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MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

IDENTIFICATION OF METRICS USED FOR VARYING LEVELS OF TRAFFIC ANALYSIS

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16. Abstract

This project was completed to support the Maryland Department of Transportation State Highway Administration (MDOT SHA) as it actively pursues the most appropriate metrics for transportation projects decision making. The goal of this research project was to identify the state-of-the-practice performance metrics currently employed by state agencies across various transportation projects.

To achieve the research goal, the MTI team surveyed stakeholders—including federal, state, and local agency staff and private-sector professionals—who have experience with various transportation projects and associated project decisions and performance evaluation. From the survey results, the MTI team produced a metrics flowchart that documents the current performance metrics used in three stages: (1) Feasibility and Planning, (2) Design and Construction, and (3) Maintenance and Operations. Within those stages, six different categories—Mobility, Reliability, Safety, Environment, Socio-economic, and Recreation—were evaluated. At the Feasibility and Planning stage, performance metrics were listed under each project type. Metrics that were more frequently used in practice based on the survey responses were listed at the top of the decision chart. One key finding is that equity, multimodal, and vulnerable roadway user metrics are consistently missing from the breadth of metrics used. The focus of vehicle-based metrics could lean decision makers to advance projects that are not necessarily supportive of other modes.

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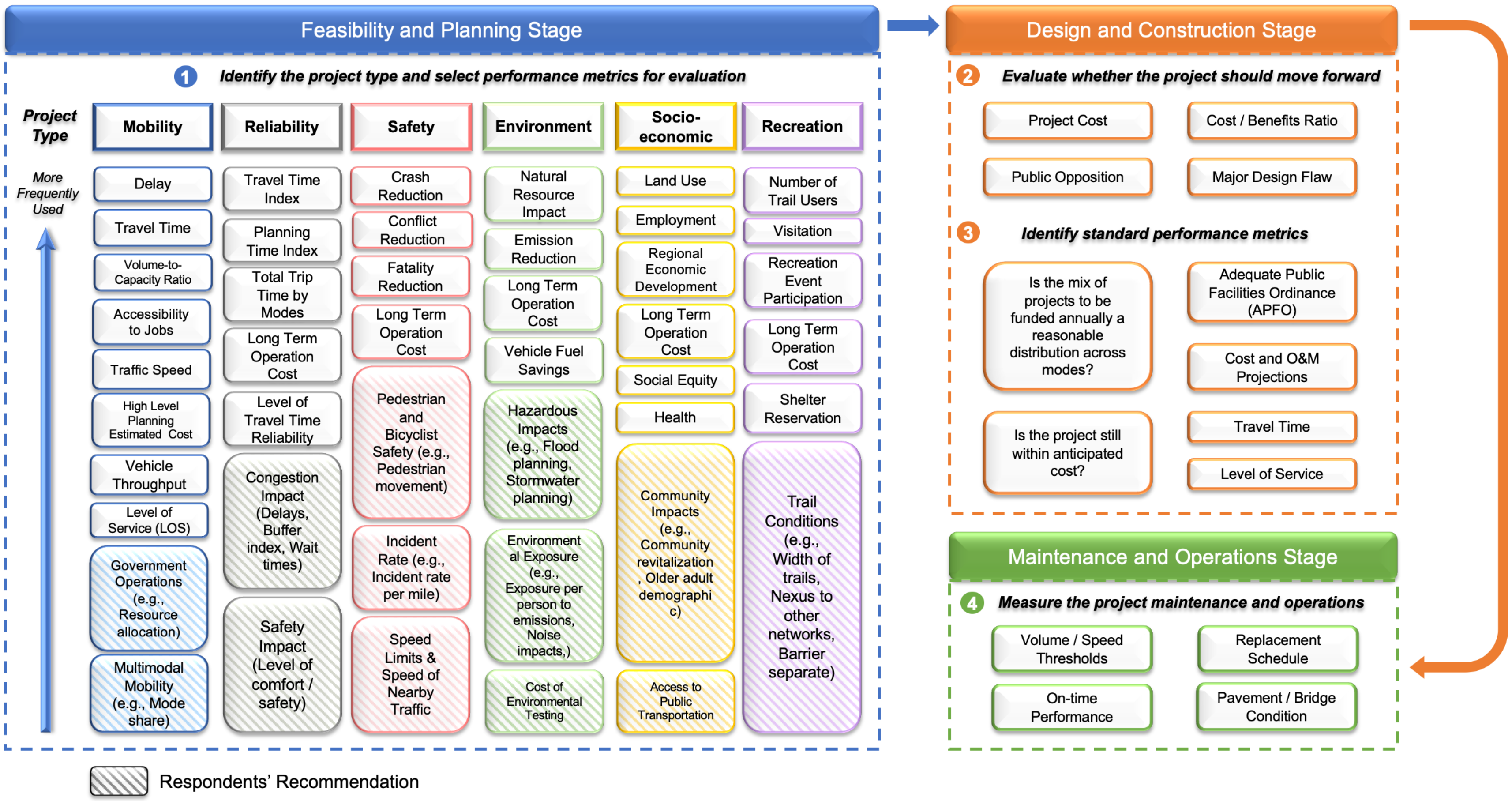
EXECUTIVE SUMMARY

This project was completed to support the Maryland Department of Transportation State Highway Administration (MDOT SHA) as it actively researches the most appropriate metrics to apply during transportation projects analysis to support decision making. The goal of this research project was simply to identify the current state-of-the-practice performance metrics employed by state agencies for different types of transportation projects.

To achieve the research goal, the MTI team surveyed stakeholders—including federal, state, and local agency staff and private-sector professionals—who have experience with various transportation projects and associated performance evaluations. From the survey results, the MTI team produced a flowchart that documents the current performance metrics used in three stages: (1) Feasibility and Planning, (2) Design and Construction, and (3) Maintenance and Operations. Within those stages, six different categories—Mobility, Reliability, Safety, Environment, Socio-economic, and Recreation—were evaluated. The figure below illustrates the final flowchart as a result of this research effort.

At the Feasibility and Planning stage, best-practice performance metrics are listed under each project type. Metrics that are more frequently used in practices based on the survey are listed at the top of the chart. In addition, critical performance measures for Design and Construction and Maintenance and Operations were surveyed and summarized in the framework. For instance, project cost, cost/benefits ratio, public opposition, and major design flaws are deemed the critical metrics for evaluating whether the project should move forward for implementation/construction. One key finding was that equity, multimodal, and vulnerable roadway user metrics are consistently missing from the breadth of metrics used. It is expected that the focus of vehicle-based metrics could lean decision makers to advance projects that are not necessarily supportive of other modes. This is an assumption based on the initial table top exercise of metrics and that respondents did not report those metrics as "missing" when identifying if other metrics might be important.

