, ***the overarching goal of this study is to identify and propose effective performance measures and analytical procedures for assessing system performance on the Michigan trunkline system***. To satisfy this goal, the proposed work has the following research objectives:

1. Evaluate past MDOT practices, including historical approaches in the 2015 Sufficiency Report, for assessment of the Michigan trunkline system performance.

2. Identify the pertinent MDOT staff and work areas to be interviewed regarding the Michigan trunkline system performance assessment.
3. Explore current MDOT needs and practices regarding system planning performance measures, their data needs, and their use within MDOT business processes.
4. Review the national state-of-the-practice to explore appropriate system planning performance measures to define congestion, delay, reliability, and level-of-service for the Michigan trunkline system.
5. Identify relevant approaches and tools for calculating, estimating, forecasting, and publishing (for technical and non-technical audiences) the proposed performance metrics in this study.
6. Recommend strategies regarding planning and operational analysis for implementation of the proposed performance measures determining their thresholds and target values based on the Michigan trunkline system needs and national trends.

1-3 Research Plan

To accomplish the aforementioned objectives, the research team prepared a detailed research plan to outline the process for assessing the system performance of the Michigan trunkline. This research plan includes the following tasks:

- Task 1: Literature review.
- Task 2: Perform a nationwide state DOT survey.
- Task 3: Review MDOT current/historical practices.
- Task 4: Perform MDOT staff interviews.
- Task 5: Identify potential performance measures for Michigan trunkline.
- Task 6: Perform needs assessment, gap analysis, and cost assessment.
- Task 7: Recommend performance measures for Michigan trunkline.
- Task 8: Development and delivery of draft and final reports.

These tasks and their relationships are illustrated in Figure 1-1.

1-4 Report Structure

The remainder of this report is structured as follows: Chapter 2 provides a comprehensive review of literature regarding operational performance management. Chapter 3 describes the nationwide agencies survey analysis. Chapter 4 provides a review of MDOT current and historical practices regarding operational performance management. Chapter 5 presents the details of interviewing the MDOT staff pertinent to the performance management. Chapter 6 provides the procedures for identifying the potential performance measures for the Michigan trunkline system. Chapter 7 provides the summary of findings of the research tasks of the project. To conclude, Chapter 8 includes the recommendations regarding the Michigan trunkline performance measures.

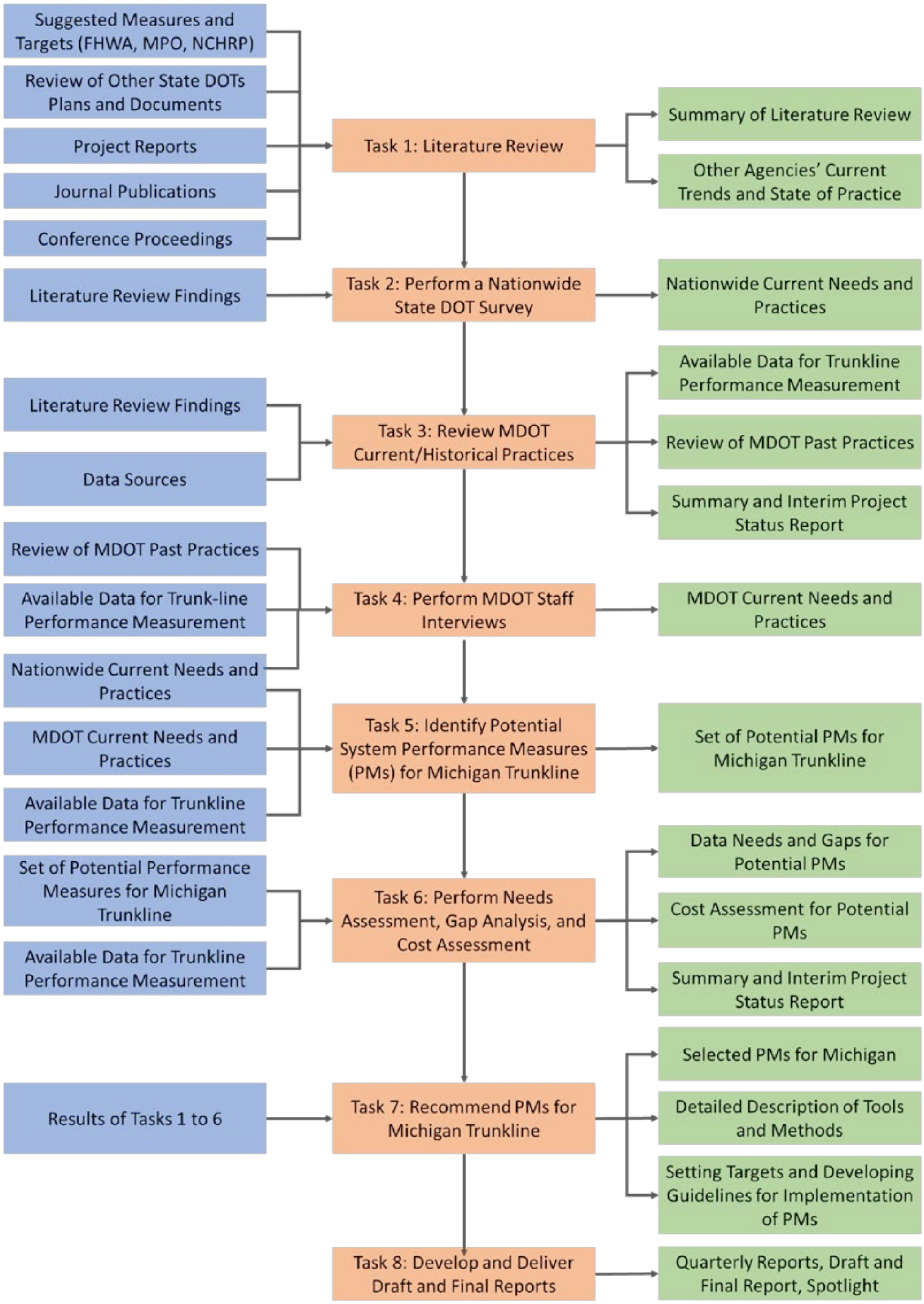


Figure 1-1 Project research and data collection plan flowchart

CHAPTER 2 – LITERATURE REVIEW

2-1 Federal Guidelines and Resources

Several federal guidelines and programs are in place to improve the operational performance of highway systems. In 2003, National Cooperative Highway Research Program (NCHRP) Synthesis 311 ("Performance Measures of Operational Effectiveness for Highway Segments and Systems") provided useful information regarding the development and use of performance measures (Shaw, 2003). In 2006, NCHRP Report 551 ("Performance Measures and Targets for Transportation Asset Management") presented guidelines and criteria for selecting the performance measures and how to link them to resource allocations (Cambridge Systematics et al., 2006). In 2013, a task force of the Standing Committee on Performance Management (SCOPM) of the American Association of State Highway and Transportation Officials (AASHTO) made recommendations to the Federal Highway Administration (FHWA) for establishing a set of national performance measures (AASHTO, 2013). National goals have been established for transportation system performance in areas such as safety, pavement condition, bridges, freight, system performance, and congestion mitigation and air quality. The SCOPM performance measures for system performance and congestion mitigation and air quality were annual hours of delay and reliability index defined based on the 80^{th} percentile of travel time distribution.

Under MAP-21, FHWA established national performance measures (PM3) to be used by State DOTs for assessing traffic congestion level on the National Highway System (NHS). PM3 measures include percent of person-miles traveled (PMT) on the interstate NHS that are reliable, percent of person-miles traveled (PMT) on the non-interstate NHS that are reliable, and truck travel time reliability index (TTTR) on the interstate NHS. In addition, under MAP-21, some of the transportation agencies are required to assess the traffic congestion level under the Congestion Mitigation and Air Quality (CMAQ) improvement program (U.S. Department of Transportation, 2018). The applicability of the agencies to follow the CMAQ measures is based on the type of the area under their jurisdiction and its population. Three measures that assess the traffic congestion level under the CMAQ program are annual hours of peak hour excessive delay (PHED) per capita, the percent of non-single occupancy vehicle travel (non-SOV), and on-road mobile source emissions reduction for CMAQ-funded projects.

The Fixing America's Surface Transportation (FAST) Act extended the performance-based management approach introduced in MAP-21, and required State DOTs, MPOs, and transit agencies to coordinate and set targets for national performance measures (U.S. Government Publishing Office, 2015). This bill also required states to follow a coordinated performance-based approach for decision-making in transportation related projects to support national goals for highway systems.

The guidelines published by FHWA also contain requirements for calculating these performance metrics. In addition to the performance measures required by FHWA, state DOTs are highly encouraged to identify their own performance measures/metrics and targets for mobility and congestion, in line with national goals and programs, with decisions based on their current needs, and available tools and data (NADO Research Foundation, 2014). A report published by the Strategic Highway Research Program (SHRP 2) in 2014 provides guidelines to establish monitoring programs for travel time reliability measures (Transportation Research Board, 2014). This document is a handbook for incorporating the reliability measures into planning and provides a detailed explanation of applications of the performance measures. Furthermore, in 2019, NCHRP Report 920 ("Management and Use of Data for Transportation Performance Management: Guide for Practitioners") promotes the practices that enable agencies to go beyond meeting the requirements and to get valuable insights from the available data sets for different agencies (Transportation Research Board, 2019).

There are several on-going efforts that examine operational performance at the national level, most notably the *Urban Mobility Report*, which details various mobility and reliability performance measures across 494 urban areas, including 17 urban areas in Michigan (Texas A&M Transportation Institute, 2021). These reports assess congestion patterns both spatially and temporally and discuss the application of reliability measures and congestion mitigation strategies. The later versions of reports leverage INRIX speed data and FHWA's Highway Performance Monitoring System (HPMS) volume data, both of which are also important aspects of MDOT performance measurement processes. Finally, the FHWA Model Inventory of Roadway Elements (MIRE) provides details of critical traffic and roadway data, including traffic flow and operations/control data such as annual average daily traffic (AADT), annual AADT escalation rate, hourly traffic volume, and mean and 85^{th} percentile speeds (FHWA, 2021).

2-2 State DOT and MPO Practice

To investigate the performance management practices of state DOTs and MPOs, the performance measurement activities of 34 U.S. states were reviewed through their websites, project reports, and their PM3 reports. Figure 2-1 illustrates the state DOTs covered in the literature review task (34 states). A summary table for the findings is provided in Appendix A. In the Appendix A table, each row presents a performance measure used by a specific agency. The table includes information, including the type of measure, its definition, threshold, targets, and data sources used to calculate the measure by that agency.

The most commonly-used performance measures were identified based on this review to incorporate into Task 2 — conducting a nationwide state DOT survey. The most common measures include Total Delay, Travel Time Index (TTI), Planning Time Index (PTI), Congestion Duration, Percent of Miles Congested, Cost of Congestion and Delay, Level-of-Service (LOS), and the traffic variables (e.g., Average Speed). Through the survey, the project team also identified the most common data sources used by agencies in their performance measurement, including the Regional Integrated Transportation Information System (RITIS) (RITIS, 2020) and the National Performance Management Research Data Set (NPMRDS) (NPMRDS, 2022).

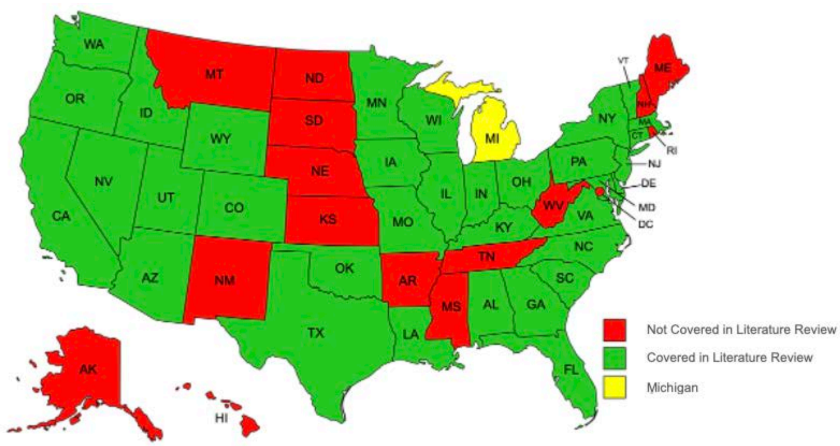


Figure 2-1 States with project reports focusing on performance measures that are reviewed as part of the literature review task

Several agencies have relatively more comprehensive and up-to-date documents for the operational performance measures, including:

- Texas Department of Transportation (TxDOT) provides an online dashboard to report its performance measures (TxDOT, 2022). Multiple unique performance measures are presented through this dashboard including Urban Congestion Index and Most Congested

Chokepoints with their definitions and calculation processes. In addition, in cooperation with the Texas A&M Transportation Institute (TTI), TxDOT has sponsored multiple projects regarding operational performance management. In recent years, one of these reports is the *Urban Mobility Report*, which was discussed earlier. Also, the Analysis Procedures and Mobility Performance Measures from the 100 Most Congested Roadway Sections project (Texas A&M Transportation Institute, 2020) provides multiple measures as well as the methodologies used to calculate and report the measures.

- Florida Department of Transportation (FDOT) publishes the FDOT Source Book, which provides 14 people-related (including multi-modal) and 11 freight-related performance measures (Florida DOT, 2020b). Also, a comprehensive explanation for their calculation methods, reporting periods, and data needs are provided. FDOT has published other documents that present detailed descriptions of the methodologies to be used to calculate mobility and reliability measures (FDOT, 2022).
- California Department of Transportation (Caltrans) publishes Mobility Performance Reports quarterly for each of its districts (Caltrans, 2020). The reported measures are Vehicle-miles Traveled (VMT) per capita, Peak Travel Time Reliability Index, Buffer Time Index, and Bottleneck Locations. Also, this agency uses its own collected data, named Performance Measurement System (PeMS), to calculate the measures (Caltrans, 2022).

There are also other agencies with up-to-date performance measurement documents such as Colorado DOT performance reports and Washington DOT Gray Notebook, which are included in the summary provided in Appendix A.

Some of the reviewed documents regarding the performance measurement are for previous years, as the most recent years are not available through the online resources. Additionally, many online resources provided by agencies do not contain pertinent information, such as procedures for target value determination, the data sources that agencies use to calculate the measures, the data analysis procedures for performance measurement, and other agencies' projects related to the evaluation of their performance measurement systems. To fill these gaps in knowledge, the research team has developed a nationwide survey to investigate current agency practices regarding performance measurement. This survey is explained in Chapter 3 in greater detail.

2-3 Journal Articles and Conference Proceedings

The travel demand growth in the past few years has caused severe mobility and reliability challenges in transportation networks. Therefore, recent efforts have been directed toward raising awareness among users and motivating transportation planners to develop solutions to these challenges. Performance measures are essential means that enable planners to evaluate transportation systems and assist them in decision-making (Falcocchio, 2004; Zito & Salvo, 2011). These measures are defined to quantify the mobility and reliability of transportation facilities.

The procedures for developing performance measures and their implementation in decision-making have been widely investigated in the literature. Most notably, McLeod et al. (2016) provided the key aspects of the formation and operation of the Florida DOT's performance measures and agency's responsibilities. In another study, Cesme et al. (2017) defined a data-driven framework for monitoring mobility performance for transportation systems. They emphasized that the data availability is important in defining and using the performance measures.

There is a wide range of measures used by transportation agencies to quantify mobility and reliability. In a recent study, Braga et al. (2019) identified the most used mobility performance measures by means of a bibliometric analysis. They found 228 categories of measures. It is critical to use the measures that indicate the subsystems in which the mobility problem is more severe and needs to be prioritized. In this regard, Smith (2016) examined several performance measures for their ability to accurately present the conditions on an arterial. In another study, Al-Kaisy et al. (2018) identified the measures that are more effective in describing the performance of a rural two-lane highway. In addition, there are studies in the literature aimed to find the analytical relationships between the measures (Pu, 2011). In addition to the definitions of the performance measures and their relationships, their calculation methods have been the topic of research as well. In this regard, multiple studies focused on data aggregation and preparation techniques for calculating the performance measures (Khan & Patire, 2020; Olszewski, Dybicz, Jamroz, Kustra, & Romanowska, 2018).

Collectively, the literature suggests a lack of research pertaining to performance management systems, including the specific set of performance measures, thresholds, target values, target setting process, resource needs, and reporting. In this regard, Eisele et al. (2015) described the methodology for computing a number of measures as well as the target setting process to meet Virginia DOT needs. While this provides an important template for development of such a system, research is needed to develop a similar method for the Michigan performance measurement system.

CHAPTER 3 – NATIONWIDE SURVEY OF CURRENT PRACTICES

3-1 Purpose

Each state has its own performance measurement system and pertinent requirements in addition to the federal requirements, and there is not any uniquely defined criterion to unify the practices. Consequently, the project team developed and implemented a nationwide survey to investigate current practices related to system performance assessment. This survey, which targeted state DOTs and major MPOs, was supplemented by an exhaustive online search of the current policies and practices for all 50 state DOTs regarding assessment of their highway systems, with particular emphases on system planning performance measures. The nationwide survey, along with results from the literature review, were the primary means of determining best practices related to system planning performance measures that may address the needs and gaps associated with MDOT's trunkline system assessment. The main objectives of this survey were to identify:

- Frequent performance measures used for highway system performance
- Threshold and target values for performance measures
- Data sources used for calculation and estimation of mobility-related performance measures
- Current practice and approaches in publishing, reporting, and communicating operational performance measures
- Tools, methodologies, and platforms used for data analyses
- Costs associated with data collection, storage, and analysis

To inquire about the specifications of the performance measures and also quantify the importance of each measure for the application categories in other agencies, a nationwide agencies follow-up survey was also conducted, which was covered in Task 6 of the project, and focused only on the potential performance measures for the Michigan trunkline, that were identified based on Tasks 1 to 6.

3-2 Survey Design and Administration

The MSU research team developed a questionnaire survey to investigate the state-of-the-practice for system performance assessment. The topics and questions included were developed based on the literature review and were revised based on MDOT feedback. The survey was designed and implemented in a web-based format through the Qualtrics platform and consisted of three sections that sought the following information:

- Sets of performance measures that are used (applications, assessment frequency, measurement time period, and vehicle type)
- Threshold and target values for the performance measures
- Data sources that are used to calculate/estimate each of the performance measures
- Current practices in publishing and reporting the performance measures
- Relevant projects, in which the agencies have evaluated their performance measurement system
- Suggestions, recommendations, and lessons learned by other agencies regarding the operational performance management

In spring and summer 2021, the survey was distributed to:

- AASHTO Research Advisory Committee (RAC) members
- AASHTO Performance Measure Committee members.
- A list of planning and performance reporting staff from 398 MPOs and 50 DOTs.

The survey was distributed in three phases: initial distribution, reminder, and follow-up. Initial distribution of the survey was conducted in March 2021. The survey was completed by representatives from 21 states, after a 1-month period. However, recorded responses were mostly from MPOs. The second round of survey distribution was conducted in April 2021 by sending a reminder email to those invited in the first-round invitation, in addition to several new contacts from state DOTs, collected via an exhaustive online search. A unique survey link was re-generated and shared with agencies that provided incomplete responses to complete their responses. In mid-April, follow-up emails were sent to state DOTs that had yet to respond, and the survey was officially closed by May 2021. Some agencies only provided a link to their operational performance report. Where possible, pertinent information was manually added by the research team based on published online reports. In addition, some agencies provided multiple responses, for which the research team combined the responses into a single coherent response. The survey form is provided in Appendix B.

The respondents were asked to provide detailed contact information to allow for follow-up calls, which will be performed in Task 6 of the project, where the set of potential performance measures for use by MDOT is determined. These follow-up calls focused on topics, including:

- Identify the relevance and applicability of the potential performance measures in other agencies

- Explore the detailed specifications of the potential performance measures, including definition, calculation equation, thresholds, and targets

3-3 Summary of Survey Results

3-3-1 Overview of the responses

Transportation agencies responding to the survey included states from across the US, covering a vast range of operational needs and conditions. A total of 75 valid responses were received from 26 state DOTs (Figure 3-1a) and 49 MPOs (Figure 3-1b), which were from 45 US states (Figure 3-1c). Figure 3-1d illustrates the state DOTs covered in the survey and the literature review task (37 states). It is noteworthy to mention that 9 state DOTs and 7 MPOs were covered in the literature review task that did not respond to the survey.

3-3-2 Relevant Projects

To gather more information on relevant projects and research conducted by other agencies, the agencies were asked whether they have ever evaluated their performance measurement system. None of the agencies had documentation of such an evaluation, while nine agencies stated they are currently evaluating their performance measurement system. In the follow-up survey, these states will be queried for further information regarding these studies.

3-3-3 Performance Measures Used by Other Agencies

The percent of agencies using each of the mobility measures and reliability measures identified in the literature review are presented in Figure 3-2a and Figure 3-2b, respectively. As shown in Figure 3-2a and 3-2b, vehicle-miles traveled (VMT) and travel time index (TTI) are the most frequently used mobility measures, while level of travel time reliability (LOTTR) and planning time index (PTI) are the most commonly used reliability measures among these agencies. It is also worth mentioning that delay-based mobility measures, such as total delay and congestion duration, are used by 24% and 23% of the agencies, respectively. It should be noted that the higher frequency does not necessarily reflect a higher quality for a given performance measure. For instance, as can be seen in Figure 3-2a, VMT is the most frequently used mobility measure among the agencies. However, this measure is a data element that helps to form more complex measures. Therefore, it is intuitively collected by many agencies.

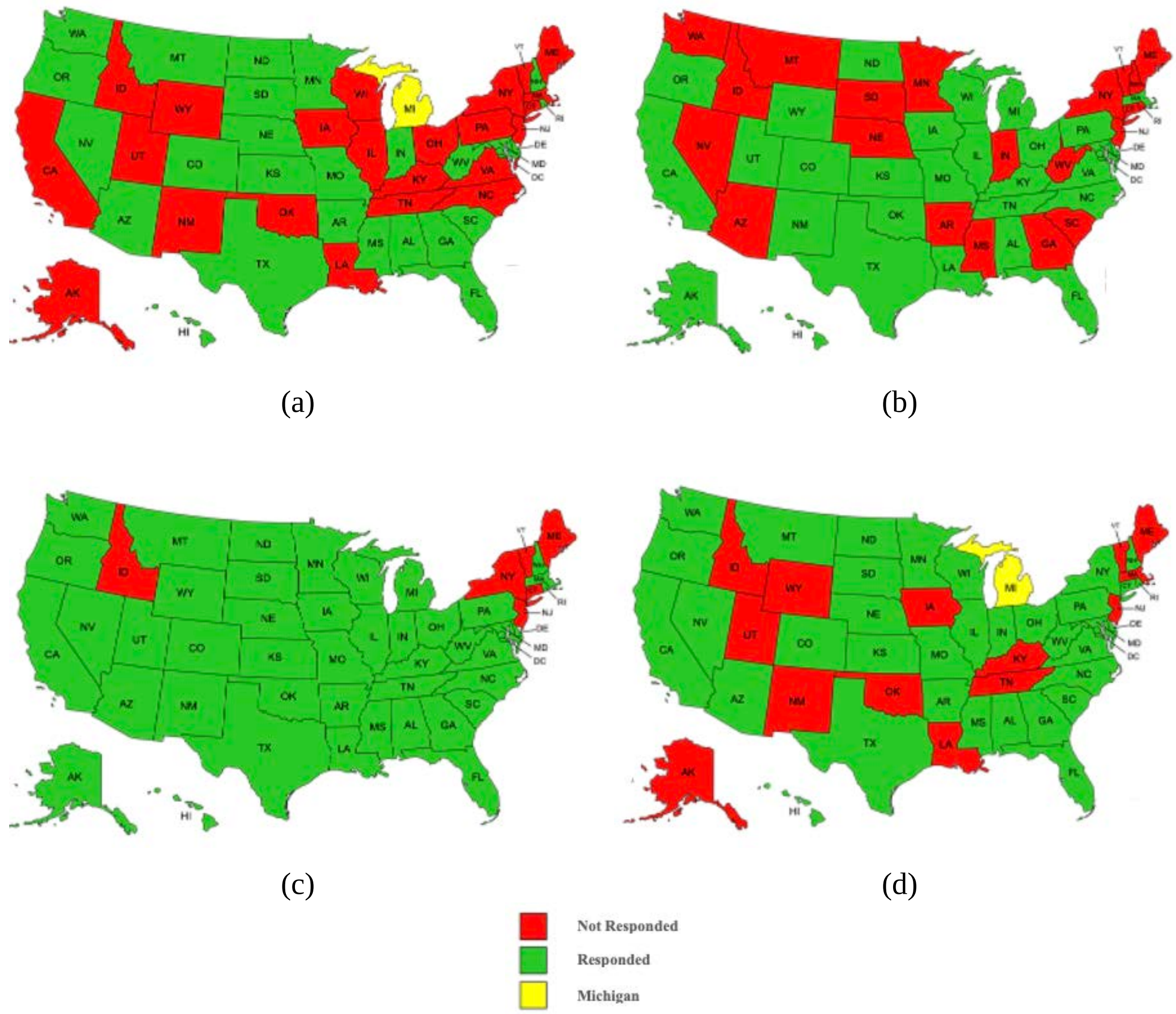
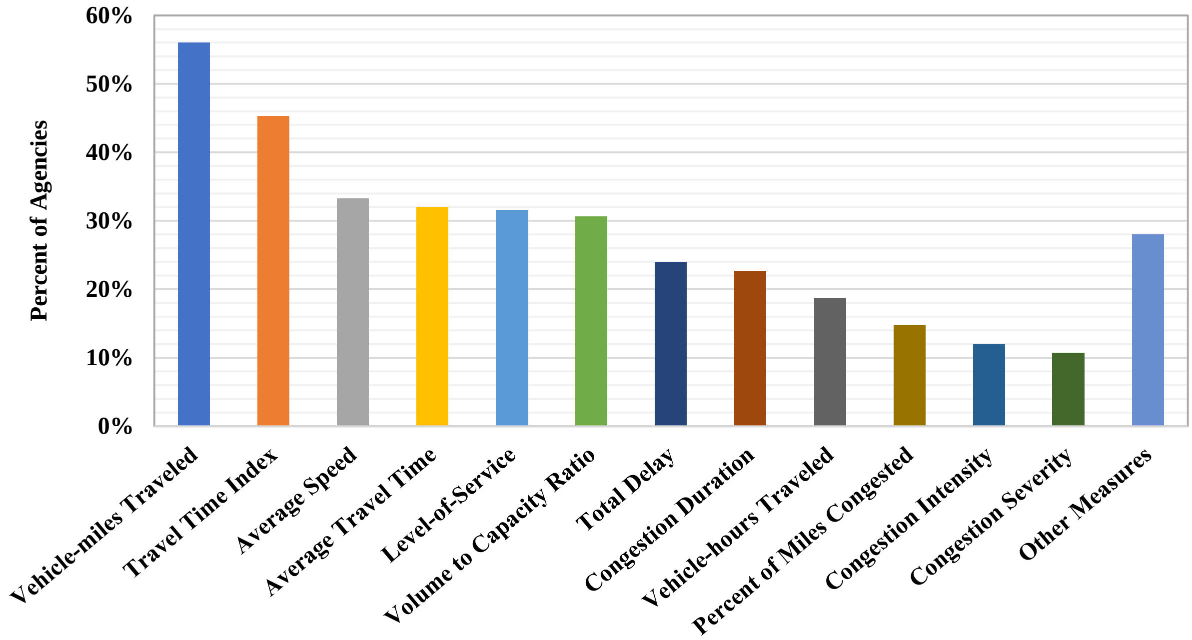