Measures of Effectiveness Used Across Respondents



In addition to the survey results, the MTI team conducted a quick table-top review of current national practices for project analysis. The selection of analysis, modeling, and simulation tools that support performance metrics should be different for different stages of the transportation planning process. At the long-range planning stage, it may not be practical to apply the most complex tool for each conceived traffic operations project. Sketch planning tools or travel demand model postprocessing tools may be more suitable. At the Transportation Improvement Program (TIP) and project planning stages, mesoscopic and microscopic traffic simulation tools may be considered for traffic operations project studies. Multi-scenario and multi-resolution tools for estimating travel reliability impact under different weather and accident conditions may also be added at these stages to provide more comprehensive information to support decision making. Post-project evaluation could rely on existing performance monitoring dashboard tools such as the Regional Integrated Transportation Information System (RITIS).

In summary, this research project provides timely information to help understand what performance measures are actually being used across the nation as staff make a decision at the planning, construction, and operations stages of a transportation project. A flowchart framework that documents the current metrics for evaluating projects in different stages of planning and operations was produced to support transportation planners and engineers in their decision making. This research also highlights gaps in metrics used during project analysis, specifically vulnerable roadway users, equity-based metrics, and social justice. This research makes no recommendations on best metrics to use, only reports industry findings.

INTRODUCTION

The Maryland Department of Transportation's State Highway Administration (MDOT SHA) has committed to improving mobility, safety, reliability and sustainability through transportation planning. The current federal transportation legislation, "Moving Ahead for Progress in the 21st Century" (MAP-21), which was signed into law July 6, 2012, advances statewide and metropolitan planning processes to incorporate a more comprehensive performance-based approach to decision-making. Typical performance metrics in planning for traffic operations include changes in vehicle trips; vehicle miles traveled; emissions reduction; travel time savings; improvements in travel time reliability; energy consumption reduction; noise impacts; safety impacts; monetary values of these changes; and lists of traffic operations equipment and costs.

In addition to the more traditional planning analyses, emerging data sources such as probe data, video-based traffic counts, connected vehicle data, and passively collected mobile device location data have enabled additional performance metrics for planning and more real-time traffic operations management. It is now possible to tell which users and which origin-destination pairs are using a particular transportation facility and in turn, which facilities can benefit from traffic operations improvements. Compared to traditional travel demand models, mesoscopic modeling and dynamic traffic assignment are more in line with strategic congestion management. Reliability metrics have also been integrated into newer models/tools and the planning process. For instance, the MDOT SHA *Reliability Roadmap* implements a four-step process for managing congestion. How should MDOT SHA report and evaluate projects, considering that new tools can do so much more than before? Additionally, state agencies increasingly must provide performance metrics that can tell a story, rather than report technical data that only engineers can understand. To support ongoing efforts to keep a data-driven agency, it is important to define appropriate performance metrics at various stages of planning and to ensure data sources and modeling tools are available to quantify these performance metrics to support decision making. For example, the Maryland Department of Transportation (MDOT) has implemented the Excellerator dashboard for performance management across the agency and continuously searches for best methods to report out accuracy of those existing performance measures, or new ones that help MDOT better understand the current conditions of our transportation ecosystem. In addition to contributing to the Excellerator dashboard, MDOT SHA also produces the State Highway Mobility Report annually and leverages various performance dashboards for situational awareness and metrics monitoring.

The goal of this research project is to identify state-of-the-practice performance metrics and evaluation tools currently employed by state agencies for different types of transportation projects. To achieve this goal, this project attempted to:

- Identify different types of planning-level projects occurring at state agencies and determine the level of analysis required to make reasonable recommendations. Different types of planning-level projects would be identified through coordination with state DOTs and their experience reporting various metrics.
- Produce a flowchart that documents the metrics used.

MDOT SHA OPERATIONS PRACTICE SCAN SURVEY

The MTI team conducted a survey named "MDOT SHA Operations Practice Scan Survey" (see Appendix for the detailed survey results) to collect information from stakeholders including staff from federal, state, and local agencies and other private-sector professionals with experience in performance evaluation of transportation projects. Based on a literature review and discussions with MDOT SHA, the team identified three major stages of a transportation project: **Feasibility & Planning**, **Design & Construction**, and **Maintenance & Operations**. For each of the stages, various performance metrics may be used by practitioners to evaluate the project. Based on these presumptions and categorization, the team conducted a web-based survey of current practices with a focus on performance metrics chosen for the evaluation of projects at different stages of the traffic operations planning process.

The team collected 78 usable responses from the web-based survey. The figure below summarizes the agency distribution of the respondents from across the nation. Most of the respondents were from county (26), local municipality (16), state department of transportation (14) and private consulting firms (9), while the remaining (23) were from other agencies or organizations. The respondents had mixed backgrounds, with 37 of them working most frequently on highway projects, 16 of them on arterial projects, 13 of them on pedestrian- and bike-related projects, and 8 of them on transit-related projects.

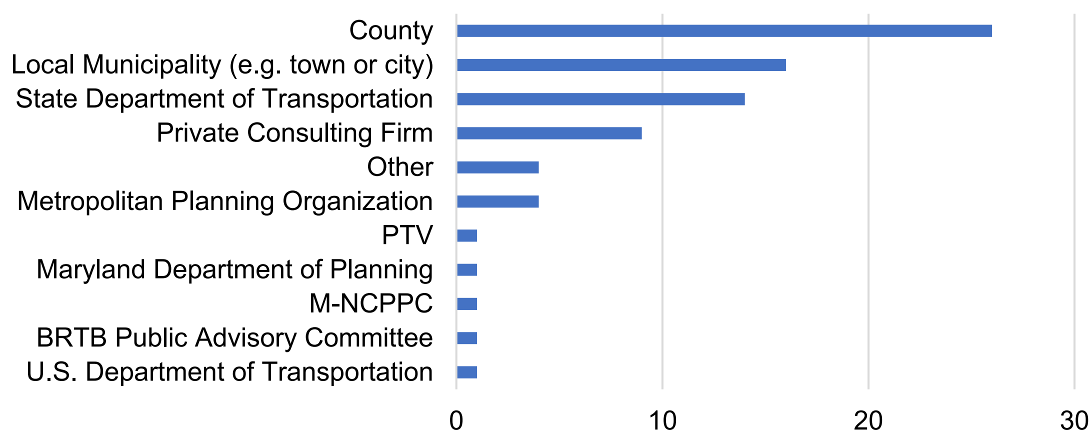


Figure 1. Survey Sample Distribution among Agency Types

Based on the survey results, the MTI team produced a flowchart (see Figure 2) that documents the performance metrics used in evaluating projects for three stages (**Feasibility and Planning**, **Design and Construction**, and **Maintenance and Operations**) of transportation planning projects.