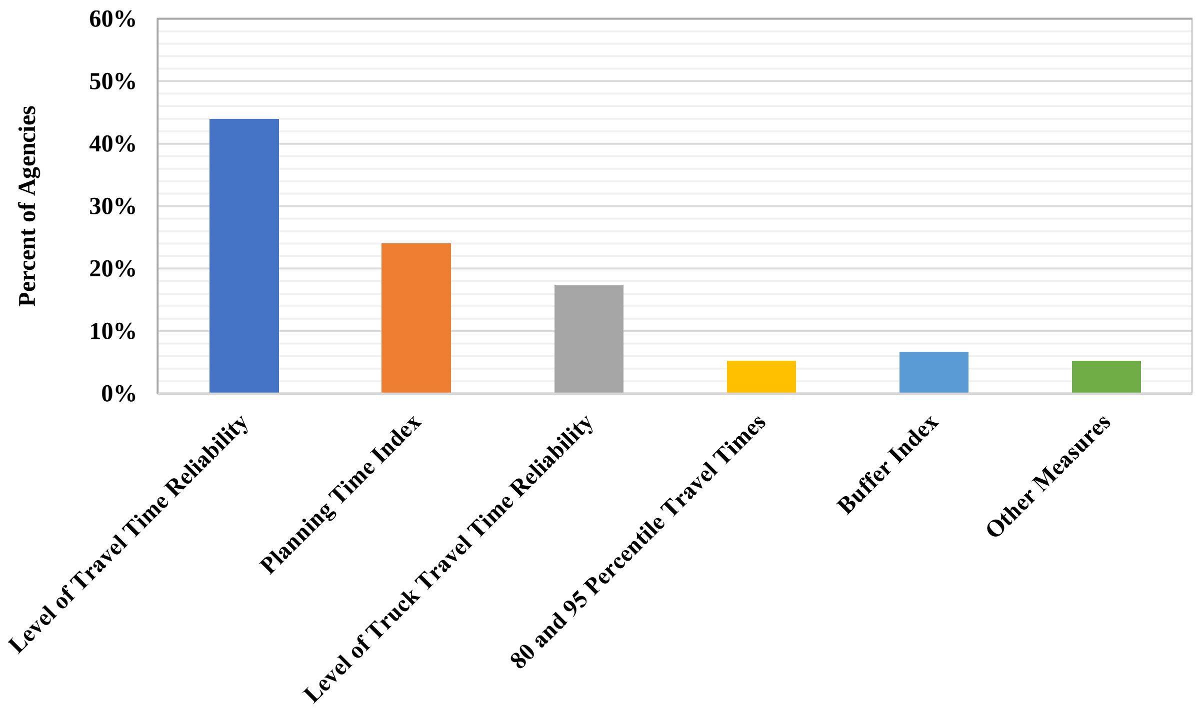
Figure 3-1 Spatial distribution of the survey respondents (a) State DOTs, (b) MPOs, (c) Either state DOT or an MPO, and (d) State DOTs covered in the nationwide survey or the literature review task

In addition, calculation of several measures such as level of travel time reliability (LOTTR) is federally required, so state DOTs are using these measures in their performance measurement, which results in a high frequency for them. Note that the frequency is not 100% for the federally required measures, because the survey respondents include major MPOs in addition to DOTs. Although the delay-based measures are known to be more informative than traditional measures such as volume-to-capacity ratio, they are less frequently reported than the data element measures such as average speed and average travel time. The project team hypothesizes that this is because some agencies are holding onto traditional measures due to lack of system-wide data and/or resources to compute the measures at the system level. Thus, the frequencies provide a “snapshot” of the state-of-the-practice by various state agencies.

A list of other, less frequently used measures is provided in Table 3-1 and subsequent figures (indicated as “Other Measures”). In Table 3-1, measures in *italics* include the predefined set of measures included among the response choices, while the other measures were added manually by the respondents. Note that the reported percentage values reflect the number of state DOTs and MPOs among the total number of agencies responded to the survey (75 DOTs and MPOs).



(a)



(b)

Figure 3-2 Percent of agencies using each of the (a) mobility and (b) reliability measures ("Other Measures" are listed in Table 3-1)

Table 3-1 List of less frequently used performance measures by the agencies ("Other Measures" in Figures 3-2a and 3-2b)

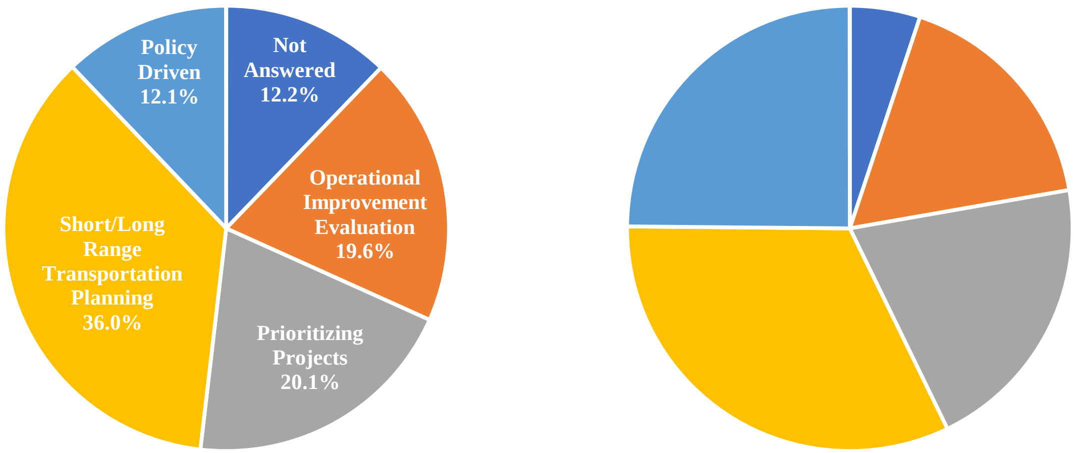
Type	Measure	Percent
Mobility	*Total Delay Cost*	*8*
	Density	*4*
	Delay per Mile	*2.7*
	Total Wasted Fuel Cost	*1.3*
	Bottleneck Locations	4
	AADT to Capacity Ratio	1.3
	Delay per Person	1.3
	Bus Ridership	1.3
	Percent Below Free-flow Speed	1.3
	Average Commute Time	1.3
	Truck Delay Cost	1.3
Reliability	Transit On-time Performance	2.7
	On-time Arrival	1.3
	Incidence Clearance Time	1.3

3-3-4 Applications of Performance Measures

Figure 3-3a and Figure 3-3b illustrate the overall response rate of the agencies for the applications of the mobility measures and reliability measures. Note that the respondents were able to choose multiple applications for each of their selected measures. The definition of each application is as follows:

- The performance measure is used for assessing the financial policies for allocating funds across programs and prioritizing the projects (Prioritizing Projects).
- The performance measure is used for monitoring the efficiency and effectiveness of projects (Short/Long Range Transportation Planning).
- The performance measure is used for improving situational awareness and identifying trends (Operational Improvement Evaluation).
- Your agency is required to assess the performance measure (Policy Driven).

As illustrated in these figures, expectedly, the most selected application for the measures is for short-/long-range transportation planning (36% for mobility measures and 32% for reliability measures). Also, it can be concluded from these figures that 24.8% of the responses for the applications of the reliability measures are policy-driven, which is higher than the equivalent application for the mobility measures (12%).



(a) (b)

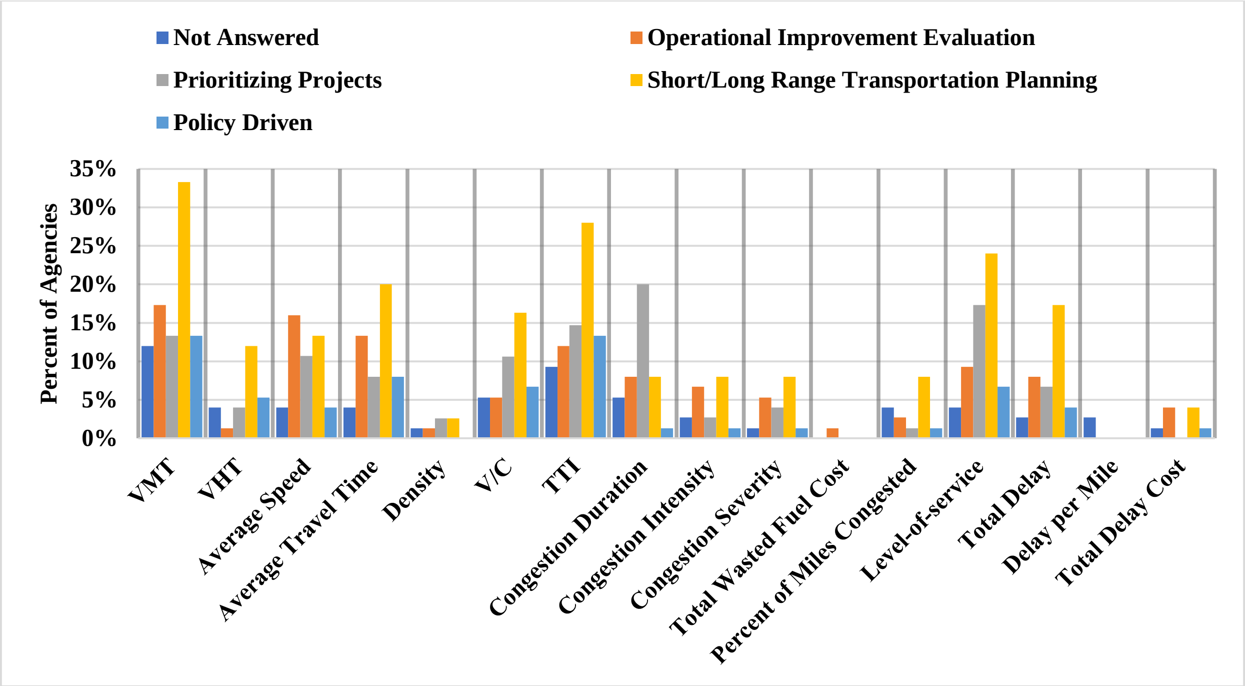
Figure 3-3 Overall response rates for the applications of the (a) mobility and (b) reliability measures

Figure 3-4 presents the response rate for the applications of particular measures that are commonly used by agencies. By comparing the response rate for the applications of each measure and the overall response rates (Figure 3-3), the most frequently used measures for each of the applications were determined, which are presented in Table 3-2. Also, Figure 3-5a and Figure 3-5b present the percent of agencies using each mobility and reliability measure for particular applications, respectively.

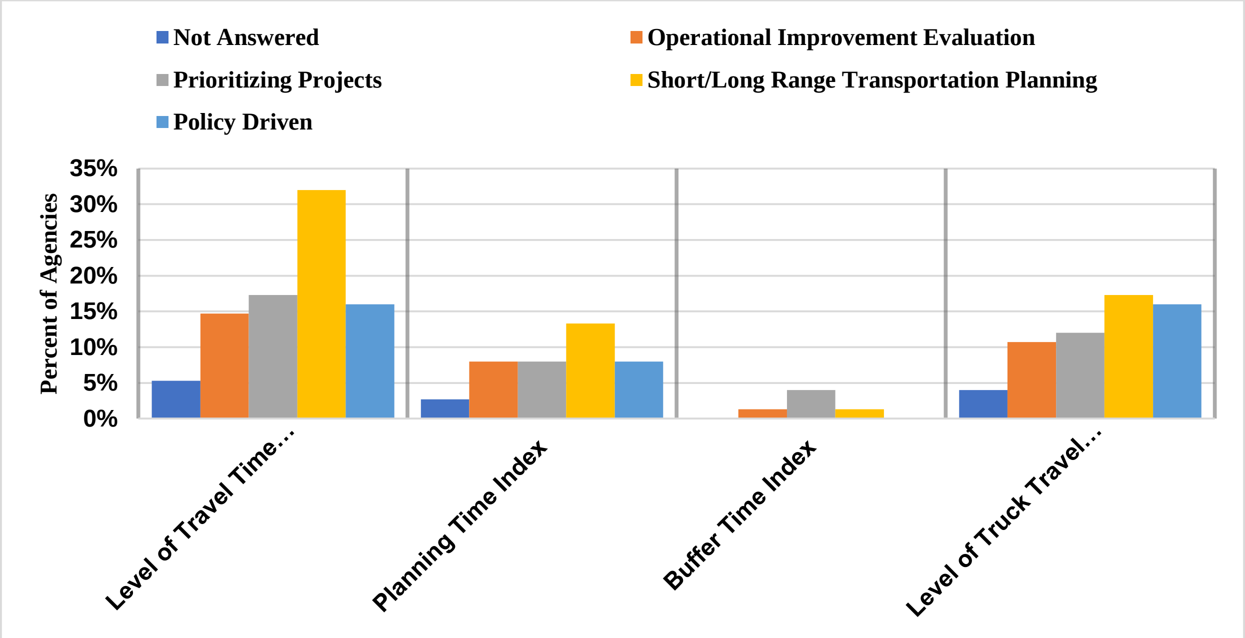
Figure 3-4 Number of agencies that incorporate (a) VMT, (b) TTI, (c) Total Delay, and (d) LOTTR for different applications

Table 3-2 Most frequently reported performance measures for each application

Type	Application	Most Frequent Measures
Mobility	Operational Improvement Evaluation	Vehicle-miles Traveled, Average Speed, Average Travel Time
	Prioritizing Projects	Level-of-Service, Congestion Duration
	Short/Long Range Transportation Planning	Vehicle-miles Traveled, Average Travel Time, Total Delay
	Policy Driven	Average Travel Time, Travel Time Index
Reliability	Operational Improvement Evaluation	Planning Time Index, Level of Truck Travel Time Reliability
	Prioritizing Projects	Planning Time Index
	Short/Long Range Transportation Planning	Planning Time Index, Level of Travel Time Reliability
	Policy Driven	Level of Truck Travel Time Reliability



(a)



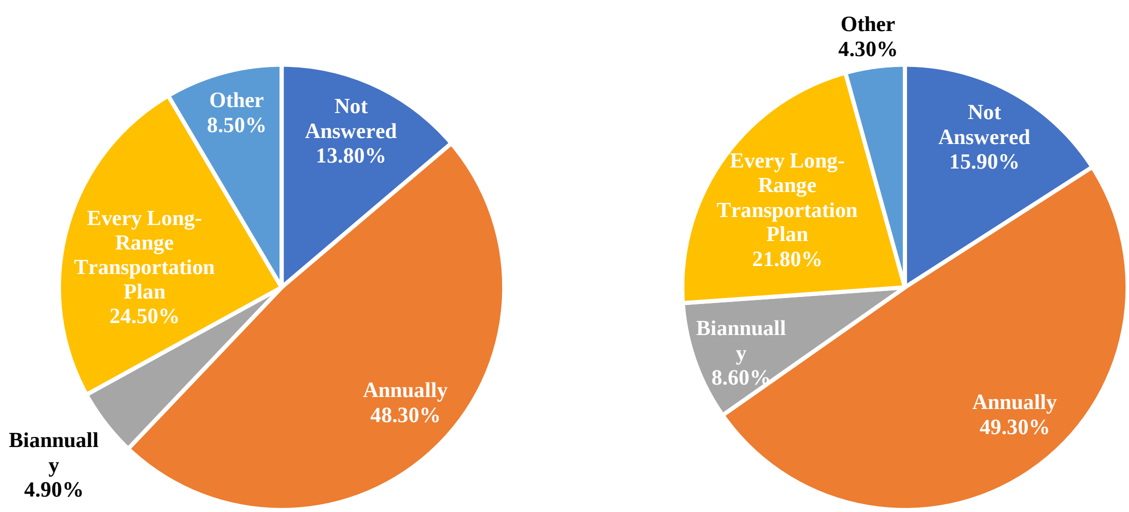
(b)

Figure 3-5 Percent of agencies using each (a) mobility and (b) reliability measure for different applications

As stated in the previous section, the more frequent use of a measure for an application does not indicate that it is more suitable for the purpose. As an example, according to Figure 3-4, LOS is frequently used for short/long range transportation planning. However, this measure is too qualitative and can be substituted with other more informative measures such as delay-based ones.

3-3-5 Assessment Period of the Performance Measures

Respondents were also asked about the periods over which each performance measure target is computed (e.g., quarterly, annually, etc.). The overall response rate for the calculation frequency of the mobility and reliability measures are presented in Figure 3-6a and 3-6b, respectively. According to these figures, most of the measures are assessed annually by the agencies (48% for mobility measures and 49% for the reliability measures). Figure 3-7 presents the response rate for the assessment period for the commonly used measures by the agencies.



(a) (b)

Figure 3-6 Overall response rate for the assessment period of the (a) mobility and (b) reliability measures

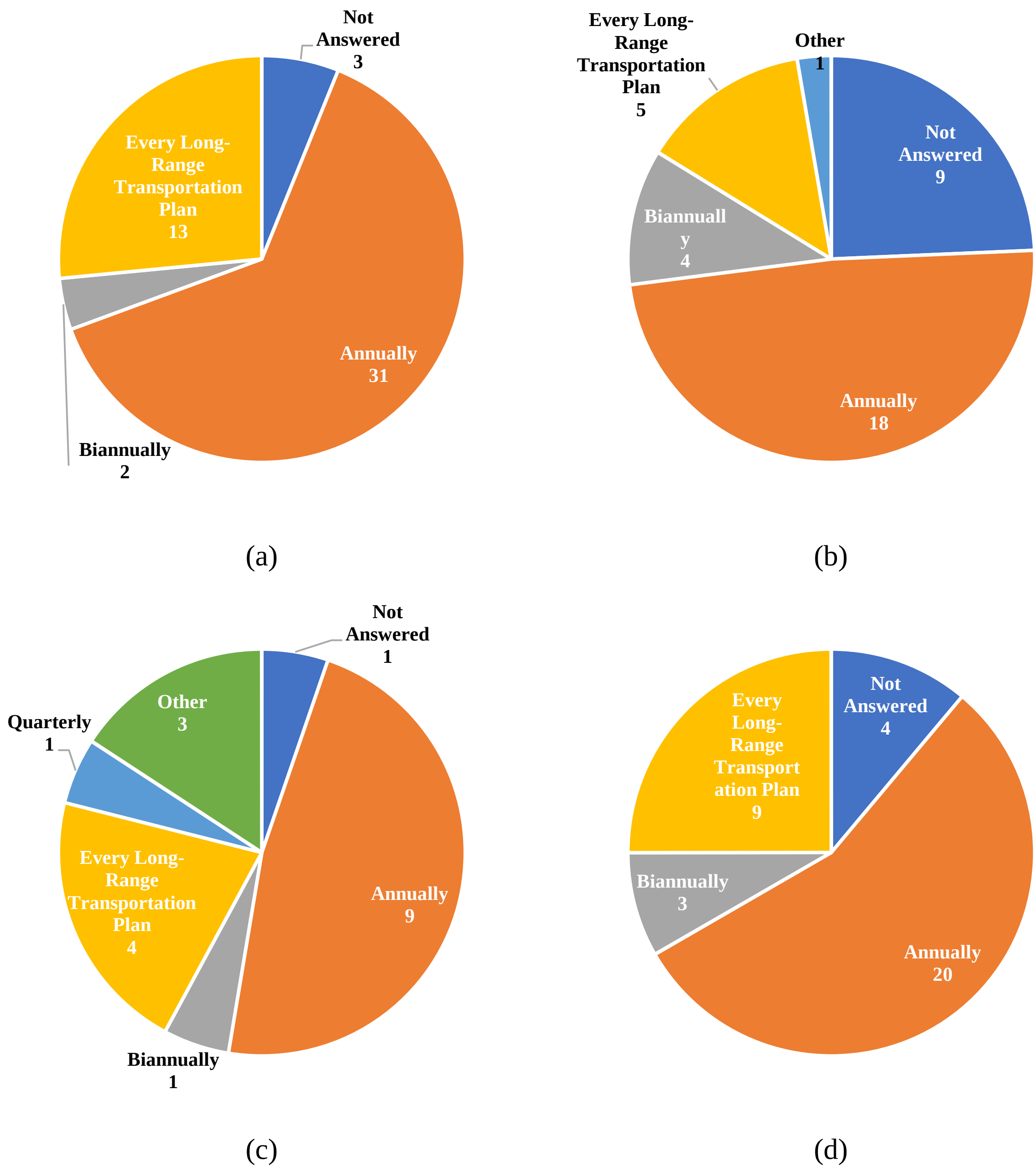
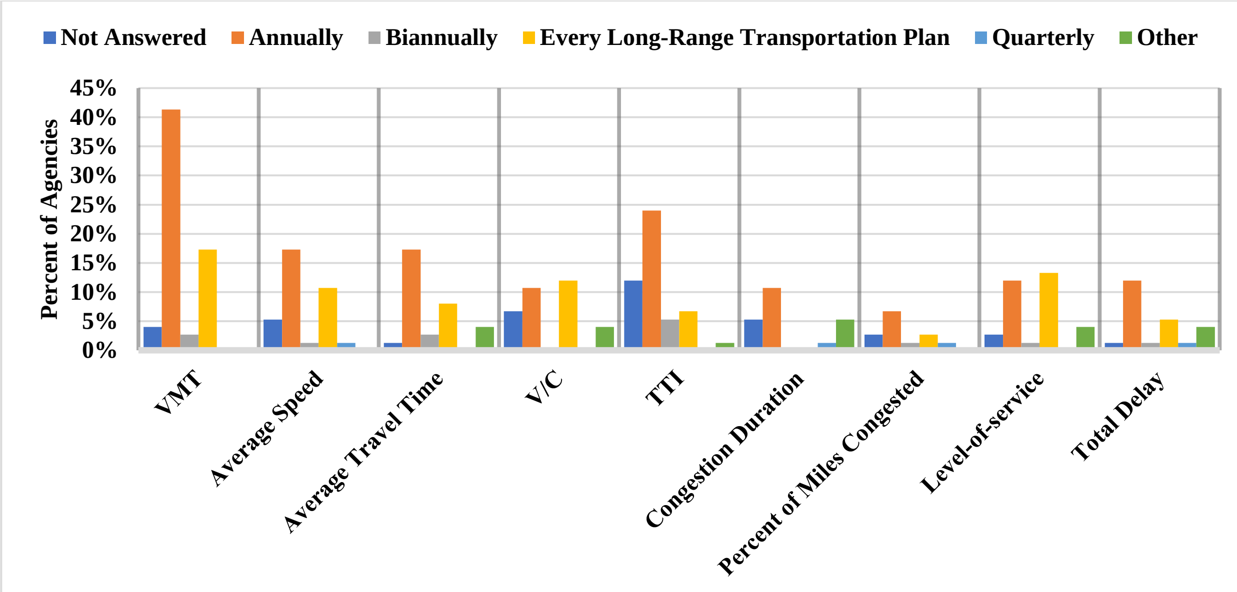
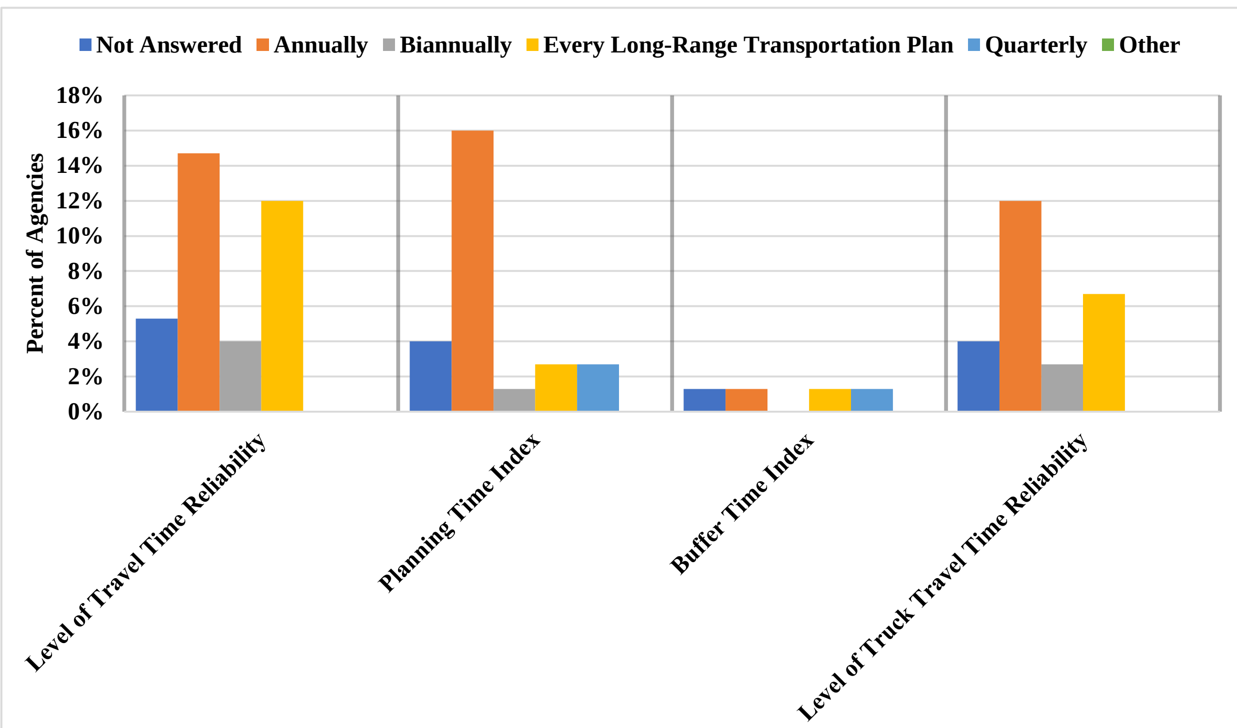


Figure 3-7 Number of responses for each assessment period (a) VMT, (b) TTI, (c) Total Delay, and (d) LOTTR

Also, Figure 3-8a and Figure 3-8b present the percent of agencies assessing each mobility and reliability measure for different assessment periods, respectively.



(a)



(b)

Figure 3-8 Percent of agencies assessing each (a) mobility and (b) reliability measure over different assessment periods

3-3-6 Time Period and Vehicle Type for Which Performance Measures are Calculated

Figure 3-9 illustrates the number of responses reported by agencies for each time period over which the performance measures are calculated. These numbers are reported for the most frequently used performance measures. As can be seen in Figure 3-9b and Figure 3-9c, TTI is more often calculated for peak hour, and total delay is more often calculated for peak period. Also, the summary of the concluding remarks is provided in Table 3-3.

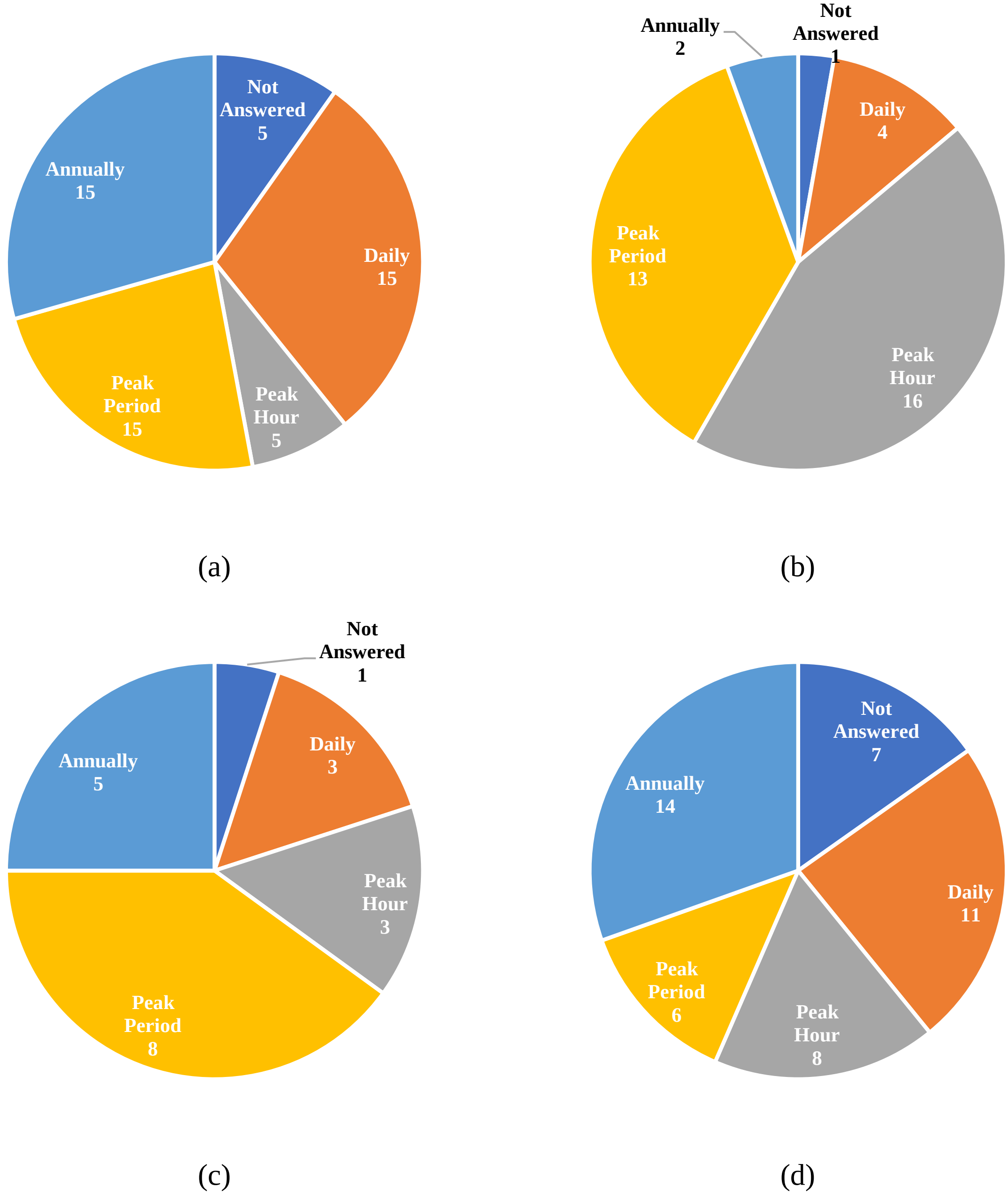


Figure 3-9 Number of responses for each calculation time period (a) VMT, (b) TTI, (c) Total Delay, and (d) LOTTR

Table 3-3 Most frequently reported performance measures for each calculation time period

Type	Calculation Time Period	Most Frequent Measures
Mobility	Peak Hour	Travel Time Index
	Peak Period	Average Speed, Average Travel Time, Total Delay
	Daily	Vehicle-miles Traveled, Average Travel Time
	Annually	Vehicle-miles Traveled, Total Delay
Reliability	Peak Hour	Planning Time Index
	Peak Period	Planning Time Index
	Daily	Level of Travel Time Reliability, Level of Truck Travel Time Reliability
	Annually	Level of Travel Time Reliability, Level of Truck Travel Time Reliability

In addition, Figure 3-10 presents the number of responses reported for the vehicle type combination for which the performance measures are calculated. These numbers are reported for the most frequently used measures by the agencies. As shown in these figures:

- Most of the measures are calculated for “all vehicles together” or “trucks and passenger vehicles separately.”
- Only a few agencies calculate the measures for “trucks only”.
- Out of 34 agencies using TTI, 7 responded that they calculate this measure for “passenger vehicles only.”
- No agency reported that it calculates the PTI for trucks.

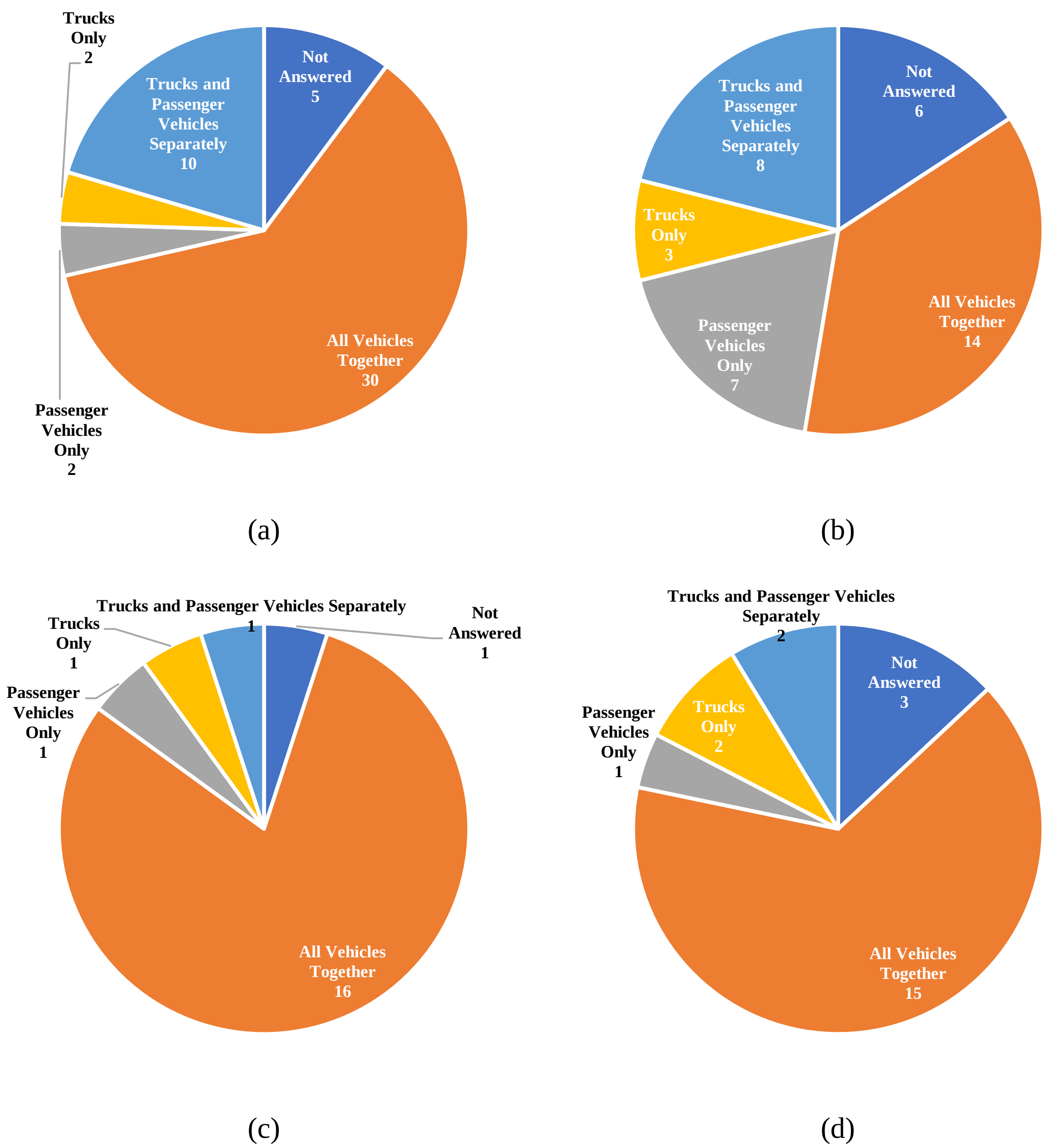


Figure 3-10 Number of responses for each Vehicle type (a) VMT, (b) TTI, (c) Total Delay, and (d) LOTTR

3-3-7 Data Sources Used by Other Agencies to Calculate/Estimate the Performance Measures

Figure 3-11 shows the percent of agencies using each of the data sources for different performance measures. Also, the list of less frequently used data sources is provided in Table 3-4. In this table, the data sources in *italic* font style were accommodated in the predefined set of measures to be chosen by the respondents, and the non-italics data sources were added manually by the respondents. As it is mentioned in this table, 21.3% of the respondents did not specify the data sources they use to calculate the measures. Also, as shown in Figure 3-11, In-house Traffic Count Data, INRIX, and NPMRDS are the data sources that are most frequently used by agencies for performance measurement.

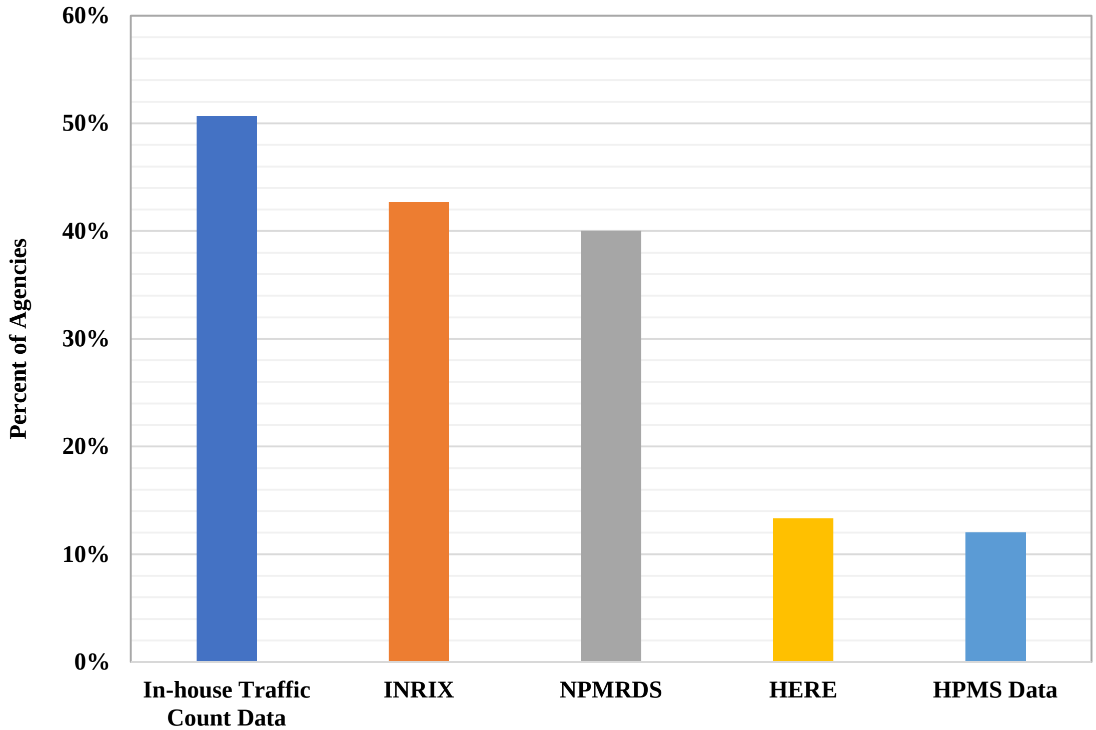


Figure 3-11 Percent of agencies using each data source

Table 3-4 List of less frequently used data sources by the agencies that are not listed in Figure 3-11

Data Source	Percent of Agencies
Not Answered	*21.3*
ATRI	*1.3*
Data Source Specific to Agency	6.7
State Traffic or Travel Demand Model	6.7
GPS Speed Data	1.3
Bluetooth Data	1.3

Figure 3-12 presents the number of reported responses for each data source or combination of data sources to calculate the most frequently used performance measures by the agencies. Note that the respondents were able to choose multiple data sources that they use together to calculate the measures. It can be concluded from these figures that multiple data sources are used together to calculate the performance measures based on their features and availability to the agencies. For example, for volume to capacity ratio, in-house traffic count data are the most frequently used data source, which provides the volume on the roadways.

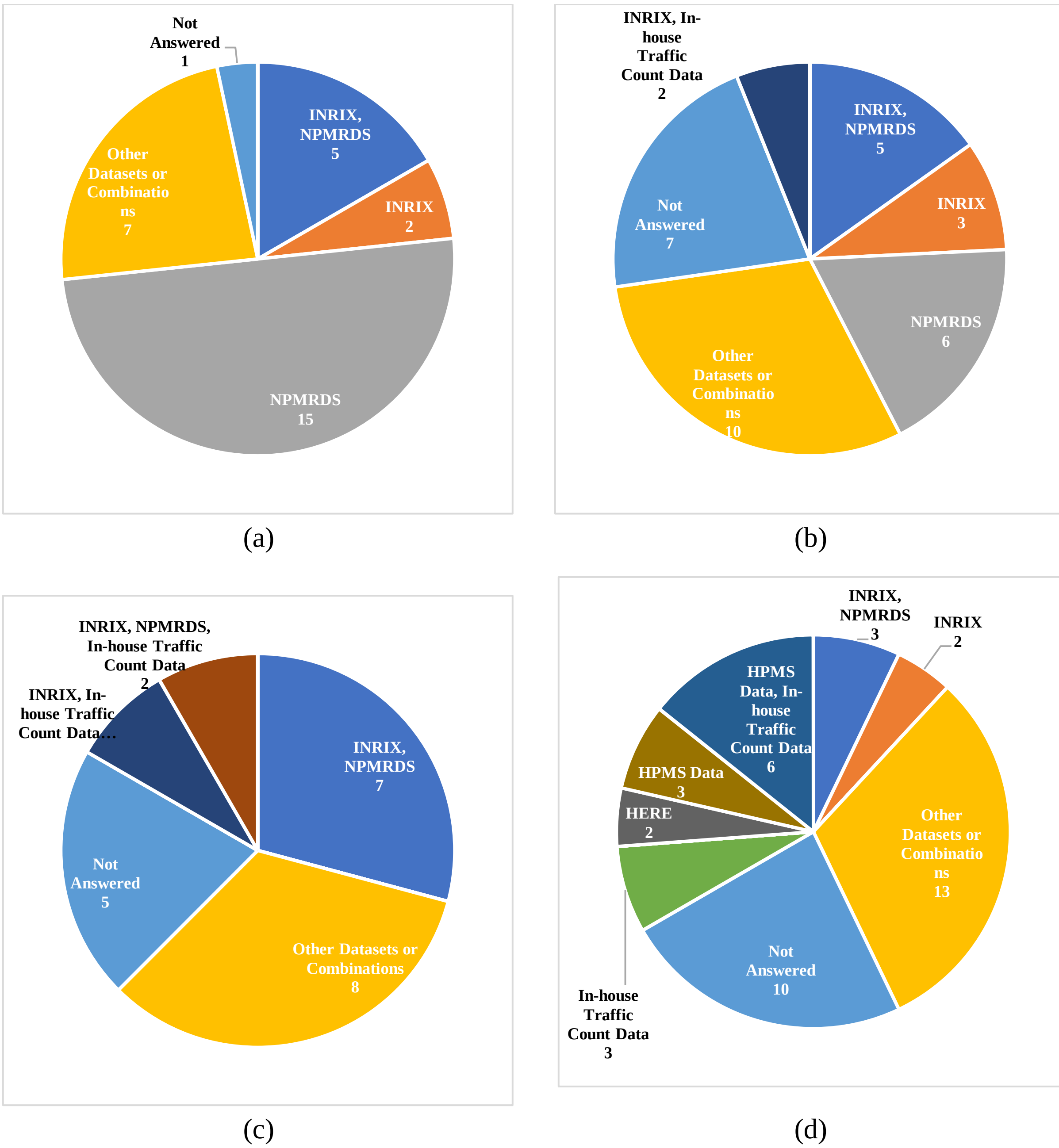


Figure 3-12 Number of responses for each combination of data sources used by agencies to calculate (a) VMT, (b) TTI, (c) Total Delay, and (d) LOTTR

3-3-8 Current Practices in Publishing and Reporting the Performance Measures

The respondents were also asked about the method they use to publish and report their performance measures. The percent of agencies using each of the methods and tools for reporting the measures are illustrated in Figure 3-13. Also, the list of less frequently used methods by respondents is also presented in Table 3-5. As shown in Figure 3-13, 26 agencies responded that they have a public website for reporting the measures, out of which 18 have an online performance dashboard and 8 provide interactive maps. In addition, the respondents were asked to determine the audience of their reports, and their responses are provided in Figure 3-14.

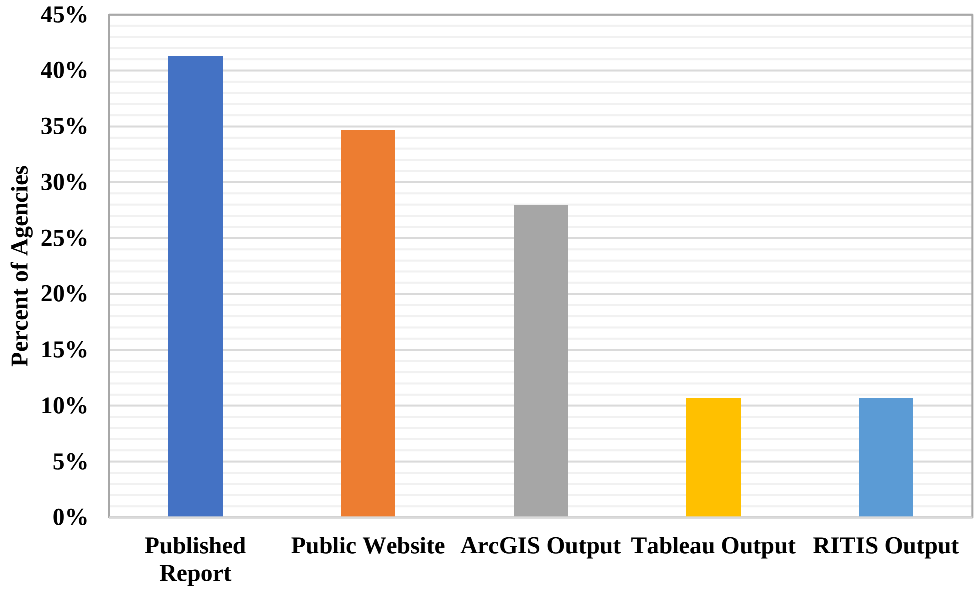


Figure 3-13 Percent of agencies using each of the publishing and reporting methods

Table 3-5 List of Less frequently used publishing and reporting methods by the agencies that are not listed in Figure 3-13

Response	Percent of Agencies
Not Answered	*24*
Python Output	*1.3*
Microsoft Power BI Output	*2.7*
Output of Other Agency Software	*1.3*
Google Data Studio	1.3
R Output	1.3
Trans CAD Output	1.3

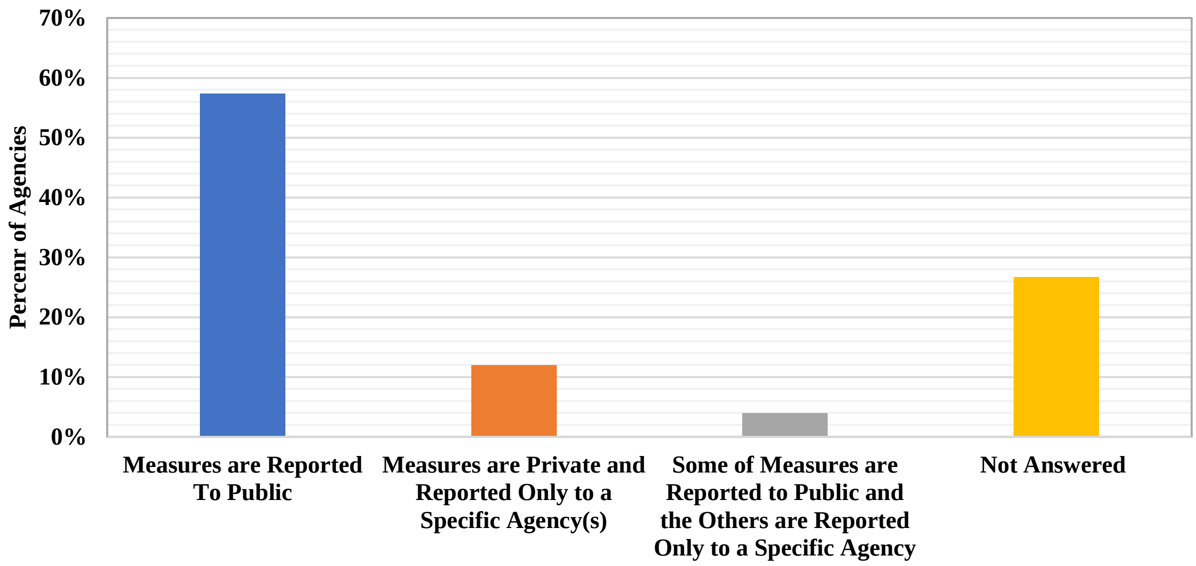


Figure 3-14 Percent of agencies that report performance measures for each category of audience

3-3-9 Recommendations and Lessons Learned from Survey Respondents

State DOTs were also asked if they have any comments, recommendations, and lessons learned for roadway system performance measurement. Their recommendations are categorized into four main groups as listed below:

1. Performance Measures
   - In some cases, agencies seek to use performance measures specific to their area, resources, and travel patterns (e.g., special events, high tourist locations, etc.).
   - The FHWA Congestion Management Process guidebook (Grant et al., 2011) provides useful information for agencies to develop their performance measurement system and transportation improvement plan.
   - It is important to include multimodal measures (e.g., mode share and pedestrian delay) in the performance management process.
   - Agencies tend to use a small set of measures that can be easily used and supported.
   - Measures such as volume to capacity ratio no longer serve the needs as the congestion level grows in transportation networks. This calls for using more informative measures that capture various aspects of congestion and reliability.
2. Communication between Agencies and Staff:

- Agencies are inclined toward conducting the performance measurement process themselves in the long run, instead of using consultant services to ensure consistency, reduce costs, etc. However, this requires significant initial investment in terms of tools and qualified staff.
- It is beneficial to promote communication and cooperation between different departments of public agencies for performance measurement. Dedicating a central agency office to oversee the performance management of different departments (e.g., safety, mobility, asset management, maintenance), and integrating common software, platforms, and data sources as part of the agency culture are recommended.
- Including MPOs in target setting and performance measurement methodology workshops provides them with a great opportunity to provide valuable local input.
- To improve the performance measurement system, resources are needed to obtain data and obtain and keep skilled technical staff.

3. Data Source and Data Quality:

- The INRIX data source provides the travel time data on local roadways in addition to NHS, which helps the agencies interested in local roadway performance measures.
- Agencies tend to work with RITIS due to its simple interface.
- Switching between different data sources and vendors entails significant challenges for agencies in conducting before/after studies and time-series reporting.
- It is important to quality control the raw data regularly to validate the calculated and reported performance measures.
- State DOTs are mainly responsible for purchasing and providing the datasets to the MPOs.
- Building (or using a cloud software as a service) centralized data warehouse is recommended.

4. Publishing and Reporting the Measures:

- Clarifying and communicating performance measures in an understandable way to non-technical audiences is critical.

- Moving from printed performance reports to an online performance dashboard improves communication and transparency and promotes broad application of performance measures.
- Evolving and updating the performance measures and analysis tools are important due to constant adaptation of the data and the transportation planning and operation practices.

CHAPTER 4 – REVIEW OF MDOT CURRENT/HISTORICAL PRACTICES

In this chapter, the research team details the evolution of MDOT's operational performance management practices. Using available online resources and feedback from MDOT, this chapter also provides input for the upcoming MDOT staff interviews (Task 4). The remainder of this chapter is as follows. First, a review of the MDOT studies regarding operational performance management is presented. Then the research team provides a review of the Annual Sufficiency Reports. This is followed by a review of the MDOT PM3 Reports. Then, the Annual Freeway Congestion and Reliability Reports and Arterial Performance Reports are reviewed. Finally, the features of the RITIS tool are explained.

4-1 Review of the Operational Performance Management Studies in Michigan

MDOT started emphasizing performance-based approaches for evaluating its transportation system congestion in 1998 (MDOT, 1998). The measures used at that time included LOS, percent of VMT at the acceptable LOS, and design-hourly volume (30^{th} highest hour). The data used for calculating measures were provided by the database of the Transportation Management System (TMS). Since then, MDOT has advanced its performance-based management, and the evolution of the performance-based planning at MDOT reflects a focus on transparency and accountability to the public as well as strategic decision-making for investments. The next major step in this regard was developing the MI Transportation Plan Moving Michigan Forward, known as the MI long-range transportation plan, the objectives and core performance measures for which were determined in 2005 (MDOT, 2005). This plan allowed MDOT to track progress toward addressing transportation needs and challenges for the next 25 years. The updated versions of the MI long-range transportation plans were published in 2012 and 2016, which reflected the enactment of MAP-21. The latest version of this report is the Michigan Mobility 2045 (MM2045) state long-range transportation plan that was adopted in November 2021 (MDOT, 2021). In addition to the long-range plans, MDOT publishes five-year transportation programs, in which the MDOT priorities are defined, and available funding and timetable for delivery of various projects are presented (FHWA, 2014).