Feasibility and Planning Stage

In the **Feasibility and Planning** stage, the project type was further refined, knowing that best-practice metrics would differ structurally within different project types and that different metrics may need to be measured for all project types. The MTI team thus identified six transportation projects:

- **Mobility**: projects that focus on reducing congestion delays and typically include capacity improvements, micro-mobility infrastructure, transit solutions, etc;
- **Reliability**: projects that focus on maximizing existing operations, such as technology deployments to manage the transportation system more effectively;
- **Safety**: projects that focus on systematically and holistically promoting safety, using metrics such as the severity of crashes, high rate of crashes, vulnerable user interactions with vehicles, freight design concerns, etc.;
- **Environmental**: projects that focus on managing environmental impact, sustainability, energy/emissions, and public health. Metrics could also include stream restoration, flooding mitigation, etc.;
- **Socio-economic**: projects that focus on economic revitalization, food desert programs, environmental justice/equity, etc.;
- **Recreational**: projects that include trails, visitor rest stops, etc.

Based on these predefined project goal category/types, the team comprehensively reviewed the typical performance metrics used for each type of project and listed these metrics in the survey questions to facilitate post-processing of responses. Respondents were then asked to rank the frequency of these performance metrics when performing a planning-level analysis or feasibility assessment. In case there were metrics missing from the list, the respondents were asked to fill in an open-ended section with the metrics they felt were relevant to the question. We note that while recurring metrics across industry were highlighted in this survey, several were not emphasized that are in fact used, including but not limited to bicycle level of stress, transit coverage, etc.; however, the open ended "add your own metric" also helped us identify that if those metrics were not reported, it was likely they were not frequently used. This report makes no stance of whether those metrics should or should not be used, only identifies what is most frequently reported. As shown in the flowchart, during the feasibility and planning stage, more frequently used performance metrics were identified based on the respondents' answers. Below is a summary of the major findings:

- **For mobility-related projects**, "Delay", "Travel Time" and "Volume-to-Capacity Ratio" are the three most frequently used performance metrics. Respondents also suggested metrics such as "Government Operations" (e.g., resource allocation, master plan comformance, equipment availability) and "Multimodal Mobility" (e.g., mode share, transfer time, bicycle network).

- **For reliability-related projects**, in addition to the commonly used “Travel Time Index” and “Planning Time Index”, “Total Trip Time by Modes” is also frequently used. Respondents also suggested metrics such as “Congestion Impact” (e.g., delays, buffer index, wait times) and “Safety Impact” (e.g., level of comfort / safety).
- **For safety-related projects**, the typical performance metrics include “Crash Reduction”, “Conflict Reduction”, and “Fatality Reduction”. Respondents emphasized the importance of “Pedestrian and Bicyclist Safety” (e.g., pedestrian movement). Some other frequently used performance metrics mentioned by the respondents include “Incident Rate” (e.g., incident rate per mile) and “Speed Limits & Speed of Nearby Traffic”.
- **For environment-related projects**, “Natural Resource Impact” and “Emission Reduction” are deemed frequently used. Respondents also suggested “Hazardous Impacts” (e.g., flood planning, stormwater planning), “Environmental Impacts” (e.g., exposure per person to emission, noise impact)”, and “Cost of Environmental Testing”.
- **For socio-economic-related projects**, “Land Use”, “Employment”, and “Regional Economic Development” are deemed frequently used. Respondents also suggested “Community Impacts” (e.g., community revitalization, older adult demographic) and “Access to Public Transportation”.
- **For recreation-related projects**, “Number of Trail Users”, “Visitation”, and “Recreation Event Participation” are deemed necessary for decision-making. Respondents also suggested “Trail Conditions” (e.g., width of trails, nexus to other networks, barrier separate).