Also, in 2010, MDOT began the MI Dashboard online feature, which presented changes in the transportation-related measures in the areas of safety, mobility, and infrastructure conditions. In

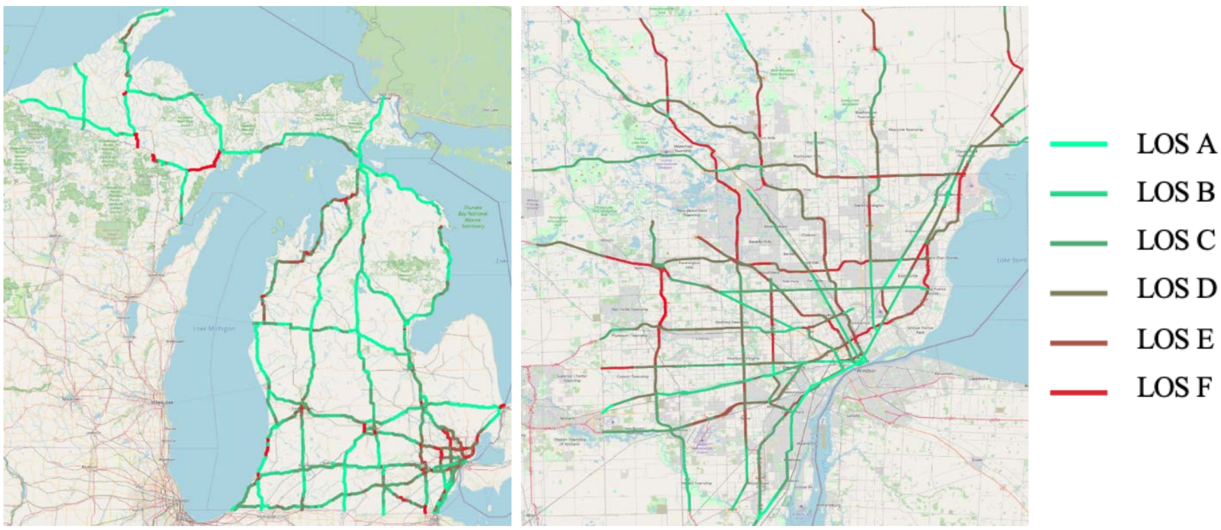
2011, MDOT started to publish the Mi-Scorecard to the public, which includes the state legislative measures with their associated targets, but it does not include the operational performance measures (MDOT, 2019b). Also, in 2011, in cooperation with Texas A&M Transportation Institute (TTI), MDOT published A Michigan Toolbox for Mitigating Traffic Congestion (Crawford, Carlson, Eisele, & Kuhn, 2011). In this report, 47 congestion mitigation strategies in two categories of supply management and demand management were presented, which were based on the operational performance measures. Additionally, in 2012 MDOT started publishing the State Transportation Improvement Program (STIP) annually that includes the list of the projects that the state proposes to fund with federal aid (MDOT, 2020).

Then, in 2013, MDOT examined using user delay cost as the primary measure for operational performance management (Kratofil, Geib, & Cook, 2013). This study concluded that using this measure as the primary measure is more beneficial than using travel time reliability, due to its capability to incorporate non-recurring traffic incidents. The conclusions of this study are reflected in the earlier versions of the MDOT Freeway Congestion and Reliability Reports, which are thoroughly reviewed in section 4-4 (MDOT, 2019a). Moreover, MDOT has also been involved in various federal programs regarding performance management. As an example, MDOT hosted a peer exchange with FHWA in 2015 for establishing and integrating the performance measures (Middleton, 2015). This exchange program aimed to assist local agencies and MPOs in preparing for the rulemaking under the MAP-21 act and to provide guidelines for developing the measures and setting their associated targets.

4-2 Review of the Annual Sufficiency Reports

Through 2015, roadway inventory data were provided in the Annual Sufficiency Reports, which were formatted similar to the HPMS data. The latest Annual Sufficiency Report, published in 2015, contained information for 7,620 highway segments (12,685 pavement miles) on the Michigan trunkline system. Each homogeneous highway segment was associated with a physical road number and beginning/ending mile points allowing integration with the MDOT Linear Referencing System (LRS). Sufficiency information provided for each highway segment included the area type and characteristics, route designation and geometric characteristics, pavement conditions and characteristics, crash rates, and traffic operations characteristics. Mobility-related information included the annual average daily traffic (AADT), designed hourly volume (DHV), cluster (seasonal factor), and traffic expansion factor (annual change in volume) data for each segment. Also provided were the two operational performance measures, volume-to-capacity ratio and level-of-service (LOS), calculated based on the Highway Capacity Manual Methodology. Figure 4-1a and Figure 4-1b present the state-wide and Metro Region LOS based on the data of the Sufficiency Report published in 2015.

This report is no longer published, and data other than volume-to-capacity ratio and LOS are reported through other MDOT resources. Speed data are reported in real-time through Mi Drive, which also provides information regarding lane closures and special events[1]. Moreover, in 2016, MDOT used the data of the Sufficiency Report published in 2015 to calculate the percent of miles uncongested (based on LOS) and its predicted value through 2040.



(a) (b)

Figure 4-1 LOS (a) state-wide map (Interstate and US Highways) and (b) Metro Region (Interstate, US Highways, and State Routes) based on the Sufficiency Report 2015

4-3 Review of the Annual PM3 Reports

To fulfill the federal requirements after the enactment of MAP-21, MDOT has been reporting the PM3 measures to USDOT. The PM3 measures reported by MDOT include:

- Average vehicle occupancy for cars, buses, and trucks
- 50th percentile and 80th percentile travel times for cars and trucks, separately
- Level of travel time reliability (LOTTR)
- Level of truck travel time reliability (TTTR)

[1] https://mdotjboss.state.mi.us/MiDrive

The LOTTR and TTTR are reported for the AM peak period, PM peak period, and midday peak period. TTTR is also reported for the overnight period. MDOT is currently using the NPMRDS data, INRIX data, and RITIS tool to calculate the PM3 measures. Also, the 2-year and 4-year targets for PM3 measures are reported in the MDOT Biennial National Performance Program Target Summary.

4-4 Annual Freeway Congestion and Reliability Reports

Since 2014, MDOT has used probe vehicle data to publish the Annual Freeway Congestion and Reliability Report (MDOT, 2019a). Due to the difficulty of managing, maintaining, and analyzing the enormous amount of data provided by probe vehicles, MDOT started using the RITIS tool for these reports, which enables monitoring of speeds, incidents, weather, special events, and other data sources. The RITIS tool has been used to download the raw data, and it is managed externally to calculate the measures and visualizing them in these reports. These reports have been used internally to help MDOT regions expand their knowledge on how the Michigan freeways are operating, and where potential improvement projects may be necessary. In effect, The LOTTR that is reported in these reports is used alongside PTI and TTI measures in the MDOT Operations Template for project prioritization process. In addition, these reports assist transportation planners in identifying congested areas, when and how often congestion occurs, and also the corridor rankings based on their congestion. These reports have been prepared through a research contract under the guidance of the MDOT Congestion and Reliability Unit. This contract includes accessing the probe data, accessing the analytical tool, and developing the report.

To get further insights into the Annual Freeway Congestion and Reliability Reports and identify the MDOT needs, the MSU research team met with the MDOT staff responsible for preparing these reports. The Annual Freeway Congestion and Reliability Reports contain eight chapters. The first chapter summarizes the performance measures used in the report, and the remaining seven chapters present those performance measures in each of the MDOT seven regions, including Bay, Grand, Metro, North, Southwest, Superior, and University regions. The following nine performance measures are provided in this report, with their definitions, thresholds, calculation methods, and reporting methods:

- Delay
- Delay index
- Maximum delay

- Average speed
- Congestion severity
- Travel time reliability
- Average travel time
- 95th percentile travel time
- Level of travel time reliability

Note that the definitions of the measures might differ from their traditional ones. Please refer to the reports for the specific definitions of the measures.

In earlier reports, user delay cost was used as the primary measure, though this measure was eliminated due to concerns related to data uncertainty. In recent reports, delay index is considered as the primary performance measure, and the top 30 freeways in each region, ranked based on this measure, are presented. The amount of congested miles per region is also provided for both AM and PM peak periods. Moreover, in these reports, five visualization techniques are provided, which can be classified into three categories, including:

- State-wide color-coded maps for each of the performance measures
- Region-level color-coded maps for each of the measures
- Corridor-level figures for the segment of the freeways within each region

It should be noted that in these reports, the performance measures are reported at the corridor-level, instead of using the Traffic Message Channels (TMCs), to keep the report length manageable. However, TMC-level data can be acquired using the RITIS tool, if needed.

4-5 Annual Arterial Performance Reports

Similar to the Freeway Congestion and Reliability Reports, this recently developed report is proposed to provide a snapshot of the Michigan arterials throughout the state. Unlike the Freeway Congestion and Reliability Report, this report is not publicly available yet, and is used only for internal purposes at MDOT. The performance measures presented in these reports are grouped by varying time periods and days of the week using the spatially mapped XD probe data from INRIX. The individual corridors are identified by the Signal Grouping ID, which is a unique and dynamically assigned naming convention. The performance measures presented in this report include:

- Planning time index (PTI)

- Buffer index (BI)
- Travel time index (TTI)
- Level of travel time reliability (LOTTR)
- 80^{th} percentile travel time

Similar to the Freeway Congestion and Reliability Reports, the definitions of the measures might differ from their traditional ones. Please refer to the reports for the specific definitions of the measures.

The time periods for which the performance measures are calculated in this report include AM peak period, midday peak period, PM peak period, and weekends. Also, the arterial rankings are based on the average values of the TTI, PTI, and LOTTR. In addition, this report presents a set of factors that cause the travel times to be unreliable, which includes incidents, inclement weather, work zones, special events, traffic control device timing, demand fluctuations, and inadequate base capacity. Also, common applications for each of the performance measures are provided. The annual average values for each of the measures between 2017 and 2019 and the changes of the measures between these years are provided for the arterials and the region-level color-coded maps.

4-6 RITIS Tool

As mentioned earlier, most of the MDOT work areas use the RITIS tool, which is powered by the INRIX data to calculate and report the performance measures. This tool is an automated data sharing, dissemination, and archiving system, which includes many performance measures and visual analytics tools to communicate information between agencies and to the public. The features of this tool include real-time data feeds, real time situational awareness tools, and archived data analysis tools. The MSU research team received access to the RITIS tool and explored its capabilities for performance management. The PM3 measures can be calculated and reported in this tool as built-in measures. The time periods for the calculation of the measures can be daily, monthly, and annually, with the capability to limiting to specific days of week. The aggregation of the data can be chosen from 5-min, 10-min, 15-min, and 1-hour. Figures 4-2 and 4-3 are videos that illustrate the planning time index and buffer time index measures as examples for the Michigan trunkline segments at different hours of the day, averaged over 2021.

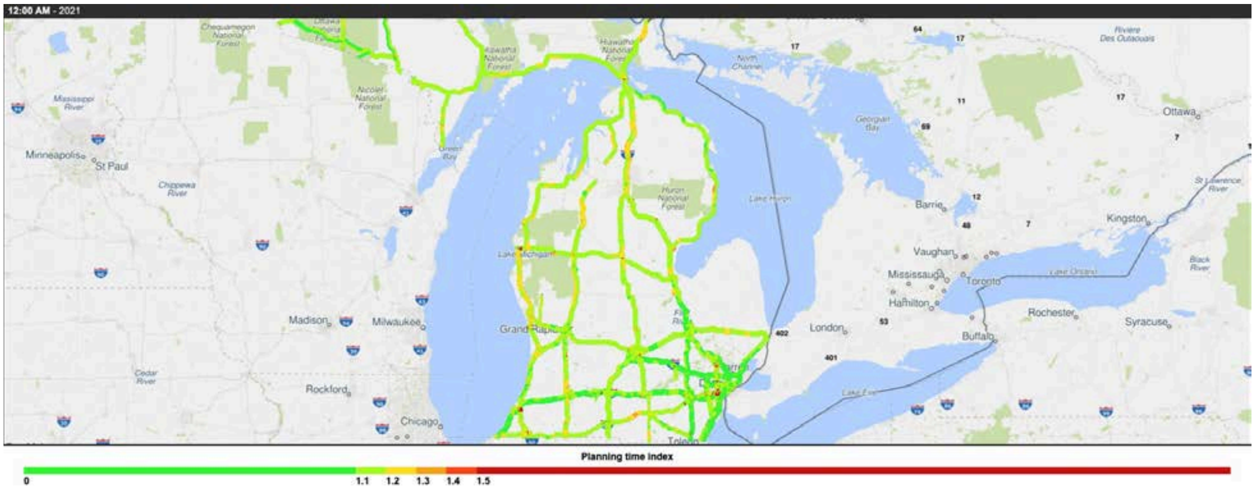


Figure 4-2 Planning time index for Michigan trunkline segments at different hours of day, averaged over 2021

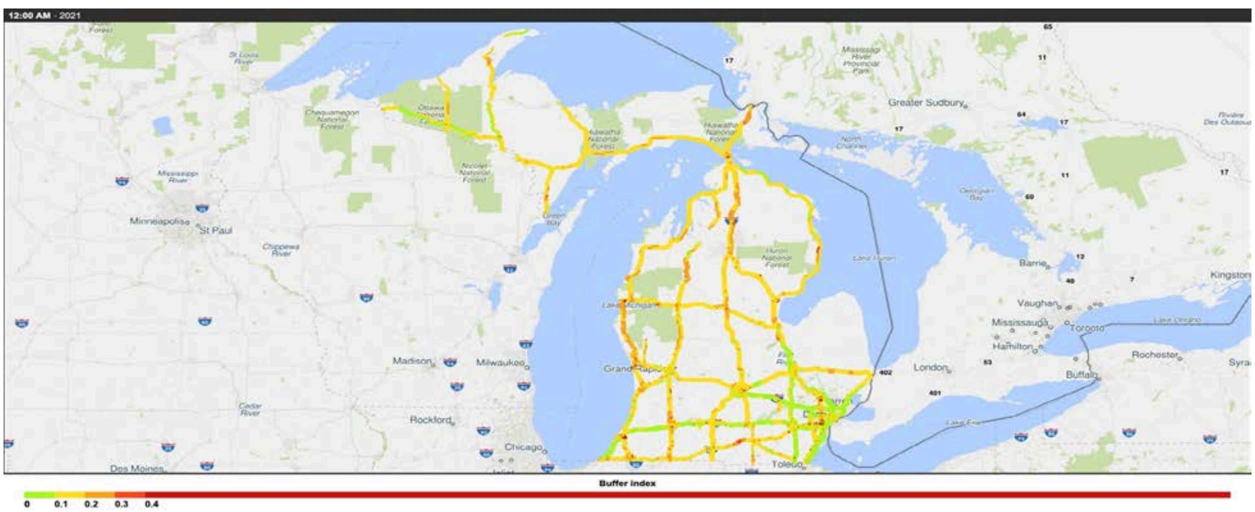


Figure 4-3 Buffer time index for Michigan trunkline segments at different hours of day, averaged over 2021

CHAPTER 5 – MDOT STAFF INTERVIEWS

5-1 Purpose

The performance measures are used for various applications, and consequently, current needs and practices regarding the performance assessment vary among different MDOT work areas. Thus, MDOT staff should be inquired directly to thoroughly identify these needs. To this end, the pertinent staff from selected MDOT work areas were interviewed. To do so, a questionnaire was developed and implemented, in which the questions and discussions were determined based on the findings of the previous tasks, with particular emphases on system planning performance measures. The outputs of these interviews, along with results from the previous tasks,

were used as the main input to Task 7 to recommend the most appropriate performance measures for the Michigan trunkline system.

The main goals of these interviews were to identify:

- Frequent performance measures used by different MDOT work areas
- Definition, threshold(s) and target values for currently used performance measures
- Data sources used for calculation and estimation of currently used performance measures
- Current practices and approaches in publishing, reporting, and communicating performance measures
- Tools, methodologies, and platforms used for data analyses
- Costs associated with the data collection, storage, and analysis
- Critical concerns and needs regarding the MDOT performance assessment system

5-2 Interview Contents Design and Administration

The research team developed a questionnaire to investigate the MDOT work areas' current needs and practices for performance assessment. The questionnaire was designed and implemented in a web-based format through Qualtrics platform. The topics and questions included were developed based on the previous tasks and were revised based on the MDOT feedback, and sought the following information:

- Sets of performance measures used by MDOT work areas (definitions, thresholds, and applications)
- Critical concerns regarding the use of the performance measures

- Main reasons for using the traditional performance measures, including, volume-to-capacity ratio and level-of-service
- Use of the values of the performance measures reported by the MDOT Operations Unit, in the Annual Freeway Congestion and Reliability Reports and Annual Arterial Performance Reports
- Data sources used for calculation and estimation of currently used performance measures, as well as access to these data sources, and cost assessment associated with the data collection, storage, and analysis
- Current practices and approaches in publishing, reporting, and communicating performance measures
- MDOT current needs regarding the performance assessment system
- Suggestions and recommendations regarding the system planning performance management

The contact list of the associated staff to be interviewed was provided by the MDOT Research Advisory Panel (RAP) to the research team, and the targeted MDOT work areas included:

- Transportation Service Centers (TSCs) and the seven Regional Offices
- The Southeast Michigan Council of Governments (SEMCOG) and Grand Valley Metropolitan Council (GVMC) MPOs (non-MDOT staff)
- Bureaus of Field Services, Development, and Transportation Planning

The managers of work areas were also asked to invite any staff in their work areas that could provide valuable inputs during the interviews. The questionnaire was distributed to the MDOT pertinent staff before the interviews. The MDOT pertinent staff from all MDOT seven regions were categorized into six groups by the RAP, and separate group interviews were conducted via conference calls to fill out the developed questionnaire by the MDOT staff. This process provided guidance and explanations to the interviewees to fill out the questionnaire. In Table 5-1, researchers present the schedules of the interviews as well as the MDOT work areas from which the pertinent staff participated in the interviews. Note that in all the interviews, MDOT RAP members were present to monitor the progress, and administrate the interviews. The questionnaire form for this task is provided in Appendix C.

Table 5-1 Schedules of the interviews and the MDOT work areas from which the pertinent staff participated

Interview Group	Date and Time	Work areas participated
1	April 19, 2022	Metro Region TSCs and SEMCOG MPO
2	April 29, 2022	Grand Region TSCs and GVMC MPO
3	March 17, 2022	Bay, University, and Southwest Regions and TSCs
4	March 31, 2022	North and Superior Regions and TSCs
5	April 11, 2022	Bureaus of Field Services and Development and Development Services Division
6	April 15, 2022	Bureau of Transportation Planning

5-3 Summary of Interviews Results

5-3-1 Overview of the responses

MDOT work areas responding to the survey and attending the interviews included from across the state of Michigan, covering a vast range of operational needs and conditions. A total of 71 valid responses were received from 37 MDOT work areas.

5-3-2 Performance measures used by MDOT work areas

5-3-2-1 Frequency of the performance measures used

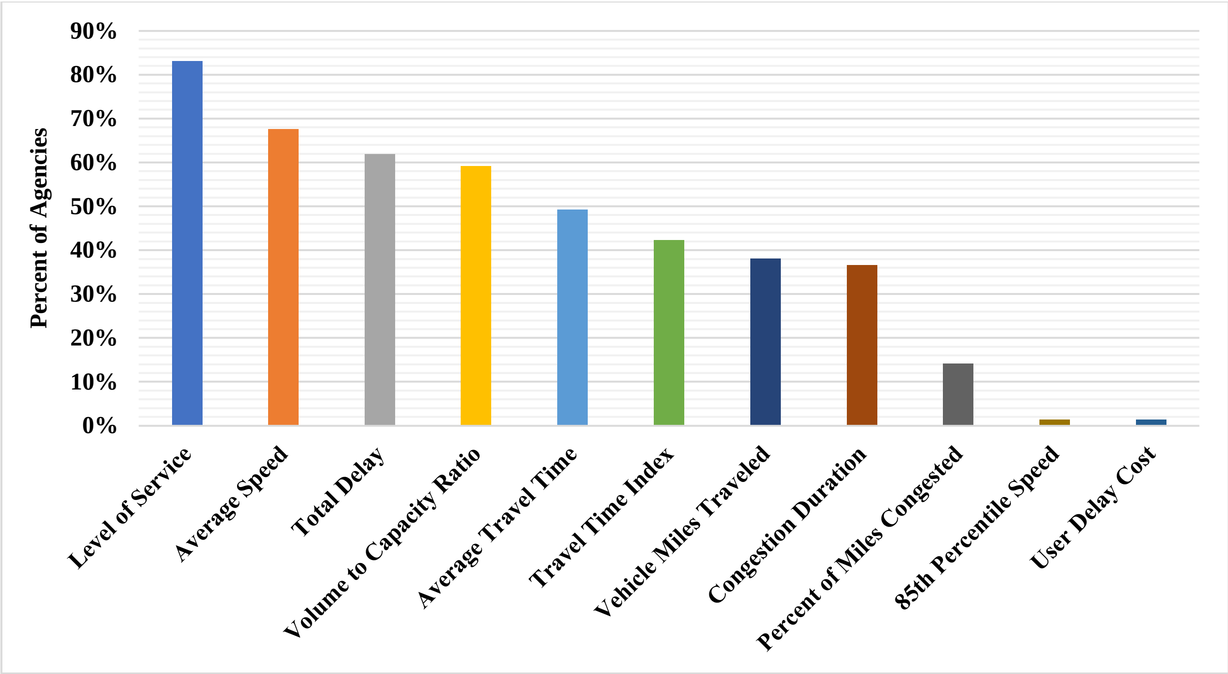
The percent of agencies using each of the mobility and reliability measures identified based on the previous tasks are provided in Figure 5-1a and Figure 5-1b, respectively. The disaggregated data based on responses for each of the MDOT regions are provided in Appendix D. As shown in these figures, LOS, average speed, and total delay are the most frequently used mobility measures, while LOTTR and PTI are the most commonly used reliability measures among these work areas. It is worth mentioning that the average speed and average travel time are highly used by the work areas as they are also data elements used in calculating the other performance measures. In addition, LOS and V/C, which were previously reported in the Sufficiency Reports, are among the most frequently used measures and still used by 83% and 59% of the work areas, respectively. This is because some work areas are holding onto traditional measures to maintain consistency in their historical reports. Also, as mentioned earlier, the higher frequency does not necessarily reflect a higher quality for a given performance measure. For instance, the results of the nationwide agencies survey indicated that the V/C measure can be replaced by more informative performance measures (e.g., delay-based measures) to serve the needs as the congestion level grows over the transportation networks.

5-3-2-2 Thresholds and targets incorporated for the performance measures

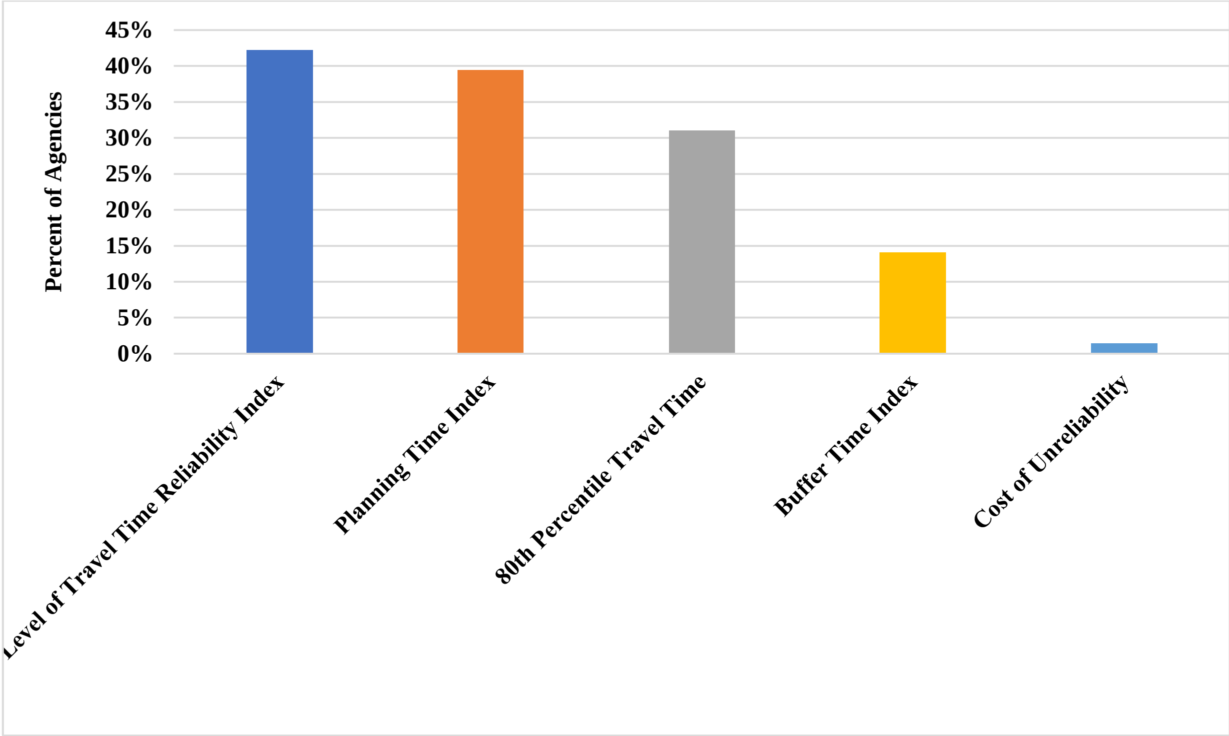
As mentioned in the previous chapters, setting appropriate targets for the performance measures is vital in performance assessment. Besides, thresholds are critical variables in the definitions of the measures, for instance in many of the delay-based measures, the threshold variable defines uncongested conditions for comparison with actual conditions in their computation. Therefore, the respondents were asked about the targets and thresholds they incorporate for the measures they use, which are illustrated in Table 5-2. As it can be seen, target values for different measures can be project-based (average travel time and total delay), and also can be used for operational evaluation. Besides, the target values vary between different geographic areas. Also, the threshold for the delay-based measures is free-flow speed for the MDOT work areas.

5-3-2-3 Important notes from the interviews regarding the performance measures

- Differentiating between different geographic areas (rural vs. urban and different location) for defining the thresholds is critical.
- Reliability measures are good for communicating with the public, especially in congested areas, so it would be helpful to incorporate them into the performance assessment system.
- The target values for the federally required measures (PM3) cannot be changed at the state-level because they are determined by the federal agencies. However, at the project-level, the target values depend on the project context.