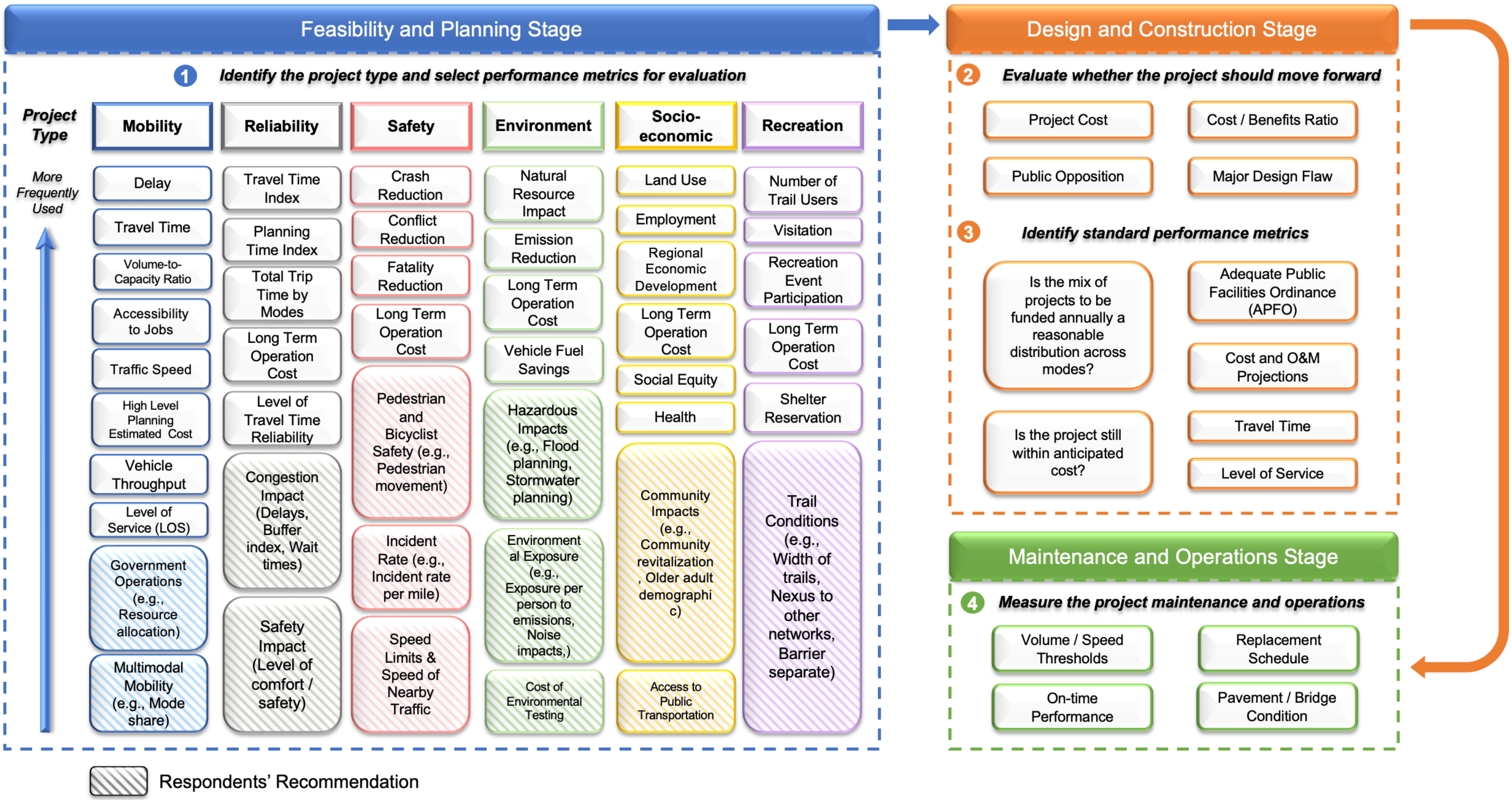


Figure 2. Flow Chart of Measures of Effectiveness Used Across Respondents

Design and Construction Stage

In the **Design and Construction** stage, the actual design and construction plan for the project should be the main consideration. Therefore, when the project moves to the **Design and Construction** stage, most performance metrics at this stage are used to determine whether the project reaches critical failure points. In the survey, respondents were asked to rank the performance metrics used to examine project performance. The survey results helped identify four major performance metrics to support decision making, including “Project Cost”, “Cost/Benefits Ratio”, “Public Opposition”, and “Major Design Flaw”. Furthermore, a list of standard performance metrics was also suggested by respondents based on their own experiences. These standard performance metrics included “Is the mix of projects to be funded annually a reasonable distribution across modes”, “Is the project still within anticipated cost”, “Adequate Public Facilities Ordinance (APFO)”, “Cost and O&M Projects”, “Travel Time”, and “Level of Service”.

Maintenance and Operations Stage

The **Maintenance and Operation** stage refers to the stage when the project finishes construction and is under operation. During this stage, the focus shifts to how to maintain and operate the project at the expected levels. Based on the results, these can be measured with “On-time Performance”, “Alternative Routes”, “Bridge Condition”, “State of Good Repair”, “Age of Transit Fleet”, “Surface Condition”, “Signage Availability”, “Sufficient Funding”, “Clear Marking (e.g., marking for crosswalks, travel lanes)”, “Reporting Issues” and “Priority Lists”.

TOOLS USED IN PROJECT EVALUATION

In addition to the survey, the MTI team also researched tools and methodologies developed by state agencies and Metropolitan Planning Organizations (MPOs) for planning and designing transportation projects in consideration of systemic feasibility and efficiency. Transportation project decisions require cooperative actions across various organizations, offices, and working groups within an organization when the plans cover different municipal areas or the techniques are governed by multiple authorities. For effective and efficient implementation, many organizations have introduced such tools. This literature review is organized in increasing level of complexity of use for the generation of performance measures and is by no means comprehensive. The tools outlined here are meant to generate an understanding of the increasing need to identify the appropriate tools for the level of detail required to make decisions.

Highway Capacity Manual (HCM) Tool

The HCM tool is likely the most used sketch-level planning tool across the nation. It turns the hardcopy version of the HCM into a software engineers can use quickly to answer transportation planning and feasibility questions. This sketch-planning tool provides a simple, quick, and low-cost estimation of transportation planning strategies.

Florida Standard Urban Transportation Model Structure (FSUTMS)

The FSUTMS is a fairly comprehensive system of tools generated by the Florida Department of Transportation and its partners, to include sketch level planning tools and the way through to detailed microscopic analysis. This tool could span across all categories identified in this report. One example at the sketch level includes the Intelligent Transportation System (ITS) evaluation tool 678. It aims to assess and develop tools and procedures to perform the sketch-planning evaluation of the cost and benefits of ITS alternatives. The tool was developed by using the script language Cube, the modeling engine of FSUTMS. It can produce ITS impacts on various performance measures including vehicle miles of travel (VMT), vehicle hours of travel (VHT), average speed, number of accidents, fuel consumption, monetary benefits to users and/or agency, and emission. The ITS evaluation process includes five steps: (1) a deployment identification module that associates ITS deployments with deployment locations; (2) a benefit module that provides benefit estimations regarding travel time, fuel consumption, emissions, and monetary values; (3) a cost module that calculates the required equipment, and initial and recurrent costs in annual values; (4) a benefit/cost ratio module that converts all the benefits to dollar values to calculate B/C ratios of ITS deployments; and (5) an output that presents a performance summary, benefits summary, and benefits and costs summary.

CalTrans California Life-Cycle Benefit/Cost (Cal-B/C) Analysis

The state of California developed the CalTrans California Life-Cycle Benefit/Cost (Cal-B/C) Analysis suite of tools 91112. Cal-B/C uses a set of spreadsheet-based tools that consists of (1) the Cal-B/C Sketch model, which covers a wide variety of highway and transit physical and operational improvements; (2) Cal-B/C Corridor, which is based on the same platform as the Sketch model but allows the user to post-process travel demand and micro-simulation model data; (3) Cal-B/C Active Transportation (AT), which includes biking and walking facilities; (4) Cal-B/C Park and Ride (PnR), which covers commuter parking and ride-sharing facilities; and (5) Cal-B/C Intermodal Freight (IF), covering freight network expansion and terminal efficiency. All the tools in the Cal-B/C framework use consistent methods, rely on the same parameters, and produce comparable results. These tools cover multi-modal analysis of highway, transit, bicycle, pedestrian, ITS, operational improvement, and passenger rail projects. For instance, Cal-B/C IF model provides constant economic impacts for three benefit categories: shipper cost savings (reduce costs for shippers), accident cost savings (safety benefits), and emission cost savings (air quality and greenhouse gas benefits). Performance metrics using a 20-year project lifecycle include:

- Life-Cycle Costs (in millions of dollars), which present values for all net project costs, including the initial costs and any subsequent costs in real constant dollars;
- Life-Cycle Benefits (in millions of dollars), or the sum of the present value of the considered benefits of the project;
- Net Present Value (in millions of dollars), a measurement of project feasibility that is calculated as the difference between the lifecycle benefits and costs;

- Benefit-Cost Ratio, lifecycle benefits relative to the lifecycle costs of a project;
- Rate of Return on Investment, the discount rate that would equalize the lifecycle benefits and costs, and provide another measure of project feasibility;
- Payback Period, the number of years it would take the project to recover the initial construction costs, net of any ongoing costs;
- Emissions Reduction, the reduction a project is expected to generate by pollutant type (CO, CO2, NOx, PM10, PM2.5, SOx, and VOC).

Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) Model

The Center for Urban Transportation Research (CUTR) at the University of South Florida introduced an improved version of the initial Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) model in 2009 1314. The new version of TRIMMS quantifies the net social benefits of a wide range of transportation demand management (TDM) initiatives in terms of emission reductions, accident reductions, congestion reductions, excess fuel consumption, and adverse global climate change impacts. TRIMMS can evaluate the impacts of TDM implementation by estimating changes in travel behavior (mode shares, VMT reductions). Performance metrics include mode share changes, social costs changes (air pollution, congestion, excess fuel, global climate change, health and safety, noise pollution), emission changes, travel impacts (trip reduction, VMT reduction), and program benefits. The evaluation process follows the seven steps listed: (1) Analysis Description and Scope; (2) Geographical Area Selection (urban area, season, road type); (3) Program Details (total cost, duration, discount rate, etc.); (4) Baseline Mode Shares and Trip Length (share %, trip length in miles); (5) Employer Support Program Evaluation (subsidies in transit, vanpool, carpool, etc.); (6) Financial and Pricing Strategies Evaluation (trip cost); and (7) Access and Travel Time Improvements Evaluation (access time, travel time).

ITS Options Analysis Model (ITSOAM)

The ITS Options Analysis Model (ITSOAM) developed by the New York State Department of Transportation aimed to evaluate the merit of ITS deployment elements within a benefits-cost framework 1516. Data requirements include road condition information (such as traffic density, expected delay, and incident or hazardous driving conditions downstream), information about facilities (e.g., parking lots), and travel services information. Three models were described for benefits evaluation: (1) Delay Model, the reduction of traversal time, merge delay, queue delay, and diversion time; (2) Safety Model, the reduction of the accident rate, reduction of accident duration, or reduction of VMT; and (3) Environmental Benefits Model, the reduction of volatile organic compounds emission, oxides of nitrogen emission, carbon monoxide emission, and fuel consumption.

Integrated Regional Information Sharing and Decision Support System (IRISDS)

Florida Department of Transportation OT investigated Integrated Corridor Management (ICM) strategies for implementation in Florida and demonstrated the applications of the strategies. A web-based system, Integrated Regional Information Sharing and Decision Support System (IRISDS), was developed to provide a platform that satisfies the needs for ICM implementation 17. IRISDS receives real-time information from highway and transit agencies and utilizes the data to provide decision support for estimating and predicting system performance using data mining techniques, traffic analysis, and simulation modeling. Three decision support tools are available on incident severity, incident diversion, and transit travel time. It requires a dataset of cumulative traffic volumes for typical days and an incident day based on mainline traffic detector measurements, and bus Automatic Vehicle Location (AVL) data to estimate bus and general traffic travel time.

Virginia Department of Transportation

Virginia Department of Transportation developed a system operations performance measure 2122. A prototype monthly statewide performance report called the Virginia System Operations Performance Report is utilized as their assessment tool. Four categories of measures are included in the assessment. (1) Traffic: to assess the quality of travel (in terms of travel time, delay, throughput, and travel speeds), and also to measure traffic conditions on specialized facilities such as tunnels, bridges, ferries, and HOV lanes. Metrics include speed index (SI), which is a measure of the quality of traffic flow; and throughput, which is a measure of the quantity of traffic flow. (2) Incidents: address both the safety goal (by measuring the number of fatalities, injuries, incidents, and especially crashes), as well as the highway performance goal (by measuring the quantity of traffic served during incident conditions based on the level of capacity reduction). Metrics include average and median incident duration, the total number of incidents, and incidents by type. (3) Traveler information: measure VDOT's ability to better inform travelers, enabling them to make better route and travel time decisions. Metrics include average and median CMS message duration; the total number of CMS messages; CMS messages by type; CMS exposure; the number of 511 phone calls received and 511 phone calls received by type; the number of web site visits per month statewide; and the total number of web camera clicks and web camera clicks by the portal. (4) ITS device reliability: to see how well the devices perform, how well VDOT maintains the resources, and also for maintenance scheduling and replacement cycles. Metrics include the percentage of time a detector reports reasonable (or feasible) data; the average percentage of time CCTV cameras produced quality imagery; and the average number of days in the month CMS devices were used.

Wisconsin Department of Transportation

Wisconsin Department of Transportation provided a summary of ITS evaluation methods 23, which (1) developed a structured deployment philosophy for developing ITS strategies; and (2) identified and selected candidate case studies to cover a range of ITS applications and geographic settings. The evaluation process consists of nine steps: (1) Selection of Case Study Alternatives and Methods; (2) Develop Case Study Description; (3) Identify and Obtain Measurement Data; (4) Select Parameters for Model Testing; (5) Input Data to Models; (6) Run Models and Summarize Results; (7) Review Results with WisDOT and Revise Parameters; (8) Summarize Results; and (9) Transfer Models and Methodologies. Several performance metrics and benefits evaluation measures are assessed, including (1) performance metrics, such as vehicle miles of travel, vehicle hours of travel, average speed, person-hours of travel, number of person trips, number of accidents, travel time reliability, fuel consumption, and emissions; (2) benefits valuation measures for annual benefits (change in user mobility, travel time, the cost paid by the user, external cost, public agency cost and other benefits) and annual costs (average annual private-sector costs, and annual average public sector cost); (3) net benefits; and (4) B/C ratio.