(a)



(b)

Figure 5-1 Percent of MDOT work areas using each of the (a) mobility and (b) reliability measures

Table 5-2 Thresholds and targets incorporated for performance measures used by MDOT work areas

Measure	Threshold	Target(s)
Level of Service	HCM guidelines	1) LOS C or better for rural region and LOS E or better for urban region for freeways in Grand and North regions 2) LOS D or better for signalized corridors in Metro region
Average Speed	-	1) Speed limit 2) 10 mph lower than speed limit 3) 85th percentile of distribution for average safe speed
Total Delay	Free-flow speed	10 min of average delay per vehicle is generally acceptable for work zone
Volume to Capacity Ratio	$V/C \geq 0.9$: congested $0.7 \leq V/C < 0.9$: approaching congested $0.7 > V/C$: uncongested	-
Average Travel Time	-	10 min decrease for project significance
Travel Time Index	-	-
Vehicle Miles Traveled	-	-
Congestion Duration	-	-
Percent of Miles Congested	Free-flow speed	-
85th Percentile Speed	-	Within 5 mph of speed limit is acceptable
User Delay Cost	-	-
Level of Travel Time Reliability Index	Greater than or equal to 2 is considered unreliable	-
Planning Time Index	1) Greater than or equal to 2 is considered unreliable in Metro region 2) Greater than or equal to 1.8 is considered unreliable by planning section	-
80th Percentile Travel Time	-	-
Buffer Time Index	-	-
Cost of Unreliability	-	-

5-3-3 Applications of the performance measures

5-3-3-1 Scores of the performance measures for each application category

The respondents were asked to score the measures for each of the application categories, which provided valuable insights on the importance of these measures for different MDOT work areas. The sum and average scores of the measures for three application categories based on the responses from all MDOT work areas and the planning and asset management divisions are provided in Table 5-3 and Table 5-4, respectively. The disaggregated data based on responses for each of the MDOT regions are provided in Appendix E. The results show that the scoring system for prioritizing projects varies significantly among different work areas.

Note that the high sum of scores of the measures can be stemmed from high frequency of using them by the work areas, thus the average scores of the measures are also presented. As can be seen in these tables, total delay, LOS, LOTTR have the highest average scores for overall MDOT work areas for operational evaluation. However, although the average score of total delay is the highest, its sum of scores is lower than the sum of scores for LOS. This indicates that this measure is less used by the work areas than LOS, despite being more applicable to this application category. The same trend is observed for total delay, TTI, and PTI for prioritizing projects application category, and for VMT and percent of miles congested for short/long range transportation planning. In addition, according to Table 5-4, for operational evaluation, percent of miles congested, LOTTR, total delay, and TTI measures have the highest average scores among the performance measures. For prioritizing projects, percent of miles congested, total delay, and TTI have the highest average scores, and finally for short/long range transportation planning, VMT, total delay, TTI, and percent of miles congested measures are the most important and relevant measures.

Table 5-3 Sum and average scores of the performance measures for application categories based on the responses from all MDOT work areas

	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
Measure	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Vehicle Miles Traveled	84	4.9	78	4.6	132	7.8
Average Speed	186	6	163	5.3	168	5.4
Volume to Capacity Ratio	183	6.8	176	6.5	181	6.7
Level of Service	257	7.6	246	7.2	248	7.3
Average Travel Time	161	7	146	6.4	130	5.7
Total Delay	215	8	209	7.7	189	7
Travel Time Index	144	7.2	152	7.6	114	5.7
Percent of Miles Congested	29	5.8	21	4.2	45	9
Congestion Duration	84	6	87	6.2	77	5.5
Level of Travel Time Reliability Index	171	7.4	156	6.8	139	6.1
Planning Time Index	125	6.9	137	7.6	125	6.9
80th Percentile Travel Time	65	6.5	65	6.5	55	5.5

Table 5-4 Sum and average scores of the performance measures for application categories based on the responses from planning and asset management divisions

	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
Measure	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Vehicle Miles Traveled	30	6	24	4.8	53	8.8
Average Speed	32	6.4	27	5.4	42	7
Volume to Capacity Ratio	28	7	29	7.3	42	8.4
Level of Service	18	6	21	7	26	6.5
Average Travel Time	22	7.3	18	6	22	7.3
Total Delay	17	8.5	18	9	26	8.7
Travel Time Index	17	8.5	17	8.5	17	8.5
Percent of Miles Congested	9	9	9	9	17	8.5
Congestion Duration	-	-	-	-	-	-
Level of Travel Time Reliability Index	35	8.8	33	8.3	23	4.6
Planning Time Index	25	8.3	23	7.7	25	6.3
80th Percentile Travel Time	15	7.5	16	8	8	4
Buffer Time Index	14	7	15	7.5	7	3.5

5-3-3-2 Important notes from the interviews regarding the applications of the performance measures

- Average speed is used by SEMCOG to identify non-recurring congestion.
- The scoring system for prioritizing projects differs among different work areas.
- The TSMO maintenance decision support system focuses on weather and roadway conditions, and it would be helpful to integrate mobility measures into this tool (This has been done in a project by Kansas DOT [Garrett, Ma, Mahmassani, Neuner, & Sanchez, 2020]).
- The targets for the federally required measures (PM3) cannot be changed at the state-level since they are determined by the federal agencies, and in the project-level, the targets depend on the project context.

5-3-4 Critical Concerns when using the performance measures for their applications

The respondents were asked about the concerns that need to be considered when using any of the performance measures for their specific applications. The summary of the responses for each measure are presented in Table 5-5. It was also mentioned that the segment length is a concern for all the performance measures. In addition, it was indicated that for tourist areas, it is important to differentiate between weekdays, weekends, as well as different seasons when calculating and reporting the performance measures.

5-3-5 Reasons given for using traditional V/C and LOS measures

Following reasons were mentioned for using LOS as a performance measure:

- It is used for public consumption.
- It is widely used to compare alternatives in the project selection process.
- It enables historical comparison for MDOT.
- It enables comparing traffic control systems within regional evaluation.
- It is easily calculated for intersections if the work area uses Synchro software.

Similar reasons were also provided for using V/C ratio as a performance measure:

- It is easily calculated and forecasted at the state-level using travel demand models.
- It is widely used for determining if additional capacity is needed.
- It enables historical comparison for MDOT, and it is used for public consumption.
- It can be used to compare alternatives in the project selection process.

- It is a preferred measure to LOS for the MDOT Planning Division, due to its quantitative nature relative to LOS.

Note that the definitions of these measures and the data sources that are used to calculate them for planning applications and design/operations are different. As an example, the V/C ratio is calculated from travel demand models to be forecasted. However, this measure can be used for project evaluation based on the field data.

Table 5-5 Summary of critical concerns when using each performance measure

Measure	Critical Concern(s)
Level of Service*	1) Industry is moving away from LOS 2) Defining thresholds/targets can be a concern in work zone areas, urban vs rural areas, etc. 3) Too qualitative and its use leads to missing some important information*
Average Speed	1) Long-range models may be too generous with free-flow speeds 2) Relationships to posted speed is a concern
Total Delay	1) It is critical to consider the type of motorists at different times of the day. 2) Recurring and non-recurring delays need to be differentiated 3) Not calculated easily 4) Targets should be set based on the area type (urban vs. rural)
Volume to Capacity Ratio	1) Determining the capacity of the segment is critical, it might vary and causes misinterpretation 2) This measure does not tell full story
Average Travel Time	1) Long-range models may be too generous with free-flow travel time 2) Can be skewed by the effect of driver reliance on google maps
Congestion Duration	1) Recurring and non-recurring delay needs to be differentiated
Level of Travel Time Reliability Index	1) This measure is not informative as well as PTI 2) Setting appropriate targets is a critical concern 3) This measure seems to be useful at the national level, but for statewide or MPO region, it doesn't seem to be as useful (Most roadways in MI are almost below the target value)
Planning Time Index	1) How the free-flow speed is defined 2) What time-periods are relevant for analysis -- peak periods or more, and how are they defined

* LOS is discrete from one level to another (e.g., going from E to F), this means that just 1 vehicle could, theoretically, move the measure value from LOS E to F, which is not ideal. Also, another downfall of this measure is that when the current value is LOS F, it cannot get worse; therefore, this measure is qualitative and cannot provide valuable information for operational evaluation (comparing segments with the same LOS value). That is where using more informative measures like delay-based measures can be useful, because these are continuous variables, and they have a value (and continue to accumulate quantitatively) well into congested conditions.

5-3-6 Direct use of the performance measures calculated and reported in the MDOT reports

The respondents were asked if they directly use the performance measures calculated and reported in the MDOT Annual Freeway Congestion and Reliability reports and Annual Arterial Performance reports. Table 5-6 presents the percent of respondents using each of the measures provided in these reports, which indicates scattered use of these measures by different MDOT work areas.

Table 5-6 percent of respondents using each of the measures provided in MDOT reports

Freeway Congestion and Reliability Reports	
Measure	Percent of Respondents
Delay	14.1
Delay Index	9.8
Maximum Delay	11.3
Average Speed	22.5
Congestion Severity	21.1
Travel Time Reliability	22.5
Average Travel Time	19.7
95^{th} Percentile Travel Time	12.7
Level of Travel Time Reliability Index	15.5
Arterial Performance Reports	
Measure	Percent of Respondents
Planning Time Index	9.9
Buffer Index	2.8
Travel Time Index	12.7

The following notes are highlighted regarding applications of the MDOT current reports on system planning performance measures:

- These reports are widely used to identify operational problems.
- It is suggested to develop interactive maps for these reports rather than only using published reports.
- Some MDOT work areas are struggling with using the Arterial Report and there are certain uncertainties in using this report.
- While these reports are generated by some work areas to rightfully address their specific business, they might not address direct needs of other work areas.

5-3-7 Data sources used for calculating the performance measures

As mentioned in the previous chapters, most of the MDOT work areas use INRIX data to calculate the measures for performance assessment. The respondents were asked if they use data sources other than INRIX when calculating the measures. Forty two percent (42.5%) of the respondents mentioned that they use other data sources in this regard, including:

- Transportation Data Management System (TDMS) data
- Microwave Vehicle Detector Sensors (MVDS) data
- Traffic counters
- Probe data
- Statewide and MPOs travel demand models
- HPMS data

5-3-8 Data needs for improving the performance assessment system

The respondents were asked about the data needs to improve the accuracy and/or coverage of the performance assessment system in their work areas. The following is the summary of the data needs mentioned during the interviews:

- More traffic counters
- Collecting origin and destination trip data
- More training regarding the use and capabilities of the INRIX data
- More data collection efforts for non-motorized modes
- Easier access to the MVDS data
- Using traffic monitoring cameras to collect traffic volume data

5-3-9 Tools and methods used for calculating the performance measures

The respondents were asked about the methods and tools that they use in their work area for data analysis and calculation of the performance measures. The results are illustrated in Table 5-7. As can be seen in this table, RITIS and ArcGIS tools are the most frequently used methods and tools for analyzing the data and calculating the performance measures by the work areas.

Table 5-7 Tools and methods used by MDOT work areas for calculating the measures

Method	Number of Respondents
RITIS	25
ArcGIS	19
Trans CAD	13
Synchro	8
Co3	3
Caliper	3
Rodel	2
Benefit/Cost TOP BC Tool	1
Excel Spreadsheets	1
TAMS-VueWorks	1
PTV-VISSIM	1

It was mentioned during the interviews that RITIS can be used to automatically produce the reports on performance measures, however it cannot be used for predicting the improvements and predicting the performance measures. In addition, Synchro is geared toward the LOS and delay per vehicle per movement, and work areas are able to calculate these measures easily by using Synchro.

5-3-10 Publishing and reporting the performance measures

5-3-10-1 Methods used by work areas for publishing and reporting the measures and audience of these reports

The respondents were asked about the methods that they use in their work area for publishing and reporting the measures, and the summary of the results are presented in Table 5-8. Note that it was mentioned by two work areas that they also provide an interactive map on their public websites for reporting the measures. Furthermore, the respondents were inquired about the audience of the performance reports in their work areas, which are provided in Table 5-9. As can be seen in this table, most of the work areas do not report the measures to the public and they are reporting the measures to specific agency(s). Most of these work areas are TSCs and Regional work areas that report the measures to MDOT. Following notes are also listed in this regard:

- A report similar to the sufficiency Report along with GIS maps, which enables sorting segments based on different conditions, is highly recommended (with technological capacity available for GIS-based reports at MDOT).
- It is beneficial to have a comprehensive interactive report, including different types of measures such as safety, operations, asset management, maintenance, etc.
- An interactive map would be useful to accompany the reports.
- Published reports facilitate the access for MDOT work areas.
- The cost effectiveness of providing an interactive report should be investigated.
-

Table 5-8 Methods used by MDOT work areas for publishing and reporting the measures

Method	Number of Respondents
Published report	10
Public website	8
No report is published	8
Published in the long-range transportation planning	2

Table 5-9 Audience of the performance reports by MDOT work areas

Audience	Number of Respondents
Measures are private and reported to specific agency(s)	10
Measures are reported publicly	8
Measures are not published or reported	8
Some measures are private, and some are reported publicly	2

5-3-11 Needs of the MDOT performance measurement system

The respondents were asked about the needs of the MDOT performance measurement system in their work area. The responses are summarized below:

- Defining measures that are quick and easy to calculate with the data sources currently available and easy to compare
- A multimodal performance measurement system
- More understanding of the reliability measures
- More granular traffic count data and more coverage of the data
- Considering seasonal travel patterns
- Information for non-motorized users
- Improving the communication between the Planning/Operations and the Regions/TSCs
- The measures should be developed in a way that MDOT can effectively forecast them

5-3-12 Critical concerns to consider when developing the performance measures

The respondents were inquired about the concerns that are needed to be taken into account when developing performance measures. The discussions are summarized as below:

- Complementary measures for LOS and V/C would be preferable. This would facilitate a transition period from these historical measures
- The measures and results should be easily accessible by various MDOT work areas internally and also the general public if needed
- There is a need for a more user-friendly performance measurement system
- Definition of the measures, and how relevant they are to congestion and travel time reliability analysis (thresholds, time periods, targets, etc.) should be provided
- There is a need for consistency of the performance management systems between different work areas
- It is essential to define proper thresholds for measures and set achievable targets for them.

5-3-13 Additional comments or suggestions from MDOT work areas staff

The respondents were also asked if they have any comments and/or recommendations for improving the system planning performance assessment for the Michigan trunkline. Their recommendations are summarized below:

- Enable easy comparison for the historical data collected over the years
- As long-range model development methodology evolves, it is important to inform regional staff to understand capabilities, limitations, and uses

- Combining the TDMS and MVDS data, which are managed by two different MDOT work areas would be helpful

5-4 Needs Assessment of the MDOT System Planning Performance Management

In this section, the project team presents a summary of the needs and gaps of the MDOT performance measurement system based on the outcomes of previous tasks of this project. The needs and gaps of the performance management system for the Michigan trunkline are summarized below:

- MDOT work areas are holding onto the traditional operational performance measures to maintain consistency in their historical reports.
- MDOT work areas use level-of-service and volume-to-capacity ratio due to lack of system-wide data and/or resources to compute more informative measures (e.g., delay-based measures).
- More informative measures that are capable of capturing various aspects of congestion and reliability are needed.
  - Complementary measures for volume-to-capacity ratio and level-of-service would be preferable to facilitate a transition period from these historical performance measures.
- The measures should be developed in a way that MDOT can effectively forecast them
- More understanding of the reliability measures is needed.
- Differentiating between weekdays and weekends as well as considering the seasonal traffic patterns are critical factors that need to be considered when calculating and reporting measures.
- Consistency of the performance measurement system between different MDOT work areas is needed.
- Increasing the data coverage would improve the MDOT performance management, which needs to be economically evaluated.
- Collecting data from non-motorized modes is needed to move toward multi-modal performance measurement system.

- A comprehensive report with a format similar to Sufficiency Reports is needed, which can address the needs of all MDOT work areas that are directly or indirectly related to the system planning performance management.
- Improving the communication between the Planning/Operations work areas and Regions/TSCs is a critical factor for improving the system that needs to be taken into account.

CHAPTER 6 – IDENTIFY POTENTIAL PERFORMANCE MEASURES FOR THE MICHIGAN TRUNKLINE

6-1 Purpose

There are a high number of performance measures that can be used for different applications, and due to overlaps between the measures and the required resources for calculating, analyzing, and reporting the measures, calculating all of the existing measures is not efficient and practical. Thus, it is vital to determine a set of measures that can be useful to meet the needs of the agency. To this end, potential performance measures for the Michigan trunkline need to be identified that can assist MDOT in meeting its needs regarding the performance assessment system. In addition, the specifications of the measures (e.g., their definitions, thresholds, and target values) are critical factors that need to be determined. In this regard, researchers conducted a nationwide agencies follow-up survey based on the potential measures determined by analyzing the previous research task results, focusing on the specifications of the potential measures, and the importance of the measures for each application category in other agencies.

6-2 Set of Potential Performance Measures for the Michigan Trunkline

To determine a set of potential mobility and reliability measures for the Michigan trunkline, the scores of the performance measures for each application category provided by the overall MDOT work areas and Bureau of Transportation Planning were used, which are provided in Table 5-3 and Table 5-4. In this regard, the rankings of the measures were calculated for each of the application categories, e.g., operational evaluation, prioritizing projects, and short/long range transportation planning (1 means the most relevant and important measure for the application with highest score). Then, the averages of the rankings of the measures over the three mentioned application categories were calculated by assigning 1/3 weight to each of these applications, which are presented in Table 6-1. Then, the project team selected the top six measures for the overall MDOT work areas and Bureau of Transportation Planning. There is a high overlap between the top six measures for these two categories (total of seven distinct measures). The potential measures for the Michigan trunkline system are:

- Total delay
- Travel time index

- Planning time index
- Percent of miles congested
- Volume-to-capacity ratio
- Level of service
- Level of travel time reliability index

Note that the measures, including average travel time, average speed, and vehicle-miles traveled are data elements that are also used for calculating the top six measures presented earlier.

Table 6-1 Average rankings of the performance measures by assigning 1/3 weight to each of the three application categories

Overall MDOT Work Areas		Bureau of Transportation Planning	
Measure	Average Ranking (out of 12)	Measure	Average Ranking (out of 12)
Total Delay	**1.9**	**Total Delay**	**1.3**
Level of Service	**3**	**Level of Travel Time Reliability Index**	**1.9**
Planning Time Index	**4.3**	**Percent of Miles Congested**	**2.3**
Level of Travel Time Reliability Index	**4.9**	**Travel Time Index**	**2.6**
Travel Time Index	**5**	**Volume to Capacity Ratio**	**2.9**
Percent of Miles Congested	**6.5**	**Planning Time Index**	**3.3**
Volume to Capacity Ratio	6.7	Vehicle Miles Traveled	3.4
Average Travel Time	6.9	Average Speed	3.8
Vehicle Miles Traveled	7.2	Average Travel Time	5
80^{th} Percentile Travel Time	7.9	Level of Service	6
Congestion Duration	10	80th Percentile Travel Time	6.6
Average Speed	10	Buffer Time Index	9.5

6-3 Nationwide Agencies Follow-Up Survey

6-3-1 Purpose

Determining the appropriate specifications for the performance measures, including definitions, calculation equations, thresholds, and targets, has high importance for the performance management system. Thus, a nationwide agencies follow-up survey was conducted to inquire about the specifications of the identified potential performance measures for the Michigan trunkline and also to quantify the importance of each measure for the application categories in state DOTs and MPOs across the United States. The survey consisted of two sections requesting the following information:

- The relevance and importance of the potential performance measures for different applications in other agencies
- The specifications of the potential performance measures, including definition, calculation equation, thresholds, and targets

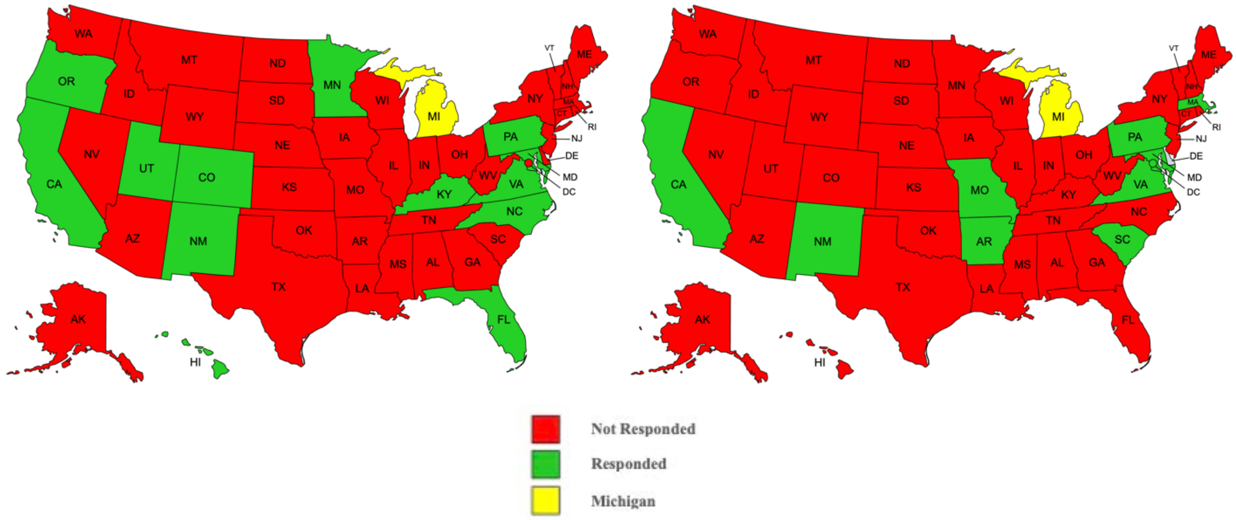
6-3-2 Survey design and administration

Similar to the approach for the first round of the nationwide agencies survey, the MSU research team designed a questionnaire survey. The survey questions, which are presented in Appendix F, were developed based on the results of previous tasks of the project and were revised based on the MDOT RAP feedback. The survey was designed and implemented in a web-based format through Qualtrics and was distributed in three phases. In the first phase, in August 2022, the survey was distributed to all the respondents of the first round of the nationwide agencies survey, conducted in Task 2 of the project. Then, reminder emails were sent to the targeted respondents. However, only 12 responses were received from 4 state DOTs and 8 MPOs. To increase the number of received responses from state DOT representatives, the second phase of distribution was conducted, in which the survey was distributed to the pertinent staff in state DOTs, including the ones that did not respond to the first round of the survey. The survey was officially closed by October 2022.

6-3-3 Summary of follow-up survey results

6-3-3-1 Overview of the responses

Transportation agencies responding to the follow-up survey included 20 states from across the US, covering a vast range of operational needs and conditions. A total of 22 valid responses were received from 12 state DOTs (Figure 6-1a) and 10 MPOs (Figure 6-2b).



(a) (b)

Figure 6-1 Spatial distribution of the follow-up survey respondents (a) State DOTs, and (b) MPOs

6-2-3-2 Applications of the potential performance measures

The respondents were asked to score the measures for each of the application categories, whether their agency uses them or not, which provided valuable insights on the applicability of these measures in the performance management. The average scores of the measures for three application categories, including operational evaluation, prioritizing projects, and short/long range transportation planning are provided in Table 6-2.

This table illustrates that the total delay, travel time index, and planning time index are the most important performance measures for operational evaluation and prioritizing projects. Besides volume-to-capacity ratio, total delay and level of service are the most relevant measures for short/long range transportation planning. Note that volume-to-capacity ratio can be easily forecasted using travel demand models.

Table 6-2 Average scores of the performance measures for application categories based on the nationwide agencies follow-up survey

Measure	Operational Evaluation	Prioritizing Projects	Short/Long Range Transportation Planning
Total Delay	6.2	6.0	6.7
Travel Time Index	5.8	5.7	6.0
Planning Time Index	4.4	4.5	4.7
Percent of Miles Congested	4	4.3	5.2
Volume to Capacity Ratio	4.6	5.1	6.2
Level of Service	5.6	5.2	6.0
Level of Travel Time Reliability Index	3.5	4.1	5

The respondents were asked if they have a different interpretation for the definition, calculation equation, and thresholds for each of the potential performance measures than the ones provided in the survey (the default specifications can be found in Appendix F).

6-3-3-3 Specifications of the Total Delay

No different definition and/or calculation equation were mentioned by the respondents for this measure. Regarding the threshold(s) for total delay:

- Some agencies use free-flow speed as uncongested travel speed.
- Some agencies mentioned that they are using posted speed limit to define uncongested travel speed.
- Some agencies use the average speed in level of service B as uncongested travel speed.
- Some respondents mentioned that they define congested condition as when the average speed falls below 75% of the free-flow speed.
- Some agencies use average speed lower than 60 mph on a freeway segment with a posted speed limit of 70 mph to define congested condition.
- An agency uses 50 mph as the threshold for “congested” versus “uncongested” on their freeways, because it is used in their reference to their Express Lane requirements via legislation. Thus, they want them to be consistent.

- One of the agencies defines congested condition as the average speed falls 20 mph below the speed limit.
- A few agencies mentioned that they are replacing the free-flow speed with the posted speed limit to define uncongested travel speed.

The respondents were also asked to explain how the threshold variables are calculated and set:

- Some agencies mentioned that they use the default thresholds that are provided in the RITIS tool.

6-3-3-4 Specifications of the Travel Time Index

No different definition and/or calculation equation were mentioned by the respondents. Regarding the threshold(s) for travel time index:

- Some agencies use posted speed limit as free-flow speed to calculate this measure.

The respondents were asked to explain how the threshold variables are calculated and set:

- Some agencies mentioned that they use the default thresholds that are used in the RITIS tool.

6-3-3-5 Specifications of the Planning Time Index

No different definition, calculation equation, and/or thresholds were mentioned by the respondents. The respondents were asked to explain how the threshold variables are calculated and set:

- It was mentioned that some agencies define the free-flow travel time as 85^{th} percentile travel time during weekday off-peak hours (9 AM to 4 PM and 7 PM to 10 PM).
- Some agencies responded that they calculate the free-flow travel time based on the segment length and posted speed limit.
- Some agencies indicated that they use the default thresholds that are used in the RITIS tool.

6-3-3-6 Specifications of Level of Service

No different definition, calculation equation, and/or thresholds were mentioned by the respondents. The respondents were asked to explain how the threshold variables are calculated and set:

- It was mentioned that the level of service handbook of the Florida DOT thoroughly describes the specifications for this measure (Florida DOT, 2020a).