Oregon Department of Transportation

Oregon DOT developed state-of-the-practice methods to support evaluation of potential ramifications of policy actions, and to demonstrate how a combined set of plans, programs, and actions work together to produce a specific result. It consists of several analysis tools and modeling tools (https://www.oregon.gov/ODOT/Planning/Pages/Technical-Tools.aspx):

- **Analysis tools:** Safety Analysis Tools (Critical Rate Calculator, Excess Proportion of Specific Crash Types Calculator); Signalized Intersection Tools (Saturation Flow Rate Calculator, Signal Progression Calculator, Synchro/SimTraffic Templates); Volume Development Tools (Planner Traffic Count Request Template, Heavy Vehicle Pavement Design Spreadsheet, TruckSum, Count Processors); Unsignalized Intersection Tools (Preliminary Traffic Signal Warrant Analysis Form, Two-Way STOP Controlled Intersection Calculator); Multimodal Analysis Tools (Separated/Buffered Bikeways Calculator, Simplified MMLOS Calculator, Shared Path Calculator, Pedestrian, and Bicycle Signalized Intersection MMLOS Calculator, Unsignalized Intersection Pedestrian Crossing Calculator); Segment Analysis Tools (Queue and Delay Cost Worksheet, FREEVAL_OR, ODOT Software Capacity Calculator V1.0, BCA Traffic Data Example).
- **Modeling Tools:**
    - Statewide Integrated Model (SWIM) and SWIM2 27: It is a second-generation model (SWIM2 model), incorporating the interaction between economy, land use, and transportation systems. This tool is used for high-level projects of statewide importance that involve freight movements and/or long-term economic impacts.
    - LUSDR (Land Use Scenario DevelopR) 28: This tool is used with a travel demand model for large-scale regional planning to develop and test a range of future land-use scenarios.
    - GreenSTEP/Regional Strategic Planning Model 2930: This model is used for large-scale regional emission planning as part of an area's GHG reduction efforts.

- Highway Economic Requirements System – HERS-ST 3132: This model is used to evaluate existing and future deficiencies based on various user-defined criteria. Output includes key system performance and improvement costs. It is typically used on a corridor-basis for determining needs including capacity, geometric alignment, and pavement based on identified funding threshold.
- Urban Travel Demand Models (4-Step Travel Demand Models) 33: A screening tool to develop future volumes for plans and projects through the post-processing method.
- DTA, VISSIM, Synchro, SimTraffic, HCS.

The performance metrics of these tools and models could be differentiated based on scenario types. (1) No-build scenarios: 30th highest hour volumes (30HV) using historical and seasonal adjustments for calibration purposes; volume-to-capacity; level of service; 95th percentile queues/travel times/speeds and overall hours of delay; multimodal evaluation across pedestrian, bicycle, and transit modes. (2) Build scenarios: Design Hour Volumes (DHVs); volume-to-capacity (v/c); level of service (LOS) compared with the HDM design; pedestrian safety analysis; multimodal evaluation across pedestrian, bicycle, and transit modes; turn bay storage lengths.

Missouri Department of Transportation

Missouri Department of Transportation described the strategic direction for the advancement of TSM&O in Missouri 34. They evaluate the system performance by cost and impact of traffic congestion; the average time to clear traffic incidents; traffic incident impacts on major interstate routes; work zone impacts to the traveling public; travel times and reliability on major routes and rural interstates; and whether MoDOT roadways comply with federal management and operations requirements. Operation planning strategies include ITS, congestion management, and road capacity management.

Maryland Department of Transportation State Highway Administration

MDOT SHA has integrated advanced travel demand models with fine-grained, time-sensitive traffic network models to support agency goals in the areas of planning, integrated planning and operations, and Transportation Systems Management & Operations. Macroscopic models aim to cover the entire State of Maryland through a state-of-the-art activity-based model (ABM), while microscopic models detail outputs at the intersection level for roadway delays, queues, etc. with the use of VISSIM, and other tools. These models operate in a synergy to support broad performance measure reporting that ensure some consistency across projects and still provides relevant metrics for decision making.

Advanced Regional Traffic Interactive Management and Information System (ARTIMIS)

Advanced Regional Traffic Interactive Management and Information System (ARTIMIS) is an interstate-level project from the region of Ohio-Kentucky-Indiana 543. It aims to optimize freeway system efficiency, improve safety, and benefit air quality. The ARTIMIS system includes over 80 cameras, 57 center-lane miles of fiber-optic cable, approximately 1100 detectors of various types, 40 fixed changeable message signs, 3 portable changeable message signs, 2 highway advisory radio frequencies, 5 freeway service patrol vans, and a control center in Downtown Cincinnati. It provides incident, congestion, and freeway management for 66 miles in Ohio and 22 miles in Kentucky in the Cincinnati metropolitan area. Funded by the Ohio Department of Transportation (ODOT) and the Kentucky Transportation Cabinet (KYTC), ARTIMIS was the first major ITS effort in Ohio and the second in Kentucky.

SUMMARY

The objective of this research project was to identify state-of-the-practice performance metrics and evaluation tools currently employed for different types of transportation projects. To achieve the research goal, the MTI team surveyed stakeholders—including federal, state, and local agency staff and private-sector professionals—who have experience with different types of transportation projects. From the survey, the team produced a decision flowchart that documents the most frequently used performance metrics used in decision making.

The selection of analysis, modeling, and simulation tools that support performance metrics should also be considered when generating results to support decision making. Highlighted in this report were examples of such tools used across the nation. For example, at the long-range planning stage, it may not be practical to apply the most complex tool for each conceived traffic operations project. Sketch planning tools or travel demand model postprocessing tools may be more suitable. At the Transportation Improvement Program (TIP) and project planning stages, mesoscopic and microscopic traffic simulation tools may be considered for traffic operation project studies. Multi-scenario and multi-resolution tools for estimating travel reliability impact under different weather and accident conditions may also be added at these stages to provide more comprehensive information to support decision making. Post-project evaluation could rely on existing performance monitoring dashboard tools such as the Regional Integrated Transportation Information System (RITIS).

In summary, this research project provides timely information to help understand what performance measures are used in practice to make a decision at the planning, construction, and operations stages of a transportation project. A flowchart framework that documents the metrics used in evaluating projects for different stages of planning was produced.

While these results showcase a breadth of experiences, the research does suggest that variance exists and engineering judgment remains a strong component of how a project may move forward. It also identified that metrics such as equity rarely make it to the top as a decision making tool, which suggests significant improvements are necessary to provide a more human-centric transportation ecosystem.

REFERENCES

1. https://ops.fhwa.dot.gov/publications/fhwahop12028/sec4.htm (2012) Chapter 4, Operations Benefit/Cost Analysis Desk Reference. FHWA-HOP-12-028. US Department of Transportation Federal Highway Administration.
2. Jeannotte, K., Alexiadis, V., & Sallman, D. (2000). Estimating Potential ITS Benefits and Costs Using IDAS. *Compendium of Papers. Institute of Transportation Engineers 2000, District 6 Annual MeetingInstitute of Transportation Engineers (ITE)*.
3. McHale, G. (2000). IDAS (ITS Deployment Analysis System): a tool for integrating ITS into the planning process. *Public Roads*, *63*(6).
4. Heither, C., & Thomas, M. (2003). Testing of IDAS Capabilities Using Northeastern Illinois ITS Deployments. Working paper, 03-06.
5. Jeannotte, K., Sankar, P., & Krechmer, D. (2001). Evaluation of the advanced regional traffic interactive management and information system (ARTIMIS). *ITS America 11th Annual Meeting and Exposition, ITS: Connecting the AmericasIntelligent Transportation Society of America (ITS America)*.
6. Florida International University (2008). Evaluation Tools to Support ITS Planning Process: Development of a Sketch Planning Tool in FSUTMS/Cube Environment. Florida International University.
7. Zhao, F., Li, M. T., Chow, L. F., & Shen, L. D. (2002). FSUTMS mode choice modeling: factors affecting transit use and access. *National Center for Transit Research, University of South Florida, Tampa, Florida*.
8. Hadi, M., Xiao, Y., Ozen, H., & Alvarez, P. (2008). Evaluation tools to support ITS planning process: development of a sketch planning tool in FSUTMS/cube environment.
9. Bailly, H., & Brinckerhoff, P. (1999). California life-cycle benefit/cost analysis model (Cal-B/C). *California Department of Transportation*.
10. Williges, C. & Mahdavi, M. (2008). Transportation Benefit–Cost Analysis: Lessons from Cal-B/C. *Transportation Research Record*, *2079*(1), 79-87.
11. Booz-Allen & Hamilton Inc. (1999). California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C)—User's Guide. California Department of Transportation. http://www.dot.ca.gov/hq/tpp/offices/ote/benefit_files/CalBC_User_Guide_v8.pdf
12. Booz-Allen & Hamilton Inc. (1999). California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C)—Technical Supplement to User's Guide. California Department of Transportation. http://www.dot.ca.gov/hq/tpp/offices/ote/benefit.html. Accessed June 2010.
13. Federal Highway Administration (FHWA) Office of Operations – Operation Benefit/Cost Analysis Desk Reference. Chapter 4 lists TRIMMS as one of 12 existing benefit-costs tools and methods: http://ops.fhwa.dot.gov/publications/fhwahop12028/sec4.htm
14. FHWA, Office of Planning, Environment, & Realty (HEP) – Congestion Management Process (CMP) Guidebook. The guidebook lists TRIMMS as one of the tools available to assess congestion management strategies: http://www.fhwa.dot.gov/planning/congestion_management_process/cmp_guidebook/chap02.cfm
15. Thill, J. C., & Yan, J. (2007). Modeling Benefits of Incident Management Systems with the ITS Options Analysis Model (ITSOAM): A Tool for Economic Analysis. *11th World Conference on Transport ResearchWorld Conference on Transport Research Society.*

16. Thill, J. C., Rogova, G., & Yan, J. (2004). The ITS Options Analysis Model (ITSOAM) User's Guide: Chapter 11. *Adaptive Ramp Metering. New York Department of Transportation, Albany, New York*.
17. Hadi, M., Xiao, Y., Wang, T., Zhan, C., Ozen, H., & Cabrera, E. (2012). Integrated corridor management and advanced technologies for Florida.
18. Xiao, Y. (2013). Development and Comparison of Planning-Level and Data-Based Evaluation Tools of 1 Intelligent Transportation Systems 2. *Intelligent Transportation Systems*, *2*(3), 4.
19. Xiao, Y., Hadi, M., & Ozen, H. (2012). Development of a Data-Based Intelligent Transportation System Evaluation Tool. *Prepared for Florida Department of Transportation, by the Florida International University Lehman Center for Transportation Research, Miami, Fl*.
20. Hadi, M., Xiao, Y., Wang, T., Majstorovic, M., & Hu, P. (2013). Demonstration of the application of traffic management center decision support tools (No. BDK80 977-24). Florida. Dept. of Transportation.
21. Swan, N., Baker, S., Hintz, R., & Trimble, T. (2004). *511 Virginia evaluation* (No. FHWA-JPO-04-036). Virginia Polytechnic Institute and State University. Transportation Institute.
22. Babiceanu, S. E., Smith, B. L., Park, B., & McGhee, C. C. (2007). *Development of Statewide System Operations Performance Measures: Virginia Case Study*, *7*(2405).
23. Dan Krechmer, Nathan Clark, Christopher Kopp and Aimee Chong. (2004) Development of Methods for Benefits Assessment of ITS Deployment in Wisconsin. WisDOT.
24. Ma, J., & Demetsky, M. J. (2013). *Integration of Travel Demand Models with Operational Analysis Tools* (No. FHWA/VCTIR 14-R5). Virginia Center for Transportation Innovation and Research.
25. Florida Intelligent Transportation Systems Evaluation (FITSEVAL) Tools – Phase II. https://www.fsutmsonline.net/images/uploads/mtf-files/FITSEVAL_Phase2_Final_Report.pdf
26. Citilabs Inc.. (2014) Florida Intelligent Transportation System Evaluation Tools (FITSEVAL) – Phase II. Citilabs Inc.
27. SWIM Version 2.5 Model Development Report. 2017 https://www.oregon.gov/ODOT/Planning/Documents/Statewide-Integrated-Model-Vers2-5.pdf
28. Gregor, B. (2007). Land use scenario developer: Practical land use model using a stochastic microsimulation framework. *Transportation Research Record*, *2003*(1), 93-102.
29. Gregor, B. (2010). GreenSTEP: Greenhouse Gas Statewide Transportation Emissions Planning Model. *Oregon Department of Transportation*.
30. Clifton, K. J., & Gregor, B. J. (2012). Development of Decision Tool for Strategies to Reduce Greenhouse Gas Emissions: Role of National Household Travel Survey Data in GreenSTEP Model Development. *Transportation research record*, *2291*(1), 124-134.
31. Eisele, W. L., Lomax, T. J., Gregor, B. J., & Arnold, R. D. (2005, January). Developing and Implementing Statewide Operations Performance Measures in the State of Oregon: Methodology and Application for Using HERS-ST and Archived Real-time Data. *85nd Annual Meeting of Transportation Research Board, Washington, DC*.