6-3-3-8 Specifications of Volume to Capacity Ratio

No different definition, calculation equation, and/or thresholds were mentioned to be used by the respondents. The respondents were asked to explain how the threshold variables are calculated and set:

- Some agencies mentioned that they use the Highway Economic Requirements System (HERS) model for calculating this measure.
- An agency uses demand-to-capacity ratio instead of volume-to-capacity ratio as field counts are often limited by capacity.
- It is stated that the level-of-service handbook of the Florida DOT thoroughly describes the specifications for this measure (Florida DOT, 2020a).
- Some agencies use the Highway Capacity Manual (HCM) methodology to determine capacity.
  - An agency found that the HCM methodology is general, and their freeway capacities never reach above 1900 vehicle per hour per lane (vphpl) and can fall as low as 1300 vphpl.

6-3-3-9 Specifications of Percent of Miles Congested

No different definition and/or calculation equation were mentioned by the respondents. Regarding the threshold(s) for percent of miles congested:

- One of the agencies uses the ADT/Capacity during peak period to identify congested conditions (greater than 0.9 is considered as congested condition) (Oregon DOT, 2019).

The respondents were asked to explain how the threshold variables are calculated and set, and the responses were similar to the ones for total delay thresholds.

6-3-3-10 Specifications of Level of Travel Time Reliability Index

No different definition and/or calculation equation were mentioned by the respondents. Note that no threshold was defined for this measure.

6-3-3-11 Targets for the potential performance measures

The respondents were asked if they use different target values than the ones provided in the survey. The summary of the received responses are provided in Table 6-3.

Table 6-3 Summary of the received responses for the target values of the potential performance measures that are different from the ones that were provided in the survey

Measure	Provided Target in Survey	Different Target Interpretation Mentioned by Respondents
Total Delay	10 vehicle-hours	1) No targets are defined by the agency 2) Delay should not grow more than 4% annually 3) Targets are dependent on available project and federal funds
Travel Time Index	Greater than or equal to 1.5 is considered congested	1) TTI<1.15: Uncongested 1.15<TTI<1.3: Moderate congestion 1.3<TTI<2: Heavy congestion 2>TTI: Severe congestion 2) Greater than or equal to 1.3 is considered unreliable 3) Greater than or equal to 1.4 is considered unreliable
Planning Time Index	Greater than or equal to 1.8 is considered unreliable roadway	Greater than or equal to 2.0 is considered unreliable roadway
Level of Service	Better than LOS C for rural highways and better than LOS D for urban highways	LOS D or better for both rural and urban highways
Volume to Capacity Ratio	Greater than 1 is considered as severe congestion Greater than 0.8 and less than 1 is considered as moderate congestion Less than 0.8 is considered as low/no congestion	V/C<1: Manageable V/C>1: Severe congestion
Percent of Miles Congested	Percent of miles that are congested on the interstate network in year 2024 should be lower than 20%	1) No targets are defined by the agency 2) Target developed using forecast model to calculate the annual growth rate 3) 10% is the statewide goal
Level of Travel Time Reliability Index	Greater than or equal to 2 is considered unreliable	-

CHAPTER 7 – SUMMARY OF FINDINGS

This section summarizes the findings from the nationwide state-of-the-practice survey, review of MDOT current and historical practices, MDOT staff interviews, and identifying the potential performance measures for the Michigan trunkline system.

<u>Nationwide Survey</u>

1. There are a few studies regarding the evaluation of the performance measurement system conducted by transportation agencies.
2. Vehicle-miles traveled and travel time index are the most frequently used mobility measures, and level of travel time reliability and planning time index are the most frequently used reliability measures among the agencies. It should be noted that the higher frequency does not necessarily reflect the higher quality of a given performance measure. For instance, although the delay-based measures are known to be more informative than traditional measures, they are less frequently noted than data element measures (e.g., VMT). Thus, the provided frequencies just reflect a "snapshot" of the state-of-the-practice by DOTs and MPOs.
3. Performance measures are used for multiple — sometimes simultaneous — applications. For instance, a required measure (policy-driven) can be also used for short-/long-range transportation planning. The most selected application of the performance measures is short-/long-range transportation planning (36% for mobility measures and 32% for reliability measures). Also, it can be concluded that the reliability measures are more frequently used for policy-driven applications, compared to the mobility measures. For each of the applications, the most frequently used measures are identified.
4. Performance measures are often assessed annually, and reported to the public for all vehicles through printed reports, interactive maps, online websites, etc.
5. In-house traffic count data, INRIX, and NPMRDS are the data sources that are most frequently used by agencies for performance measurement based upon the responses.
6. Measures such as volume-to-capacity ratio no longer serve the needs as the congestion level grows in transportation networks. This calls for using more informative measures that capture various aspects of congestion and reliability.
7. Agencies tend to use a small set of measures that can be easily used and supported.
8. Including MPOs in target setting and performance measurement methodology workshops provides them with a great opportunity to provide valuable local input.

9. It is important to quality control the raw data regularly to validate the calculated and reported performance measures.
10. Switching between different data sources and vendors entails significant challenges for agencies in conducting before/after studies and time-series reporting.
11. Moving from printed performance reports to an online performance dashboard improves communication and transparency and promotes broad application of performance measures.
12. Evolving and updating the performance measures and analysis tools are important due to constant adaptation of the data and the transportation planning and operation practices.

<u>Review of MDOT Current/Historical Practices</u>

1. MDOT has conducted or sponsored multiple studies regarding the operational performance management since 1998.
2. Michigan long-range transportation plans contain the objectives and core performance measures that allow MDOT to track progress toward addressing transportation needs and challenges for the next 25 years.
3. Through 2015, roadway inventory data were provided in the Annual Sufficiency Reports, which were formatted similar to the HPMS data and was retired in 2015.
4. Since 2014, MDOT has used probe vehicle data to publish the Annual Freeway Congestion and Reliability Reports, using HERE/INRIX data, for MDOT internal use.
5. Similar to the Freeway Congestion and Reliability Reports, Arterial Performance Reports are proposed to provide a snapshot of the Michigan arterials throughout the state. However, they are not currently publicly available.
6. There is a need for a comprehensive evaluation of the performance measurement system. In this regard, Michigan trunkline performance management system can be improved using an interactive dashboard to report system planning measures to the public and different MDOT work areas for various applications.

<u>MDOT Staff Interviews:</u>

1. Level of service, average speed, and total delay are the most frequently used mobility measures, and level of travel time reliability index and planning time index are the most commonly used reliability measures among the MDOT work areas. Note that the average speed and average travel time measures are highly used by the work areas as they are data elements

used in calculating the other performance measures. Besides, it is worth mentioning that the higher frequency does not necessarily reflect a higher quality for a given performance measure.

2. Level of service and volume-to-capacity ratio measures, which were reported in the Sufficiency Reports, are among the most frequently used measures and still used by 83% and 59% of the work areas, respectively. This is because some work areas are holding onto traditional measures to maintain consistency in their historical reports. Level of service and volume-to-capacity ratio measures are also highly used due to lack of system-wide data and/or resources to compute the more informative measures (e.g., delay-based measures) at the system level.
3. The targets for measures can be project-based (average travel time and total delay), and also can be for operational evaluation. Besides, the target values may differ between different geographic areas.
4. Differentiating between geographic areas (rural vs. urban and different locations) for defining the thresholds and/or target values is helpful but might cause inconsistencies for the reported measures between different areas.
5. The target values for PM3 measures cannot be changed at the state level because they are determined by the federal agencies, but in the project level, they can be set based on the project variables.
6. Total delay, level of service, and level of travel time reliability index measures are stated as the most important and related measures for the MDOT work areas in operational evaluation.
7. Total delay, travel time index, and planning time index measures are stated as the most applicable measures for the MDOT work areas in prioritizing projects.
8. Percent of miles congested and vehicle-miles traveled measures are stated as the most important measures for the MDOT work areas in short/long range transportation planning application category.
9. Total delay is less frequently used by the work areas than level of service, although the work areas indicate that this measure is more applicable for operational evaluation. The same trend is observed for total delay, travel time index, and planning time index in prioritizing projects, and for vehicle-miles traveled and percent of miles congested in short/long range planning application category.

10. It would be beneficial to differentiate between weekdays and weekends and also to consider seasonal travel patterns when calculating and reporting the performance measures.
11. Industry is moving away from LOS because it is too qualitative and its use leads to missing some important information, particularly during congested conditions.
12. Determining the thresholds for the performance measures is a critical consideration (e.g., the capacity of the road segment or the free-flow speed when calculating the performance measures that require a threshold in their calculation equation).
13. The performance measures reported by the MDOT Annual Freeway Congestion and Reliability reports and Annual Arterial Performance reports are used when searching for operational problems, and while these reports are generated by some work areas to rightfully address their specific business, they might not address direct needs of other work areas.
14. The MDOT work areas use data sources in addition to the INRIX when calculating the measures, including TDMS data, MVDS data, traffic counters, probe data, statewide and MPOs travel demand models, and HPMS data.
15. Increasing the data coverage is considered by the MDOT work areas to improve the performance assessment system in their work areas.
16. RITIS and ArcGIS tools are the most frequently used methods and tools for analyzing the data and calculating the performance measures by the MDOT work areas. Also, RITIS can be used to automatically produce the reports on different performance measures, however, it cannot be used for predicting the improvements and measures in future.
17. Most of the work areas do not report the measures to the public and they are reporting the measures to specific agency(s). Most of the interviewed work areas are TSCs and Regional work areas that report the measures to MDOT for internal purposes.
18. A report similar to the Sufficiency Report along with GIS maps can be a useful approach for reporting the measures. An interactive map would be useful to accompany the reports.
19. Complementary measures for LOS and V/C would be preferable. This would facilitate a transition period from these historical measures.

<u>Identifying Potential Performance Measures for the Michigan Trunkline System</u>

1. The potential measures for the Michigan trunkline system based on their importance and relevance overall to three application categories are total delay, travel time index, planning

time index, percent of miles congested, volume-to-capacity ratio, level of service, and level of travel time reliability index.

2. According to the nationwide follow-up survey, total delay is the most important measure for all three previously stated application categories, which is consistent with the results of the MDOT staff interviews.
3. The specifications (e.g., thresholds and targets) of the performance measures are different among the agencies in the United States.

CHAPTER 8 – RECOMMENDATIONS FOR MICHIGAN TRUNKLINE PERFORMANCE MEASURES

8-1 Purpose

The results of tasks 1 to 6 were used to develop recommendations and guidelines for the assessment of the Michigan trunkline system. In this chapter, the final recommended performance measures are presented, with adequate justification provided for the performance measures, their specifications, and data sources used for their calculation, as well as their reporting and communication methods.

8-2 Final Recommendations for the Performance Management of the Michigan Trunkline System

Specific recommendations for the MDOT system planning performance management of the trunkline system are provided below.

8-2-1 Set of selected system planning performance measures for the Michigan trunkline system

The selected performance measures for the Michigan trunkline system as well as their definitions are provided in Table 8-1. These selected measures are chosen based on the importance and applicability of the measures for operational evaluation, prioritizing projects, and short/long range transportation planning, which was identified according to the literature review, MDOT staff interviews and nationwide agencies follow-up survey. Based on the outcomes of these tasks, the research team suggest at least three measures be considered for MDOT system planning performance measurement: Total Delay as the main measure that can be measured based on observed data and predicted for future scenarios using planning models; Travel Time Index / Planning Time Index to measure mobility and reliability, respectively, based on observed trajectory data, and Volume-to-Capacity Ratio / Level of Service as historical measures to establish patterns in comparison with past data available on these measures during a 10-year transition to the first two measures mentioned. The recommended specifications for each of these selected performance measures are presented in the following sections.

Table 8-1 Selected system planning performance measures for the Michigan trunkline system and their definitions

Measure	Definition
Total Delay	Total delay is defined as the extra time spent driving in congested conditions as compared to uncongested travel conditions on a roadway segment. This measure can also be reported as **Total Delay per Mile** for corridor-level analysis and comparison.
Travel Time Index	Travel time index is defined as the ratio of peak-period travel time to free-flow travel time on a roadway segment.
Planning Time Index	Planning time index is defined as the ratio of the 95^{th} percentile travel time to the free-flow travel time on a roadway segment.
Volume-to-Capacity Ratio	Volume-to-capacity ratio is defined as the ratio of the volume of traffic to the capacity on a roadway segment.
Level of Service	Intensity of congestion delays on a roadway or intersection, rated from A (uncongested) to F (extremely congested) are calculated based on Highway Capacity Manual (HCM) guidelines.

Note: Total delay, travel time index, and planning time index measures are also applicable to be reported only for trucks given the data availability.

8-2-2 Recommended specifications for the selected performance measures

In this section, the MSU research team provides the calculation equations and recommended thresholds for each of the selected performance measures.

8-2-2-1 Recommended specifications for Total Delay

The total delay is recommended to be calculated using Equation (1).

$$Total\ Delay\ (vehicle.hours) = \left(\frac{Segment\ Length\ (mile)}{Average\ Speed\ of\ Vehicles\ in\ Congested\ Condition\ (\frac{mile}{hour})} - \frac{Segment\ Length\ (mile)}{Average\ Speed\ of\ Vehicles\ in\ Uncongested\ Condition\ (\frac{mile}{hour})}\right) \times Vehicle\ Volume\ in\ Congested\ Condition\ (vehicles) \quad (1)$$

This measure provides a representation of congestion and its consequences for travelers. This measure incorporates the number of vehicles that are using the roadway segment, which enables prioritizing the highly traveled segments compared to the less traveled segments. Different definitions are used for free-flow speed in the literature. For instance, 85^{th} percentile of speeds during weeknight hours from 10 PM to 5 AM(Texas A&M Transportation Institute, 2022). Based on data availability and desired applications different definitions need to be compared and a proper one can be selected. In addition, the congested condition (e.g., when the delay starts to be calculated) is suggested to be defined when the average speed of the vehicles on the segment falls below the free-flow speed.

Total delay can be used for areawide measurement (statewide, urban vs. rural areas, regions, etc.). This measure can also be normalized by distance and be reported per mile of the roadway for corridor-level analysis and project comparison.

This measure received the highest overall ranking for different applications based on the nationwide agencies survey and MDOT staff interviews. According to the results of the literature review, nationwide agencies survey, and MDOT staff interviews, total delay is recommended to be calculated for peak period, daily, and annually during weekdays and weekends. This measure is also recommended to be calculated for “all vehicles” combined and separately for trucks, which provides an opportunity to investigate truck delay conditions. The truck delay per mile on corridors and all vehicle delay per mile would also result in a separate ranking of the corridors, which can provide valuable insights on where the truck delay is located.

8-2-2-2 Recommended specifications for Travel Time Index

The travel time index is recommended to be calculated using Equation (2).

$$Travel\ Time\ Index = \frac{50^{th}\ Percentile\ Travel\ Time}{Free\_Flow\ Travel\ Time} \tag{2}$$

This measure incorporates the average travel conditions relative to the free-flow travel time. For example, a value of 1.20 means that average peak travel times are 20% longer than off-peak travel times. It is recommended to use the free-flow speed (set as the 85th percentile of speeds during weeknight hours from 10 PM to 5 AM) on a segment and segment length to identify the free-flow travel time on a segment.

This measure is highly scalable both in terms of geography and time. This measure can be weighted by VMT across corridors, urban areas, regions, or statewide. Also, it can be scaled up from peak hour to peak period to daily or annually for those peak periods (weighted by VMT). According to the results of the literature review, nationwide agencies survey, and MDOT staff interviews, travel time index is recommended to be calculated for peak hour and peak period. Also, this measure is recommended to be calculated for all vehicles combined and trucks, separately.

8-2-2-3 Recommended specifications for Planning Time Index

The planning time index is recommended to be calculated using Equation (3).

$$Planning\ Time\ Index = \frac{95^{th}\ Percentile\ Travel\ Time}{Free\_Flow\ Travel\ Time} \tag{3}$$

This is a travel time reliability measure and determines the extent of the unexpected delay. In other words, it illustrates the additional time that a traveler should budget to ensure on-time arrival to the destination at least 95th percent of the time (i.e., 19 out of 20 trips = 95%). It is recommended to use the free-flow speed (set as the 85th percentile of speeds during overnight hours from 10 PM to 5 AM) on a segment and segment length to identify the free-flow travel time on a segment.

Similar to the travel time index, this measure is highly scalable. According to the results of the literature review, nationwide agencies survey, and MDOT staff interviews, planning time index is recommended to be calculated for peak hour, peak period, and daily during weekdays. In addition, this measure is recommended to be calculated for all vehicles combined and trucks, separately.

8-2-2-4 Recommended specifications for Volume to Capacity Ratio

The volume-to-capacity ratio is recommended to be calculated using Equation (4).

$$Volume-to-Capacity\ Ratio = \frac{Traffic\ Volume\ on\ the\ segment}{Capacity\ on\ the\ segment} \tag{4}$$

The volume-to-capacity ratio measures the degree of traffic congestion on the roadway segment. The segment capacity can be set by using the HCM procedures and FHWA guidelines (Federal Highway Administration, 2021; Margiotta, Washburn, & Systematics, 2017). This measure is fairly easy to understand, easily forecasted, and it is also responsive to the changes in the volume and capacity, so it illustrates the results of demand management and multimodal policies.

According to the results of the literature review, nationwide agencies survey, and MDOT staff interviews, volume to capacity ratio is recommended to be calculated for peak hour and peak period during weekdays and weekends. In addition, this measure is recommended to be calculated for all vehicles combined.

8-2-2-5 Recommended specifications for Level of Service

Intensity of congestion delays on a roadway or intersection, rated from A (uncongested) to F (extremely congested) are calculated based on the V/C criteria for planning purposes. This measure can be reported as aggregated over a geographic area based on the percent of lane miles at different level of services.

This measure is used to qualify and categorize the volume to capacity ratios. According to the results of the literature review, nationwide agencies survey, and MDOT staff interviews, level of service is recommended to be calculated for peak hour, peak period, and daily during weekdays and weekends. This measure is recommended to be calculated for all vehicles combined.

8-2-3 Recommended data sources and tools to calculate/estimate the selected performance measures

Speed and travel time data are mostly obtained from online databases of probe-vehicle speed data. The speeds are then converted to the travel times using the segment length. As mentioned earlier, most of the MDOT work areas use the RITIS tool, which is powered by the INRIX and NPMRDS data. The data needs to be downloaded and processed to calculate the measures based on their definitions. The aggregation of the speed data can be chosen from 5-min, 10-min, 15-min, and 1-hour. For the applications defined in the context of this project, the aggregation level of 15-min is recommended to be used for calculating the measures. The NPMRDS data also contains separate records for passenger cars and freight traffic. Thus, this tool can be used to obtain the speed and travel time data for calculating the selected performance measures. The platforms enable MDOT to analyze, visualize and understand road performance without the need for additional technology investments.

In addition to the RITIS speed data, volume data can be estimated using the MDOT AADT data. By processing the AADT data, the traffic volumes can be attributed to the TMCs (traffic message channels), and then they can be used, along with the speed data for calculating/estimating the selected performance measures.

Increasing the data coverage is a critical factor for improving the MDOT performance management system, as most of the work areas mentioned this as their primary need. MDOT is recommended to collect data for non-motorized modes for developing the multi-modal performance measures in the future, not for the trunkline system, but for the urban areas.

Travel demand models are particularly useful for performance-based planning. The model needs to be calibrated using the continuous count stations, so if used along with traffic simulation models, it can forecast the performance measures, evaluate projects, and analyze different scenarios.

8-2-4 Recommended thresholds for the selected performance measures

The thresholds for the selected performance measures are not provided by most of the respondents to the nationwide agencies survey. Thus, the literature review outcomes are used to determine the recommended thresholds. A summary of these thresholds is presented in Tables 8-2 to 8-4. Note that no thresholds are set for total delay.

Table 8-2 Recommended resources for threshold(s) of Travel Time Index

Agency	Thresholds	Source
CMAP	TTI>1.75: Very heavy congestion 1.5<TTI<1.75: Heavy congestion 1.25<TTI<1.5: Moderate congestion 1.1<TTI<1.25: Light congestion TTI<1.1: Little congestion	https://www.cmap.illinois.gov/mobility/roads/cmp/performance-measurement
Maryland DOT	TTI>2.0: Severe Congestion 1.3<TTI<2.0: Heavy Congestion 1.15<TTI<1.3: Moderate Congestion TTI<1.15: Uncongested	https://roads.maryland.gov/mdotsha/pages/Index.aspx?PageId=360

Table 8-3 Recommended resources for threshold(s) of Planning Time Index

Agency	Thresholds	Source
Wisconsin DOT	PTI>1.7: Highly unreliable 1.3<PTI<1.7: Unreliable PTI<1.3: Reliable	https://wisconsindot.gov/Documents/about-wisdot/performance/mapss/perf-report.pdf
CMAP	PTI>2.55: Very severe unreliability 1.8<PTI<2.5: Severely unreliable 1.4<PTI<1.8: Moderately unreliable PTI<1.4: Generally reliable	https://www.cmap.illinois.gov/mobility/roads/cmp/performance_measurement
Florida DOT	PTI>3.0 2<PTI<3 1.5<PTI<2 1.33<PTI<1.5 1.15<PTI<1.33 PTI<1.15	http://fdotsourcebook.com/
MDOT Work Areas	PTI<1.8: reliable 1.8≤PTI<2: Approaching moderately unreliable 2≤PTI<3: Moderately unreliable 3≤PTI: severely unreliable	Michigan Mobility 2045

Table 8-4 Recommended resources for threshold(s) of Volume to Capacity Ratio

Agency	Thresholds	Source
MDOT Work Areas	V/C≥0.9: congested 0.7≤V/C<0.9: approaching congested 0.7 >V/C: uncongested	Michigan Mobility 2045

8-2-5 Recommended targets for the selected performance measures

The literature review outcomes are used to determine the recommended targets for total delay, level of service, and planning time index. A summary of these targets is presented in Tables 8-5 to 8-7. Note that for the travel time index and volume to capacity ratio measures, there were no inputs from the agencies in the nationwide survey, and also no values were provided in the online resources. MDOT needs to work with its MPO partners to set targets for each performance measure through recurring meetings to gather feedback on the gaps and necessary adjustments to the performance targets.

Table 8-5 Recommended resources for targets(s) of Total Delay

Agency	Target	Source
Wisconsin DOT	Reduce from previous year on interstates, aggregated over territories of MPOS	https://wisconsindot.gov/Documents/about-wisdot/performance/mapss/perf-report.pdf
Minnesota DOT	Reduce from previous year	https://www.dot.state.mn.us/measures/reports.html
California DOT	Reduce from previous year	https://dot.ca.gov/programs/traffic-operations/mpr/quarterly
Utah DOT	12,000 vehicle-hours over corridor (depends on corridor)	http://udottraffic.utah.gov/FPM/Delay
MDOT Work Areas	10 min of average delay per vehicle is generally acceptable for work zone areas	MDOT Staff Interviews

Table 8-6 Recommended resources for targets(s) of Level of Service

Agency	Target	Source
MDOT Work Areas	LOS C or better for rural region and LOS E or better for urban region freeways	MDOT Staff Interviews

Table 8-7 Recommended resources for targets(s) of Planning Time Index

Agency	Target	Source
Wisconsin DOT	Improve reliability from previous year at statewide level	https://wisconsindot.gov/Documents/about-wisdot/performance/mapss/perf-report.pdf

8-2-6 Recommended reporting and communication methods for the selected performance measures

As stated earlier, one of the primary goals of the performance management system is to improve communication between agencies and to the public. The performance reports need to be in a format that can be used by the transportation agencies for different applications and purposes. These reports should enable the work areas to evaluate the system performance in their jurisdiction, prioritize the projects, and to plan for short- and long-range time periods, accordingly. In this regard, a report similar to the Sufficiency Report can be a useful approach for reporting the measures to the public and different MDOT work areas for various applications. By using this approach, the work areas would be able to easily extract the data provided in the reports to address their needs. It should be noted that several MDOT work areas mentioned that they prefer the Sufficiency Reports format.

Regarding the scale for calculating the measures, the INRIX XDs (eXtreme Definition) are recommended if the data are available. These segments cover more miles of road than TMC segments and generally have greater granularity. Also, they have the ability to adapt more quickly to changes in the road network and the addition of new roads.

Visualizations play an important role in translating data into easily understood maps. In this regard, GIS-based maps should be provided along with the reports, because they can be acccessible by the work areas, and they can illustrate the data for the locations of interest. See Table 8-8 for example practices:

Table 8-8 Example practices for use of interactive maps and visualizations for reporting the system planning performance measures

Agency	Web Page	Date Accessed
Florida DOT	http://fdotsourcebook.com/#menu-performance-measures	October 6, 2022
Massachusetts DOT	https://mobility-massdot.hub.arcgis.com	October 7, 2022
Minnesota DOT	https://performance.minnesotago.org/criticalconnections/reliability/reliability-and-congestion	October 7, 2022
Ohio, Kentucky, and Indiana Metropolitan Transportation Plan	https://2050.oki.org/congestion-management-system-performance/	October 7, 2022
TTI Mobility Visualization Tools	https://mobility.tamu.edu/project/mobility-analysis-visualization-tools/	October 7, 2022
TTI Urban Mobility Report	https://mobility.tamu.edu/umr/	October 6, 2022
Utah DOT	http://udottraffic.utah.gov/FPM/Delay	October 6, 2022
Wisconsin DOT	https://transportal.cee.wisc.edu/gis/webmaps/mapss	October 7, 2022

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APPENDIX A – SUMMARY TABLE OF STATE DOTS AND MPOS PRACTICES REGARDING PERFORMANCE MEASUREMENT

In this appendix, the project team presents the summary of the state DOTs and MPOs practices regarding the operational performance measurement by reviewing their online resources. These practices are summarized in Table A-1.

Table A-1 Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Alabama	State	Duration of Congestion, % of congested travel, LOS, Travel Time Reliability, Delay per VMT	Included in the report	-	-	-	Evaluation of Performance Measures, Current Practice	(Harris & Farrington, 2009)
Alabama	State	Density	Vehicles per lane-mile	-	-	-	Evaluation of Performance Measures, Current Practice	(Harris & Farrington, 2009)
Alabama	State	-	-	-	-	-	Target values are provided	(ALDOT, 2018)
Arizona	State	Delay per person	Designed to resonate with travelers and other transportation system users by reporting delay in terms that travelers can understand and relate to.	-	-	-	Evaluation of Performance Measures, Current Practice	(Kolcz & Mickelson, 2004; Phoenix Metropolitan Region, 2015)
Arizona	State	Buffer Time Index	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Kolcz & Mickelson, 2004; Phoenix Metropolitan Region, 2015)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Arizona	State	Fuel Consumption per VMT	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Kolcz & Mickelson, 2004; Phoenix Metropoli-tan Region, 2015)
Arizona	Phoenix Region	% of miles congested	Average vehicle speeds drop below 50 mph	speeds drop below 50 mph	-	Included in the report	-	(Phoenix Metropoli-tan Region, 2015)
Arizona	Phoenix Region	% of times congested per mile	Percent of Time Congested Per Mile (Out of Total of 240 Miles Measured)	Average vehicle speeds drop below 50 mph	-	Included in the report	-	(Phoenix Metropoli-tan Region, 2015)
Arizona	Phoenix Region	Travel Time Index, Buffer Index	Included in the report	-	-	Included in the report	-	(Phoenix Metropoli-tan Region, 2015)
Arizona	Maricopa	Lost Productivity, Extent of Congestion, LOS	Included in the report	Values are provided	Included in the report	Included in the report	Target values are provided	(Cambrid-ge Systemati-cs, 2010)
Arizona	Maricopa	Travel Time Index, Buffer Time Index, Planning Time Index	Included in the report	Values are provided	Included in the report	Included in the report	BI is better than other reliability measures Target values are provided	(Cambrid-ge Systemati-cs, 2010)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
California	State	VMT	Amount of travel being done on the segments of freeway with automated VDS.	-	VDS sends speed and volume data to PeMS.	Flow recorded at each VDS is multiplied by the length of freeway assigned to that respective VDS to determine the distance.	More details for PeMS in https://pems.dot.ca.gov	(Caltrans, 2021)
California	State	Vehicle Hours of Delay (VHD)	Extra time spent in traffic beyond what people would experience if they were traveling at a given benchmark speeds.	Below 35 mph for severe congestion, and below 60 mph for all congestion (based upon traffic engineering experience)	Based on PeMS data, every day of the quarter, twenty–four hours a day. Caltrans' VDS send speed and volume data to PeMS every 30 seconds.	1) Delay = (Actual TT) - (Threshold TT) 2) Daily VHD = (Delay) x (Volume) 3) Annual Total VHD* = Sum (Daily VHD) for each day of the year.	Presented as total, weekday, holiday, day of week, Saturday, Sunday/holiday, county, and hours of day Targets available	(Caltrans, 2021)
California	State	Lost Lane Miles (LLM)	Cumulative difference between maximum capacity at a location and the observed flow during congestion.	35 mph and Capacity Flow Rate (calculated by PeMS).	VDS sends speed and volume data to PeMS.	If Avg Speed < 35 mph, LLMH = Hourly Flow/ Capacity Flow Avg. LLM per hour = LLMH /Time Period** **LLM calculated for AM Peak, PM Peak, Off-Peak Night and Off-Peak Day.	Presented as AM, PM peak and non-peak	(Caltrans, 2021)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
California	State	Bottleneck Locations	Bottleneck is a persistent and significant drop in speed between two locations on a freeway. Worst bottleneck locations are determined annually.	Top 10 Bottlenecks must: 1) Occur >= 20% of weekdays during year 2) Avg. Length >= 15 minutes 3) Cause more than 100 VHD per weekday	VDS sends speed and volume data to PeMS.	PeMS declares a bottleneck when: 1) Speed drop of 20+ mph between two successive detectors and, 2) Speed drop persist for at least five of seven contiguous five-minute intervals, and 3) Speed at downstream detector is below 40 mph.	PeMS identifies detector locations where conditions are met, not actual bottleneck location. District staff use their engineering judgment and local knowledge to adjust locations.	(Caltrans, 2021)
California	State	On_Road Mobile Source Emissions	California Clean Air Act mandates the Air Resources Board to achieve the maximum degree of emissions reductions from all on- and off-road mobile sources.	-	Data is currently collected under Criteria Pollutant Emissions. Caltrans prepares the Statewide CMAQ report.	-	Targets available	(Caltrans, 2015)
California	State	Annual Hours of Truck Delay	Represents a summation of the amount of extra time (delay) in hours spent by trucks along Interstate Corridors caused by congestion and/or other factors such as severe weather.	-	Freight VMT is calculated using the HPMS AADTT and modified by both a daily and hourly truck factor.	-	Methodology is available in detail in the report Targets available	(Caltrans, 2015)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
California	State	Truck Reliability Index	Truck reliability index is defined as the ratio of the total truck travel time needed to ensure on-time arrival to the agency-determined threshold travel time	-	Private sector speed data and vehicle miles traveled from HPMS volume data are used to calculate the measures.	Truck Reliability Index80 = 80th Percentile Travel Time Agency Travel Time	Method is available Targets available	(Caltrans, 2015)
California	Tahoe Region	Greenhouse Gas Emissions and Particular Matter	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Tahoe Region Planning Agency, 2017)
California	Tahoe Region	Per-Capita Fuel Consumption	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Tahoe Region Planning Agency, 2017)
California	Tahoe Region	Congestion Index, Delay, LOS, V/C, VHT, Vehicle Trips	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Tahoe Region Planning Agency, 2017)
California	Tahoe Region	PTI, TTI	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Tahoe Region Planning Agency, 2017)
California	Tahoe Region	PHT, PMT, Person Trips	-	-	-	-	Evaluation of Performance Measures, Current Practice	(Tahoe Region Planning Agency, 2017)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
California	State	LOTTR, Truck Travel Time Reliability Index	Included in the report	-	Detailed Description is available	Detailed Description is available	Target values and setting procedures are provided	(Caltrans, 2017)
California	State	Person Hours of Excessive Delay (PHED)	Annual Hours of Peak Hour Excessive Delay Per Capita	-	Detailed Description is available in the report	Difference between the measured travel time and the delay threshold travel time Delay threshold: 20mph or 60% of speed limit, whichever is greater Multiply travel time delay by number of people traveling during that 15-minute period	Weekdays: 6am-10am/Weekdays: 3pm-7pm or 4pm-8pm Target setting procedures are provided	(Caltrans, 2017)
California	State	Non-Single Occupancy Vehicle Travel	-	-	-	-	-	(Caltrans, 2017)
Colorado	State	PM3	Included in the report	-	-	-	Evaluation of Performance Measures, Current Practice	(Klop & Guderian, 2008)
Colorado	State	PM3	Included in the report	Included in the report	Included in the report	Included in the report	Target Values are provided in the report	(CDOT, 2018)
Colorado	Denver	Travel Time Variation	Variation between peak and off peak	-	-	-	-	(Governments, 2017)
Colorado	Denver	Lane-miles of roads congested for three-plus hours	Length of congestion more than 3 hours	-	-	-	-	(Governments, 2017)
Colorado	Denver	Bottleneck Points	Same as Pennsylvania	-	-	-	-	(Governments, 2017)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Connecticut	Capitol	On_Road Mobile Source Emissions	Included in the report	-	-	-	-	(Capitol Region Council of Governm -ents, 2019)
Delaware	State	Truck Travel Time Reliability	Measured on the Interstate high-way system at various times during the day and computes the median (50th percentile) travel speed vs. the “free flow” speed	-	Freight Analysis Framework	-	-	(DelDOT, 2019)
Delaware	State	Truck Bottlenecks	Truck Freight Bottleneck Reporting Guidebook	-	-	-	-	(DelDOT, 2019)
Delaware	Wilmingt on	PM3 measures	Similar to federal guidelines	-	-	Included in the report	Target values are provided	(DelDOT, 2021)
Florida	State	Combination Truck Hours of Delay	Combination Truck Miles Traveled (CTMT) is computed by multiplying VMT by the combination truck factor. The combination truck factor is provided on a county-by-county basis.	-	-	Described	-	(FDOT, 2017, 2019)
Florida	State	Miles Severely Congested	Same as other states using % of miles congested	-	-	-	-	(FDOT, 2019)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Florida	State	% of Travel Meeting LOS Targets	-	Acceptable is defined as LOS D (two-hour peak and daily) for largest MPO urbanized areas, LOS D (one-hour peak and daily) for other urbanized areas, and LOS C (one-hour peak and daily) everywhere else.	-	Described in detail	The percent of travel meeting LOS target is reported on daily and peak period basis for the 7 largest MPO urbanized areas, and on a daily and peak hour basis for all others.	(FDOT, 2019)
Florida	State	On-time Arrival	-	Same as previous row	-	Described in detail	-	(FDOT, 2019)
Florida	State	% of Travel Achieving Posted Speed Limit	-	-	-	Described	-	(FDOT, 2019)
Florida	State	% of Travel Heavily Congested	-	45 mph (Congested)	-	Described	-	(Transpor-tation Solutions Inc, 2004)
Florida	State	Truck Cost of Delay	Cost comes from average marginal cost of labor per hour and multiplying that by the number of hours of delay for combination trucks.	-	-	Described	-	(Transpor-tation Solutions Inc, 2004)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Georgia	State	PM3	Included in the report	Included in the report	Included in the report	Included in the report	-	(GDOT, 2017)
Georgia	State	V/C	Volume to Capacity Ratio	0.5, 0.75, 1 for moderate, heavy, and sever congestion	Included in the report	Included in the report	-	(GDOT, 2017)
Georgia	State	TTI, TDI	Included in the report	-	-	Included in the report	-	(GDOT, 2017)
Georgia	State	Monetary Cost of Travel Time Variability	Putting a dollar value on service reliability	-	-	C = a1*T + a2*Var(T) + a3*M	-	(GDOT, 2017)
Illinois	State	PM3	Included in the report	-	RITIS, NPRMDS	Described	-	(IDOT, 2019)
Illinois	State	Milage of Highly Congested Routes	-	-	-	-	-	(IDOT, 2019)
Illinois	Chicago	Congested Hours per Weekday	Data shows the average number of hours per weekday with at least a light level of congestion	Having a free flow speed greater than 1.10 times the congested speed. Free-flow speed is the average speed from 8 pm to 5:30 am.	Atlas Data Hub for Chicago	Described	-	(CMAP, 2021)
Indiana	State	Distance Weighted Congested Hours	The number of congestion hours multiplied by the segment length in miles.	45 mph (Congested)	Crowd-sourced GPS Speed Data	Appendix of Synthesis	-	(INDOT, 2018)
Minnesota	State	Average Hours of Delay	-	-	-	-	-	(MnDOT, 2018)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Minnesota	State	Travel Time Index, Buffer Time Index, Misery Index	Percent of person-miles traveled on the Interstate network that are considered reliable.	45 mph	-	-	-	(MnDOT, 2018)
Minnesota	State	Miles and Duration of Congestion	MnDOT defines congestion as traffic flowing at speeds less than 45 mph. At 45 mph, most vehicles will brake in a traffic stream, resulting in stop-and-go traffic.	45 mph	-	-	Target is to not exceed 10 year moving average	(MnDOT, 2021)
Minnesota	State	Travel Time Reliability on Interstate	Percent of person-miles traveled on the Interstate network that are considered reliable. This measure applies to both the Twin Cities metropolitan area and the state as a whole	45 mph	-	-	-	(MnDOT, 2021)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
NCHRP Synthesis 311	National	Travel rate, Delay rate, Total Delay, Congested Travel in person-miles	Included in the report	-	Included in the report	Included in the report	-	(Shaw, 2003)
NCHRP Synthesis 311	National	Buffer Time Index (BI)	Difference in the average travel rate and the 95th percentile travel rate divided by the average travel rate times 100%	-	Included in the report	Included in the report	-	(Shaw, 2003)
NCHRP 398	National	Travel rate, Delay rate, Total Delay, Relative Delay rate, Delay ratio, Mobility Index, Congested Travel in person-miles	Definitions are included in detail in the report	-	Included in the report	Included in the report	-	(Lomax, 1997)
New York	New York	PM3	Included in the report	Included in the report	Detailed Description is available	Included in the report	Target values are provided	(New York Metropoli-tan Transport-ation Council, 2020)
New York	New York	Person Hours of Delay / Vehicle Hours of Delay	Definitions are provided in the report	-	-	-	-	(New York Metropoli-tan Transport-ation Council, 2020)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
New York	New York	TTI	Same as previous states	-	-	-	-	(New York Metropoli -tan Transport -ation Council, 2020)
New York	New York	Total Emission	Same as previous states	-	-	-	-	(New York Metropoli -tan Transport -ation Council, 2018)
Pennsylvania	State	PM3	Included in the report	Included in the report	Included in the report	Included in the report	-	(PennDO -T, 2017, 2021a)
Pennsylvania	State	Time Delay / Time Delay per VMT	Time delay is the amount of extra time spent traveling due to congestion, represented as total vehicle hours of delay	60% of free flow speed	Volume information is derived from PennDOT-collected average annual daily traffic (AADT) volumes, with hourly and daily adjustments applied to develop hourly volumes.	Included in the report	-	(PennDO -T, 2017, 2021a)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Pennsylvania	State	Delay Cost	The user delay cost is calculated by multiplying the time delay by a cost per hour.	60% of free flow speed	Based on passenger VOT and commercial operating cost.	Included in the report	-	(PennDOT, 2021b)
Pennsylvania	State	Bottleneck Ranking	Bottlenecks consist of congestion occurring on consecutive road segments and/or time. A road segment is considered congested if the reported speed falls below 60% of the free-flow speed.	60% of free flow speed	Identifies bottlenecks in a dynamic manner, allowing the bottleneck to change locations, merge, and split apart over time, as described in Appendix 1 of the report	Queue lengths calculated in the Bottleneck Ranking tool are based on the length of TMC segments meeting the bottleneck activation criteria (60% of the free-flow speed).	-	(PennDOT, 2021b)
Texas	TTI	Delay per Mile	Normalized Delay	Included in the report	Described	Exhibit 2 of the report	-	(Texas Transportation Institute, 2021)
Texas	TTI	Texas Congestion Index	Actual per Free Flow TT	Included in the report	Described	Exhibit 2 of the report	-	(Texas Transportation Institute, 2021)
Texas	TTI	Congested Time	Time of congestion	80% of free flow speed	Described	Exhibit 2 of the report	-	(Texas Transportation Institute, 2021)
Texas	TTI	Congestion Cost	Cost of Congestion based on assumptions	-	Described	Exhibit 2 of the report	-	(Texas Transportation Institute, 2021)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Texas	TTI	Variability Index	A ratio of peak to off-peak variation in travel conditions. The index is calculated as a ratio of the difference in the upper- and lower-95 percent confidence intervals between the peak period and the off-peak period	-	-	Page 29 of the report	-	(Lomax & Schrank, 2002)
Texas	TTI	Misery Index	The use of the 20 percent value might be explained as focusing on the worst day of the week.	-	-	Page 31 of the report	-	(Lomax & Schrank, 2002)
Washington	State	PM3	Included in the report	Excessive delay based on travel time of 20 mph or 60% of posted speed limit, whichever is greater	Described in detail	-	Target values are provided	(WSDOT , 2020)
Washington	State	VMT	Included in the report	-	Described in detail	Included in the report	Target values are provided	(WSDOT , 2018)
Washington	State	% of miles congested and congestion Duration	Included in the report	Presented in 66	Described in detail	Included in the report	Target values are provided	(WSDOT , 2018)
Washington	State	Lost Throughput	Lost capacity due to congestion	-	Described in detail	Included in the report	Target values are provided	(WSDOT , 2018)

Table A-1 (Continued) Summary table of state DOTs and MPOs practices regarding performance measurement

Entity	State/MPO/ National	Measure	Definition	Threshold	Data	Calculation	Notes	Source
Washington	State	On-Road Mobile Source Emissions	Included in the report	-	-	Included in the report	Target values are provided	(WSDOT , 2020)
Wisconsin	State	Planning Time Index, Travel Time Index	-	1-1.3 - reliable/1.3-1.8 moderate/1.8 -3 unreliable	-	-	Target values are provided	(Wisconsin DOT, 2021)
Wisconsin	State	Annual Hours of Delay	Defined as the extra time spent driving in congested road conditions as compared to free-flowing travel conditions.	-	-	Calculated by measuring the number of vehicles on a corridor and then comparing actual travel times to the amount of time it would take to travel the same corridor at the posted speed limit.	Target values are provided	(Wisconsin DOT, 2021)
Wisconsin	State	LOS	Determined by guidebook	-	-	-	-	(Wisconsin DOT, 2021)
Wyoming	State	PM3	Included in the report	-	-	Included in the report	-	(WYDOT , 2021)

APPENDIX B – NATIONWIDE SURVEY

In this appendix, the project team presents the nationwide survey that was developed and distributed in Task 2 of the project. Note that this is the written form of the survey, and an online version was used to record survey attendees' responses.

Brief Description:

The Michigan Department of Transportation (MDOT) is evaluating its practices regarding the assessment of trunkline system performance. Michigan State University has been awarded a project funded by MDOT to evaluate past MDOT practices regarding Michigan trunkline operational performance measures with a goal of proposing performance measures based on current and future needs and the pertinent tools and methodologies for their implementation. To this end, the project team is identifying and evaluating a set of performance measures that meet the current needs of MDOT and maintain future state-owned highway condition assessment capabilities for planning and operational analysis purposes. This agency state-of-the-practice survey is critical to identifying possible measures, and we appreciate your responses!

Please share your name and contact information for survey follow-up (if necessary) and to share the results of our work with you in the future.

- **Your name:**
- **Agency name:**
- **Title in the agency:**
- **Contact information:**
  - **Email address:**
  - **Phone number:**

<u>Performance Measures and Data Sources to Power the Measures:</u>

1. Considering the following table demonstrating typical mobility and reliability performance measures, as well as commonly-used data sources to estimate the performance measures, please answer the following questions:

   1.1 **Check all the performance measures that your agency uses** to assess highway performance within your jurisdiction. If your agency uses any performance measure(s) other than those mentioned below, provide them under the "others" option.

   1.2 Which **data source(s)** do you use to extract/estimate each of the performance measures you selected above? For each performance measure, **check all that apply.** If your agency uses any data source(s) other than those mentioned below, provide them under the "others" option.

Performance Measures						Applicable Dataset(s)								
Category	Performance Measure [1]	Do you use this measure?	Which type of vehicle(s) do you use this measure for? [2]	Reporting period [3]	How often do you assess this measure? [4]	INRIX	NPRMDS	HERE	ATRI	In-house Traffic Count Data	Bluetooth Data	GPS Speed Data	HPMS Data	Others
Mobility	Vehicle-Miles Traveled													
	Vehicle-Hours Traveled													
	Average Speed													
	Travel Time													
	Density													
	Volume to Capacity Ratio													
	Level-of-Service													
	Total Delay (Vehicle Hours or Person Hours)													
	Delay per Mile													
	Total Delay Cost													
	Travel Time Index													
	Congestion Duration													
	Congestion Intensity													
	Percent of Miles Congested													
	Total Wasted Fuel													
	Total Wasted Fuel Cost													
	Others													
Reliability	Planning Time Index													
	Buffer Time Index													
	Travel Time Reliability Index													
	Others													

Notes for the table in Question 1 (comes with the table):

1 – If your definition of the measure or your calculation method for the measure is different from the provided definition in the survey, please provide them.

Definitions and Calculation Equations for Performance Measures in the Survey

Vehicle-miles Traveled (VMT)

Definition: Total distance traveled by all vehicles in a geographic region over a period of time (typically a year). VMT for segments of roadway can be summed to provide a system VMT estimate for geographic regions of interest (e.g., MPO area, DOT sub-region, urban area, etc.) and/or roadway functional classification.

Calculation Equation: $VMT\ (of\ a\ Segment) = Traffic\ Volume\ on\ Segment * Length\ of\ Segment$

$$VMT\ (of\ a\ Geographic\ Region) = \sum VMT\ (of\ Segments\ in\ the\ Geographic\ Region)$$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-2016-2.pdf

Vehicle-hours Traveled (VHT)

Definition: Total time spent by all vehicles in a geographic region over a period of time (typically a year). VHT for segments of roadway can be summed to provide a system VHT estimate for geographic regions of interest (e.g., MPO area, DOT sub-region, urban area, etc.) and/or roadway functional classification.

Calculation Equation: $VHT\ (of\ a\ Segment) = \sum_{n=1}^{N} \frac{Length\ of\ Segment}{Vehicle\ Speed_n}$, N = Total number of vehicles on the segment during the specified time period

$$VHT\ (of\ a\ Geographic\ Region) = \sum VHT\ (of\ Segments\ in\ the\ Geographic\ Region)$$

Average Speed

Definition: The average speed for a segment is calculated from the mean of speed of vehicles traversing the segment during a specified time period.

Calculation Equation:
$Average\ Travel\ Speed = \frac{\sum_{n=1}^{N} Vehicle\ Speed_n}{N}$, N = Total number of vehicles on the segment during the specified time period

Source: https://www.fdot.gov/docs/default-source/Planning/FTO/mobility/2017SBmethods.pdf

Average Travel Time

Definition: Average of the time spent by each vehicle traveling a segment for a given time interval. (e.g., 15-min).

Calculation Equation:
$Average\ Travel\ Time = \frac{\sum_{n=1}^{N} Vehicle\ Travel\ Time_n}{N}$, N = Total number of vehicles on the segment during the specified time period

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019-appx-a.pdf

Density

Definition: The number of vehicles per unit length per lane over a given time interval.

Calculation Equation: $Density = \frac{Number\ of\ Vehicles}{Segment\ Length * Number\ of\ Lanes\ of\ Segment}$

Source: https://uahcmer.com/wp-content/uploads/2011/01/Establishing-Performance-Measures-for-Alabamas-Transportation-System-FINAL.pdf

Volume to Capacity Ratio

Definition: Measures the level of congestion on a roadway by dividing the volume of traffic on the roadway segment by the capacity of the roadway segment.

Calculation Equation: $Volume\ to\ Capacity\ Ratio = \frac{Volume\ of\ the\ Segment}{Capacity\ of\ the\ segment}$

Source: http://www.dot.ga.gov/BuildSmart/ResearchDocuments/RP1016.pdf

Level-of-Service

Definition: Level of service (LOS) is a term used to qualitatively describe the operating conditions of a roadway based on factors such as speed, travel time, maneuverability, delay, and safety. The level of service of a facility is designated with a letter, A to F, with A representing the best operating conditions and F the worst, based on Highway Capacity Manual (HCM) guidelines.

Source: https://ccag.ca.gov/wp-content/uploads/2014/07/cmp_2005_Appendix_B.pdf

Total Delay (vehicle-hours or person-hours)

Definition: Delay is defined as the extra time spent driving in congested road conditions as compared to free-flowing travel conditions. Vehicle hours of delay is calculated as the sum of delay of the vehicles on the segment. Person-hours delay is calculated by multiplying the vehicle-hours delay by the average vehicle occupancy.

Calculation Equation:

$$Total\ Delay\ (vehicle - hours) = [Actual\ Travel\ Time - Freeflow\ Travel\ Time] * Vehicle\ Volume$$

$$Total\ Delay\ (person - hours) = [Actual\ Travel\ Time - Freeflow\ Travel\ Time] * Vehicle\ Volume * Average\ Vehicle\ Occupancy$$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2020-8.pdf

Delay per Mile

Definition: Delay is defined as the extra time spent driving in congested road conditions as compared to free-flowing travel conditions. Vehicle hours of delay is calculated as the sum of delay of the vehicles on the segment. Person hours of delay is calculated by multiplying the vehicle hours of delay by the average vehicle occupancy. Delay per mile in vehicle hours (person hours) is calculated by dividing vehicle hours (person hours) of delay by the road miles.

Calculation Equation:

$$Delay\ per\ Mile\ (vehicle - hours) = \frac{[Actual\ Travel\ Time - Freeflow\ Travel\ Time] * Vehicle\ Volume}{Road\ Miles}$$

$$Delay\ per\ Mile\ (person - hours) = \frac{[Actual\ Travel\ Time - Freeflow\ Travel\ Time] * Vehicle\ Volume * Average\ Vehicle\ Occupancy}{Road\ Miles}$$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2020-8.pdf

Total Delay Cost

Definition: Delay is defined as the extra time spent driving in congested road conditions as compared to free-flow travel conditions. Vehicle-hours of delay is calculated as the sum of delay of the vehicles on the segment. Total Delay Cost (in dollars) is the value of lost time due to congestion. It is computed as the person-hours of delay multiplied by the hourly value of person time.

Calculation Equation:

$$Total\ Delay\ Cost = [Actual\ Travel\ Time - Freeflow\ Travel\ Time] * Vehicle\ Volume * Average\ Vehicle\ Occupancy * Average\ Value\ of\ Person\ Time$$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019-appx-a.pdf

Travel Time Index

Definition: Ratio of peak-period travel time to free-flow travel time.

Calculation Equation: $Travel\ Time\ Index = \frac{Peak\ Travel\ Time}{Freeflow\ Travel\ Time}$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019-appx-a.pdf

Congestion Duration

Definition: This measure is used to identify the total amount of time during peak periods that are congested (e.g., speeds slower than the off-peak reference speed). It is calculated by summing all 15-min intervals during peak periods in which the road segment is congested.

Calculation Equation: $Congestion\ Duration = 15 * n$, in which n is the number of 15-min time intervals during peak period in which the road segment is congested.

Source: https://www.mdpi.com/2306-5729/2/4/39

Congestion Intensity

Definition: A two-dimensional measure, which accounts for the percentage of congested area in the time-space map. The congested area represents the sum of the duration of congestion during AM and PM peak periods for each segment multiplied by the length of the corresponding subsegment.

Calculation Equation: $Congestion\ Intensity_{ij}(\%) = \frac{\sum_1^K (Duration\ of\ Congestion_{kij} * Length_{kij})}{Time * Length_i}$

i: segment code
j: workday
k: subsegment number
Time: Study Period (AM or/and PM peak hours)

Source: https://www.mdpi.com/2306-5729/2/4/39

Congestion Severity

Definition: Delay is defined as the extra time spent driving in congested road conditions (e.g., speeds slower than the off-peak reference speed) as compared to traveling with off-peak reference speed. Vehicle hours of delay is calculated as the sum of delay of the vehicles on the segment. Congestion Severity is a ratio of vehicle -hours of delay to VMT.

Calculation Equation:
$Congestion\ Severity\ Index = \frac{[Actual\ Travel\ Time - Freeflow\ Travel\ Time] * Vehicle\ Volume}{VMT\ of\ Segment}$

Source: http://onlinepubs.trb.org/Onlinepubs/trr/1992/1360/1360-023.pdf

Percent of Miles Congested

Definition: The percent of the roadway that is congested. The measure is calculated by dividing the sum of length of segments in congested (e.g., speeds slower than the off-peak reference speed), by the sum of length of all segments in the network.

Calculation Equation: $Percentof\ Miles\ Congested = \frac{Sum\ of\ length\ of\ segments\ in\ congested\ condition}{Sum\ of\ length\ of\ all\ segments\ in\ the\ network}$

Source: http://www.trb.org/Publications/Blurbs/161859.aspx

Total Wasted Fuel

Definition: Difference between the total fuel used by vehicles during congestion (e.g., speeds slower than the off-peak reference speed) and the total fuel consumed by vehicles traversing with the off-peak reference speed.

Calculation Equation: $Total\ Wasted\ Fuel = Total\ Fuel\ Consumed\ in\ Congested\ Conditions - Total\ Fuel\ That\ Would\ be\ Consumed\ by\ vehicles\ traversing\ with\ the\ offpeak\ reference\ speed$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019-appx-a.pdf

Total Wasted Fuel Cost

Definition: Fuel cost due to congestion is calculated for vehicles by multiplying the total wasted fuel in congestion (e.g., speeds slower than the off-peak reference speed) by the cost of the fuel (dependent on the type of vehicle).

Calculation Equation:

$$Total\ Wasted\ Fuel\ Cost = (Total\ Fuel\ Consumed\ in\ Congested\ Condition - Total\ Fuel\ That\ Would\ be\ Consumed\ by\ vehicles\ traversing\ with\ the\ offpeak\ reference\ speed) * Fuel\ Cost$$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019-appx-a.pdf

Planning Time Index

Definition: Ratio of the 95th percentile travel time to the free-flow travel time.

Calculation Equation: $Planning\ Time\ Index = \frac{95th\ Percentile\ Travel\ Time}{Free-flow\ Travel\ Time}$

Source: https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2020-8.pdf

Buffer Index

Definition: A percentage that represents the extra buffer time (or "time cushion") that travelers must add to their average travel time to ensure on-time arrival for 19 of 20 trips. This extra time is added to account for any unexpected delay.

Calculation Equation: $Buffer\ Index(\%) = \frac{95th\ Percentile\ Travel\ Time - Average\ Travel\ Time}{Average\ Travel\ Time} * 100$

Source: https://ops.fhwa.dot.gov/publications/tt_reliability/ttr_report.htm

Level of Travel Time Reliability

Definition: Ratio of 80th percentile travel time to 50th percentile travel time.

Calculation Equation: $Travel\ Time\ Reliability = \frac{80th\ Percentile\ Travel\ Time}{50th\ percentile\ Travel\ Time}$

Source: https://ops.fhwa.dot.gov/publications/fhwahop19062/whatis.htm

2 - Specify the type of vehicles that you use this measure for (i.e., all vehicles together, trucks and passenger vehicles separately, trucks only, passenger vehicles only, transit only, etc.).

3 - Specify the time period for which the performance measure is calculated/estimated (i.e., peak hour, peak period, daily, yearly).

4 - Specify how often you assess the performance measure (i.e., quarterly, biannually, annually, every long-range transportation plan, etc.)

2. We are interested in the specifications you use for the performance measures you indicated above. (**Definition, thresholds, calculation equation, tools, etc.**)

   Explanation: A threshold value defines uncongested conditions for comparison with actual conditions in the computation of many of the delay-based performance measures.

Online Feature: an adaptive questionnaire should be used to have a list of thresholds mentioned in question 2, and blank fields for each performance measure to be filled.

3. How do you estimate the threshold for the performance measures that you identified in question 1.1? Please choose all that apply.

    - The threshold is/was determined based on a research study.

      Online Feature: In the online version, the survey attendee will be asked to cite the study or provide a link to the study if this option is selected.
    - The threshold is determined by engineering judgment in your agency.
    - The threshold is/was determined by other agency(s), and your agency is using it.
    - Your agency is using a threshold that is already in use by other agency(s).
    - Other
      Comments (optional):

4. What are the applications of the performance measures selected above? Please choose all that apply from the following categories and specify the performance measure(s) that are used for each application.

    Online Feature: Using an adaptive questionnaire, we can have blank fields for each of the performance measures determined in question 1.1 to be filled.

    - The performance measure is used for assessing the financial policies for allocating funds across programs and prioritizing the projects (Prioritizing Projects).
    - The performance measure is used for monitoring the efficiency and effectiveness of projects (Short/Long Range Transportation Planning).
    - The performance measure is used for improving situational awareness and identifying trends (Operational Improvement Evaluation).
    - Your agency is required to assess the performance measure (Policy Driven).
    - Other
      Comments (optional):

<u>**Data Analysis and Report:**</u>

5. Are the calculated performance measures reported to the public, or they are private and reported only to a specific agency(s)?

    - Performance measures are reported to the public
    - Performance measures are private and reported only to a specific agency(s)
    - Comment (optional):

6. Please specify the methods you use to **publish and report** the performance measures, i.e., visualization techniques. Please choose all that apply from the following tools.

    - RITIS
    - MATLAB
    - Python
    - Tableau
    - ArcGIS
    - Microsoft Power BI
    - Modeling software of your agency
      Comments (name of the software):
    - Others

<u>Pertinent Projects:</u>

7. Has your agency (or your partnering agencies) ever **evaluated its performance measurement system**? If so, please specify if you have published any report for the study (studies)?

    - Our agency has evaluated its performance measurement system and published a report.

      Online Feature: In the online version, the survey attendee will be asked to cite the report or provide a link to the report if this option is selected.

    - Our agency has evaluated its performance measurement system but has not published the results.

    - Our agency is currently evaluating its performance measurement system but has not published the results.

    - Our agency has evaluated its performance measurement system based on internal discussions and engineering judgment.

    - There has not been any official study of the performance measurement system in our agency based on my knowledge

8. If your agency has evaluated your state-owned highway performance measurement system, what lessons did you learn? What are the critical things to consider? What would you do differently? Do you have any additional suggestions or comments regarding the assessment of the performance measurement system?

APPENDIX C – QUESTIONNAIRE FOR MDOT STAFF INTERVIEWS

In this appendix, the project team presents the questionnaire developed and distributed for MDOT staff interviews (Task 4 of the project), including the survey introductory text and instructions. Note that this is the written form of the questionnaire, and an online version was used to record survey attendees' responses.

Brief Description:

The Michigan Department of Transportation (MDOT) is evaluating its practices regarding the assessment of trunkline system performance. Michigan State University has been awarded a project funded by MDOT to evaluate past MDOT practices regarding the assessment of Michigan trunkline system performance and propose performance measures based on current and future needs and the pertinent tools and methodologies for their implementation. To this end, the project team is identifying and evaluating a set of performance measures that meet the current needs of MDOT and to maintain future, state-owned highway condition assessment capabilities for planning and operational analysis purposes. This MDOT work areas survey is critical for identifying the current needs in this regard, and we appreciate your responses!

Please share your name and contact information for survey follow-up (if necessary) and to share the results of our work with you in the future.

- **Your name:**
- **Work area:**
- **Title in the work area:**
- **Contact information:**
    - **Email address:**
    - **Phone number:**

<u>Performance Measures and Their Applications:</u>

Considering the following table demonstrating the most applicable mobility and reliability performance measures as well as the application categories, please score the performance measures that are used for each of the following application categories, whether your work area uses it or not, based on their importance from 1 to 10 (10 illustrates very important and relevant measure to the application category) .

		Rankings of the Performance Measures for Each Application Category			
Category	**Performance Measure**	**Operational Evaluation[1]**	**Prioritizing Projects[2]**	**Short-/Long-range Transportation Planning[3]**	**Do you use this measure for other Applications?**
Mobility	**Vehicle-Miles Traveled**				
	Average Speed				
	Average Travel Time				
	Volume to Capacity Ratio				
	Level-of-Service				
	Total Delay (Vehicle Hours or Person Hours)				
	Travel Time Index				
	Congestion Duration				
	Percent of Miles Congested				
	Others				
Reliability	**Planning Time Index**				
	Buffer Time Index				
	Level of Travel Time Reliability Index				
	80 Percentile Travel Time				
	Others				

Notes for the table in Question 1 (comes with the table):

1- Operational Evaluation: Performance measures that are used for monitoring the effectiveness of projects.

2- Prioritizing Projects: Performance measures that are used to identify locations for possible investment and/or more detailed analysis.

3- Short-/Long-range Transportation Planning: Performance measures that are used for situational awareness and identifying trends.

1. We are interested in the specifications you use for the performance measures you indicated in Question 1 (**definition, calculation equation, threshold, etc.**).

   Explanation: A threshold value defines uncongested conditions for comparison with actual conditions in the computation of many of the delay-based performance measures.

   Online Feature: an adaptive questionnaire will be used to have a list of the performance measures that are selected in Question 1, and blank fields for each performance measure to be filled.

2. Is there any critical concern that should be taken into account when using any of the measures for their applications?

   Online Feature: In the online version, a blank field will be provided for each of the measures selected in question 1 to explain concerns, if there are any.
   If you use Level-of-Service and Volume-to-Capacity Ratio measures, please briefly explain your reason for choosing these measures for their applications in your work area.

   Online Feature: In the online version, this question will be asked if these performance measures are selected. Also, we add a note regarding the measures that are used more frequently than the Level-of-Service and Volume-to-Capacity Ratio for each application category, as below:

   Based on our nationwide survey, measures such as LOS and V/C no longer serve the needs as the congestion level grows in the transportation network. Also:

   Travel Time Index, Congestion Duration, Congestion Intensity, and Total Delay measures are more often used for Operational Improvement Evaluation than LOS and V/C among agencies.

   Travel Time Index and Total Delay measures are more often used for Short-/Long- range Transportation Planning than LOS and V/C among agencies.

   Travel Time Index and Congestion Duration measures are more often used for Prioritizing Projects than LOS and V/C among agencies.

   Note: The definitions of the mentioned performance measures will be provided in the online version.

3. Does your work area directly use the measures calculated and reported in the Annual MDOT Freeway Congestion and Reliability Reports and/or Annual Arterial Performance Reports for the mentioned applications?

   Note: In the online version, the list of the measures provided in the Annual Congestion and Reliability Reports and Annual Arterial Performance Reports will be provided.

   <u>Data Sources to Power the Performance Measures:</u>

4. Do you use data sources other than INRIX to calculate the measures? If yes, please specify them.

   Online Feature: Using an adaptive questionnaire, we can have the list of data sources determined in question 6, and blank fields for each data source to be filled.

5. Do you **collect/purchase** any of the data sources you mentioned in Question 6? If **yes**,

   Online Feature: For each of the collected/purchased data selected by survey attendee in question 6, we ask:

   7.1. Specify whether the data are collected or purchased.

   - Data are collected
   - Data are purchased

   7.2. Please provide a range or estimate of the **average annual cost of collection/purchase and data storage, including the staff time**.

8. Are there any **data needs** to improve the accuracy and/or coverage of the performance measurement system in your work area? If **yes**, please briefly explain them.

<u>Data Analysis and Report:</u>

9. Please specify the methods you use for **data analysis** and **calculation** of the performance measures, i.e., visualization techniques. Please choose all that apply from the following tools.

   - RITIS
   - MATLAB
   - Python
   - Tableau
   - ArcGIS
   - Modeling software of your work area
     Comments (name of the software):
   - Other

10. Please provide a range or estimate of the **average annual cost** of the methods you use for data analysis and calculation of the performance measures.

Online Feature: In the online version, this question will be asked for each of the methods that are selected in question 9.

11. What methods do you use in your work area to **publish** and **report** the performance measures? Please choose all that apply from the following categories.

    - Published Report
    - Public Website
        - Please check the box if an interactive map is provided on the public website.
    - Other

12. Who is the audience of the performance reports provided by your work area? Please choose all that apply from the following categories.

    - The performance measures are reported publicly.
    - The performance measures are private and reported only to a specific agency(s) or work area(s).
    - Some of the performance measures are reported to the public, and the others are reported only to a specific agency(s) or work area(s).
    - Other

    Comments (optional):

<u>Suggestions and Recommendations:</u>

13. What are the critical concerns to consider when developing a performance measurement system?

14. What are the needs of the MDOT performance measurement system, especially in your work area?

15. Do you have any additional suggestions or comments regarding the assessment of performance measurement system?

APPENDIX D – FREQUENCY OF USE OF THE PERFORMANCE MEASURES IN DIFFERENT MDOT REGIONS AND WORK AREA TYPES

In this appendix, the frequency of use of performance measures in different MDOT regions and work area types are provided.

Table D-1 Frequency of use of the performance measures in different regions and work area type

Measure	Grand Region				North and Superior Regions			Bay and Southwest Regions		
	TSCs (7)	Region (5)	GVMC (1)	**Total (13)**	TSCs (5)	Region (7)	**Total (12)**	TSCs (17)	Region (8)	**Total (25)**
Level of Service	6	2	0	**8**	5	6	**11**	15	6	**21**
Average Travel Time	4	4	0	**8**	1	1	**2**	6	7	**13**
Average Speed	4	4	0	**8**	2	6	**8**	10	5	**15**
Volume to Capacity Ratio	4	2	1	**7**	3	2	**5**	12	5	**17**
Total Delay	3	4	0	**7**	3	5	**8**	15	3	**18**
Congestion Duration	3	3	1	**7**	1	2	**3**	7	3	**10**
Travel Time Index	3	2	1	**6**	2	3	**5**	6	2	**8**
Vehicle Miles Traveled	0	2	1	**3**	1	2	**3**	6	3	**9**
Percent of Miles Congested	1	0	1	**2**	1	1	**2**	0	0	**0**
85^{th} Percentile Speed	0	0	0	**0**	0	1	**1**	0	0	**0**
User Delay Cost	0	0	0	**0**	0	0	**0**	0	1	**1**
Level of Travel Time Reliability Index	1	3	0	4	2	2	4	2	6	8
Planning Time Index	3	2	0	5	3	2	5	3	5	6
80th Percentile Travel Time	2	2	0	4	0	1	1	4	3	7
Buffer Time Index	0	0	0	0	0	0	0	1	2	3

Table D-1 (Continued) Frequency of use of the performance measures in different regions and work area type

Measure	Metro Region				Bureau of Field Services and Bureau of Development			Bureau of Transportation Planning			
	TSCs (3)	Region (3)	SEMCOG (0)	**Total (6)**	Field Services (5)	Development (3)	**Total (8)**	Planning (5)	Asset Management (0)	Data Inventory (2)	**Total (7)**
Level of Service	1	3	-	**4**	5	3	**8**	4	-	1	**5**
Average Travel Time	0	3	-	**3**	4	1	**5**	3	-	1	**4**
Average Speed	1	3	-	**4**	5	1	**6**	5	-	2	**7**
Volume to Capacity Ratio	1	2	-	**3**	3	1	**4**	5	-	1	**6**
Total Delay	1	3	-	**4**	3	0	**3**	3	-	1	**4**
Congestion Duration	0	2	-	**2**	3	0	**3**	0	-	1	**1**
Travel Time Index	1	2	-	**3**	2	3	**5**	2	-	1	**3**
Vehicle Miles Traveled	0	2	-	**2**	1	2	**3**	5	-	2	**7**
Percent of Miles Congested	2	0	-	**2**	1	0	**1**	2	-	1	**3**
85th Percentile Speed	0	0	-	**0**	0	0	**0**	0	-	0	**0**
User Delay Cost	0	0	-	**0**	0	0	**0**	0	-	0	**0**
Level of Travel Time Reliability Index	1	3	-	**4**	3	2	**5**	4	-	1	**5**
Planning Time Index	0	3	-	**3**	4	1	**5**	3	-	1	**4**
80th Percentile Travel Time	0	1	-	**1**	1	1	**2**	5	-	2	**7**
Buffer Time Index	0	1	-	**1**	0	0	**0**	5	-	1	**6**

APPENDIX E – SUM AND AVERAGE SCORES OF THE PERFORMANCE MEASURES FOR EACH APPLICATION CATEGORY PROVIDED BY MDOT REGIONS AND WORK AREA TYPES

In this appendix, sum and average scores of measures provided by MDOT regions and work area types are presented.

Table E-1 Sum and average scores of the performance measures for each application category based on responses from Metro region

	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
Measure	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Vehicle Miles Traveled	5	5	5	5	8	8
Average Speed	22	7.3	22	7.3	14	7
Volume to Capacity Ratio	11	5.5	14	7	8	8
Level of Service	24	8	22	7.3	18	9
Average Travel Time	19	9.5	15	7.5	8	8
Total Delay	25	8.3	29	9.7	16	8
Travel Time Index	14	7	15	7.5	9	9
Percent of Miles Congested	6	6	3	3	8	8
Congestion Duration	7	7	7	7	6	6
Level of Travel Time Reliability Index	27	9	22	7.3	25	8.3
Planning Time Index	15	7.5	13	6.5	17	8.5
80th Percentile Travel Time	-	-	-	-	-	-

Table E-2 Sum and average scores of the performance measures for each application category based on responses from Grand region

	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
Measure	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Level of Service	68	8.5	67	8.4	66	8.3
Average Travel Time	55	6.9	45	5.6	39	5.6
Average Speed	49	6.1	34	4.3	40	5.7
Volume to Capacity Ratio	50	7.1	51	7.3	57	8.1
Total Delay	49	7	46	6.8	41	6.8
Congestion Duration	24	4.8	28	5.6	31	6.2
Travel Time Index	41	6.8	39	6.5	33	6.6
Vehicle Miles Traveled	10	5	6	3	15	5
Percent of Miles Congested	-	-	-	-	7	7
Planning Time Index	30	6	29	5.8	30	6
80th Percentile Travel Time	32	6.4	31	6.2	28	5.6
Level of Travel Time Reliability Index	29	7.3	25	6.3	30	5.8

Table E-3 Sum and average scores of the performance measures for each application category based on responses from Bay and Southwest regions

Measure	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Level of Service	40	6.67	40	5.71	38	6.2
Average Travel Time	34	6.8	29	4.83	36	6.9
Total Delay	41	6.83	26	4.33	34	5.23
Average Speed	23	5.75	18	4.5	22	5.12
Volume to Capacity Ratio	42	7	21	7	30	6
Vehicle Miles Traveled	15	3.75	15	5	21	4.25
Travel Time Index	15	5	23	5.75	14	4.67
Congestion Duration	24	6	13	6.5	14	7
Level of Travel Time Reliability Index	25	5	18	4.5	12	4
Planning Time Index	10	5	21	7	12	6
Delay Index	7	7	5	5	8	8
80th Percentile Travel Time	18	6	8	4	11	5.5

Table E-4 Sum and average scores of the performance measures for each application category based on responses from North and Superior regions

	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
Measure	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Level of Service	83	7.55	64	5.82	78	7.8
Total Delay	73	9.13	70	8.75	64	9.14
Average Speed	51	5.67	46	5.11	39	4.88
Volume to Capacity Ratio	38	6.33	45	7.5	36	7.2
Travel Time Index	42	8.4	35	7	27	6.75
Vehicle Miles Traveled	19	4.75	23	5.75	29	7.25
Congestion Duration	21	7	21	7	18	9
Average Travel Time	21	7	22	7.33	13	6.5
Percent of Miles Congested	11	5.5	8	4	13	6.5
85th Percentile Speed	-	-	-	-	-	-
Level of Travel Time Reliability Index	49	8.17	40	6.67	41	6.83
Planning Time Index	39	7.8	33	6.67	33	6.6

Table E-5 Sum and average scores of the performance measures for each application category based on responses from bureaus of field services and development

Measure	Operational Evaluation		Prioritizing Projects		Short/Long Range Transportation Planning	
	Sum of Scores	Average Score	Sum of Scores	Average Score	Sum of Scores	Average Score
Level of Service	24	8	32	8	22	7.33
Average Speed	9	4.5	16	5.33	11	5.5
Travel Time Index	15	7.5	23	7.66	14	7
Average Travel Time	10	5	17	5.66	12	6
Total Delay	10	10	20	10	8	8
Volume to Capacity Ratio	14	7	16	8	8	8
Vehicle Miles Traveled	5	5	5	5	6	6
Congestion Duration	8	8	18	9	8	8
Percent of Miles Congested	3	3	1	1	-	-
ADT	6	6	6	6	6	6
Level of Travel Time Reliability Index	6	6	18	9	8	8
Planning Time Index	6	6	18	9	8	8
80th Percentile Travel Time	-	-	10	10	8	8

APPENDIX F – NATIONWIDE AGENCIES FOLLOW-UP SURVEY

In this appendix, the project team presents the questionnaire developed and distributed for nationwide agencies follow-up survey. Note that this is the written form of the survey, and an online version was used to record survey attendees' responses.

Brief Description:

The Michigan Department of Transportation (MDOT) is evaluating its practices regarding the assessment of state-owned highway system performance. Michigan State University has been awarded a project funded by MDOT **to evaluate past MDOT practices regarding the assessment of Michigan state-owned highway system performance and propose performance measures based on current and future needs and the pertinent tools and methodologies for their implementation.** To this end, the project team is identifying and evaluating a set of performance measures that meet the current needs of MDOT and to maintain future, state-owned highway condition assessment capabilities for planning and operational analysis purposes. You responded to the first round of survey, which was done between March 2021 and May 2021. **This is a follow-up survey to ask you further questions regarding the potential performance measures for the Michigan state-owned highway system.** This survey is critical to identifying proper specifications for the measures, and we greatly appreciate your responses!

Please share your name and contact information for survey follow-up (if necessary) and to share the results of our work with you in the future.

- **Your name:**
- **State:**
- **Agency Type: State DOT/ MPO/ National/ Other**
- **Agency Name:**
- **Role in Agency:**
- **Contact Information:**
    - **Email:**
    - **Phone:**

<u>Performance Measures and Their Applications:</u>

1. Considering the following table demonstrating a set of mobility and reliability performance measures as well as the application categories, please **score the performance measures for each of the following application categories,** whether your agency uses them or not, based on their importance from 1 to 10 (10 illustrates very important and relevant measure to the application category).

Note: The performance measures provided in the table were selected based on the first round of the nationwide survey and interviews with the MDOT staff. The definitions of the measures are also provided.

Note: The definitions and calculation equations of the measures are provided to the attendees, similar to the nationwide agencies survey in Task 2.

	Scores of the Performance Measures for Each Application Category		
Performance Measure	**Operational Evaluation[1]**	**Prioritizing Projects[2]**	**Short-/Long-range Transportation Planning[3]**
Total Delay			
Travel Time Index			
Percent of Miles Congested			
Volume to Capacity Ratio			
Level of Service			
Planning Time Index			
Level of Travel Time Reliability Index			

Notes for the table in Question 1 (comes with the table):

1- Operational Evaluation: Performance measures that are used for monitoring the effectiveness of projects.

2- Prioritizing Projects: Performance measures that are used to identify locations for possible investment and/or more detailed analysis.

3- Short-/Long-range Transportation Planning: Performance measures that are used for situational awareness and identifying trends.

2. We are interested in the specifications for the performance measures that you use among the set of performance measures provided in question 1 (**definition, calculation equation, threshold(s), target(s), etc.**). If the definition and calculation equation of each performance measure in your agency is different from the ones that are provided, please specify them. Also, please provide the threshold(s) and target(s) that you use for each of the performance measures (Table F-1)

2.1 We are interested in the calculations of the threshold(s) hat your agency uses for each performance measure. Please briefly explain how you calculate and set this variable(s).

Explanation: A threshold value defines uncongested conditions for comparison with actual conditions in the computation of many of the delay-based performance measures.

<u>Additional Recommendations and Suggestions:</u>

3. Do you have any additional suggestions or comments regarding the questions of the survey?

Table F-1 Specifications of the potential performance measures, provided for question 2 of the survey

	Specifications of the performance measures					
Performance Measure	**Definition**	**Calculation Equation**	**Threshold Explanation**	**Threshold Example**	**Target Explanation**	**Target Value Example**
Total Delay	Delay is defined as the extra time spent driving in **congested conditions** as compared to uncongested travel conditions.	Total Delay (vehicle-hours) = (segment length / average speed of vehicles in congested condition– segment length / **uncongested travel speed**) * number of vehicles traveling in congested condition	1) Congested condition is defined as when the actual speeds are less than **THRESHOLD1** on the roadway. 2) Uncongested travel speed for delay calculation is determined as **THRESHOLD2**	1) Average speed lower than 60 mph on a freeway segment with a posted speed limit of 70 mph is considered as congested condition. 2) Free-flow speed	Lower than or equal to **TARGET** during peak-period indicates acceptable for freeway segment.	**10 vehicle-hours**
Travel Time Index	Ratio of peak-period travel time to **free-flow travel time**.	Travel Time Index = Peak travel time / **Free-flow travel time**	**Free-flow travel time**	85th percentile of uncongested travel time distribution	Greater than or equal to **TARGET** is considered unreliable roadway	**1.5**
Percent of Miles Congested	The percent of the roadway that is congested. The measure is calculated by dividing the sum of length of segments in congested condition. (e.g., speeds **less than 90 percent of free-flow speed**), by the sum of length of all segments in the network.	Percent of Miles Congested = Sum of length of segments **in congested condition** / Sum of length of all segments in the network	Congested condition is defined as when the actual speeds are less than **THRESHOLD** on the roadway. In other words, speeds would have to drop below **THRESHOLD** on a freeway segment before delay would begin to be calculated.	60 mph on a freeway segment with a posted speed limit of 70 mph	Percent of miles that are congested on the interstate network in year 2024 should be lower than **TARGET**	**20 Percent**
Volume to Capacity Ratio	Measures the level of congestion on a roadway by dividing the volume of traffic on the roadway segment by the **capacity of the roadway segment**	Volume to Capacity Ratio = Volume of the segment / **Capacity of the segment**	**Capacity of the segment**	-	Greater than **TARGET1** is considered as severe congestion Greater than **TARGET2** and smaller than **TARGET1** is considered as moderate congestion Smaller than **TARGET2** is considered as low/no congestion	Greater than **1** is considered as severe congestion Greater than **0.8** and smaller than **1** is considered as moderate congestion Smaller than **0.8** is considered as low/no congestion
Level of Service	Intensity of congestion delays on a roadway or intersection, rated from A (uncongested) to F (extremely congested) are calculated based on **Highway Capacity Manual (HCM)** guidelines.	Provided in **Highway Capacity Manual (HCM) guidelines**	1) Rates from A (uncongested) to F (extremely congested) are calculated based on the capacity, roadway type, etc. according to **Highway Capacity Manual (HCM)** guidelines 2) Capacity of the segment	-	Better than **TARGET1** for rural highways and better than **TARGET2**for urban highways	Better than **LOS C** for rural highways and better than **LOS D** for urban highways
Planning Time Index	Ratio of the 95th percentile travel time to the **free-flow travel time**.	Planning Time Index = 95th percentile travel time / **Free-flow travel time**	**Free-flow travel time**	85th percentile of uncongested travel time distribution	Greater than or equal to **TARGET1** is considered unreliable roadway	Greater than or equal to **1.8** is considered unreliable roadway
Level of Travel Time Reliability Index	Ratio of 80th percentile travel time to 50th percentile travel time	Level of Travel Time Reliability Index = 80th percentile travel time / 50th percentile travel time	-	-	Greater than or equal to **TARGET1** is considered unreliable roadway	Greater than or equal to **2** is considered unreliable roadway