32. Lee, D., & Burris, M. (2005). HERS-ST Highway Economic Requirements System-State Version: Technical Report Appendix C: Demand Elasticities for Highway Travel. Federal Highway Administration.
33. Travel Demand Model Development and Application Guidelines. 1995 https://www.oregon.gov/odot/Planning/Documents/TravelDemandModelDevelopment-Application_Guidelines.pdf
34. Missouri DOT TSMO Program and Action Plan. 2018 https://transportationops.org/publications/missouri-dot-tsmo-program-and-action-plan
35. Yang, D. (2018). INTEGRATING ACTIVITY-BASED TRAVEL DEMAND AND DYNAMIC TRAFFIC ASSIGNMENT MODEL: A BEHAVIORAL USER EQUILIBRIUM APPROACH (doctoral dissertation).
36. Zhang, L., Yang, D., Ghader, S., Carrion, C., Xiong, C., Rossi, T. F., ... & Barber, C. (2018). An integrated, validated, and applied activity-based dynamic traffic assignment model for the Baltimore-Washington region. *Transportation Research Record*, *2672*(51), 45-55.
37. Zhang, L., Cirillo, C., Xiong, C., & Hetrakul, P. (2011). *Feasibility and benefits of advanced four-step and activity-based travel demand models for Maryland* (No. MD-11-SP009B4S).
38. Asadabadi, A. (2018). APPLYING MARYLAND STATEWIDE ACTIVITY-BASED TRANSPORTATION MODEL TO HIGH-SPEED RAIL AND FUTURE FUEL PRICE SCENARIOS (master's thesis).
39. Xiong, C., Zhou, X., & Zhang, L. (2018). AgBM-DTALite: An integrated modelling system of agent-based travel behaviour and transportation network dynamics. *Travel Behaviour and Society*, *12*, 141-150.
40. Xiong, C., Pan, Y., Lee, M., Zhu, Z., & Zhang, L. (2017). Integrated agent-based travel behavior and dynamic traffic microsimulation for ramp-metering analysis. *Transportation research record*, *2665*(1), 11-20.
41. Zhang, L. (2006). Search, information, learning, and knowledge in travel decision-making: a positive approach for travel behavior and demand analysis (doctoral dissertation, University of Minnesota).
42. Slate, G. (2017). Deploying Advanced Technology Infrastructure for Transportation Systems Management & Operations in Maryland: US 1 Innovative Technology Deployment Corridor. Appendix E: MDOT SHA – Maryland Integrated Travel Analysis Modeling System (MITAMS). https://ops.fhwa.dot.gov/fastact/atcmtd/2017/applications/maryland/appdxe.htm
43. Koehler, R. (2013). 2030 Regional Transportation Plan. *Intelligent Transportation Systems*, (10). Ohio-Kentucky-Indiana Regional Council of Governments.
44. Corridor Simulation (CORSIM/TSIS). https://ops.fhwa.dot.gov/trafficanalysistools/corsim.htm
45. Owen, L. E., Zhang, Y., Rao, L., & McHale, G. (2000). Traffic flow simulation using CORSIM. *2000 Winter Simulation Conference Proceedings (Cat. No. 00CH37165),* (2), 1143-1147. IEEE.

APPENDIX: SURVEY RESULTS

The appendix summarizes the responses of subjects for each survey question. Table 1 shows the state employers of respondents.

Table A1. State Employers of Respondents

State	Number of Respondents	State	Number of Respondents
Georgia	1	Mississippi	1
North Carolina	1	Nebraska	2
Maryland	50	Pennsylvania	3
South Carolina	1	Washington	3
Virginia	3	Wyoming	2
Maryland, Virginia, District of Columbia	3		

Most of the respondents are from county (26), local municipality (16), state departments of transportation (14), and private consulting firms (9).

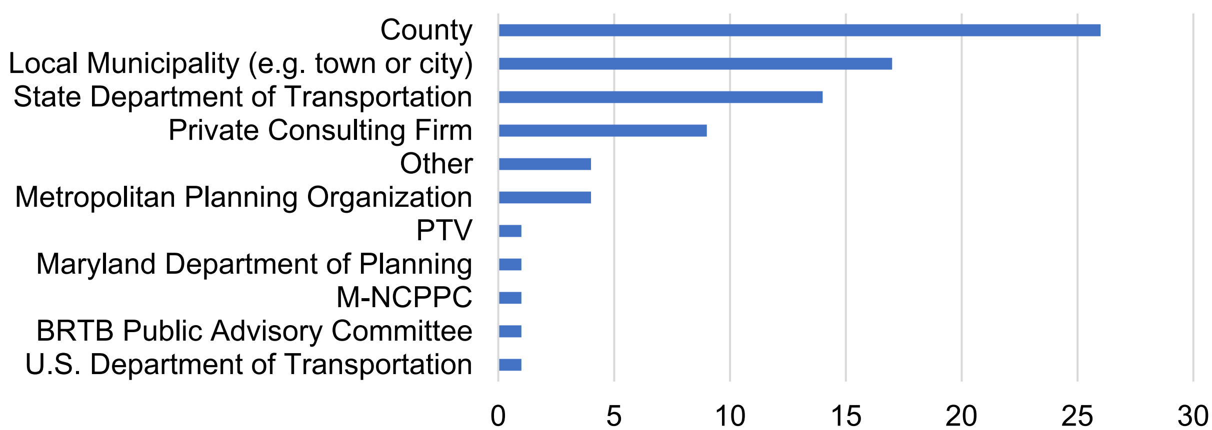


Figure A1. Agency Employers of Respondents

The respondents have mixed backgrounds, with 37 of them working most frequently on highway projects, 16 of them on arterial projects, 13 of them on pedestrian- and bike-related projects, and 8 of them on transit projects.

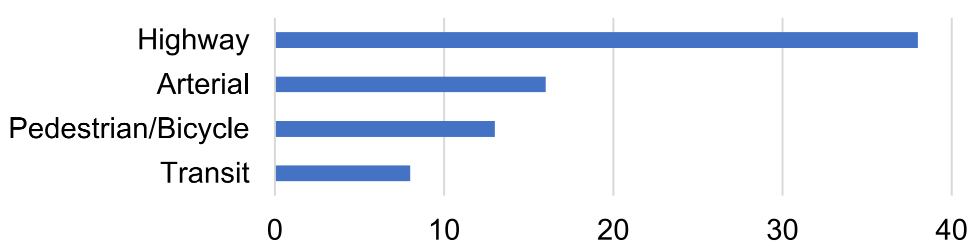


Figure A2. Predominant Project Work of Respondents

We sum the scores for each performance metric as the total score and the total score for each performance metric is divided by the number of respondents to perform the ranking. In addition, the respondents also recommended other metrics that were not included in our design and provided the scores for them. These performance metrics should also be taken into account based on the specific project needs.

For mobility-related projects (see Figure A3), the top three frequently used metrics are Delay (4.10), Travel Time (3.97), and Volume-to-Capacity Ratio (v/c) (3.95). The three least used metrics are Number of Mode Shift Transfers (2.55), Bus Ridership (2.87), and Long Term Operational Cost (2.92).

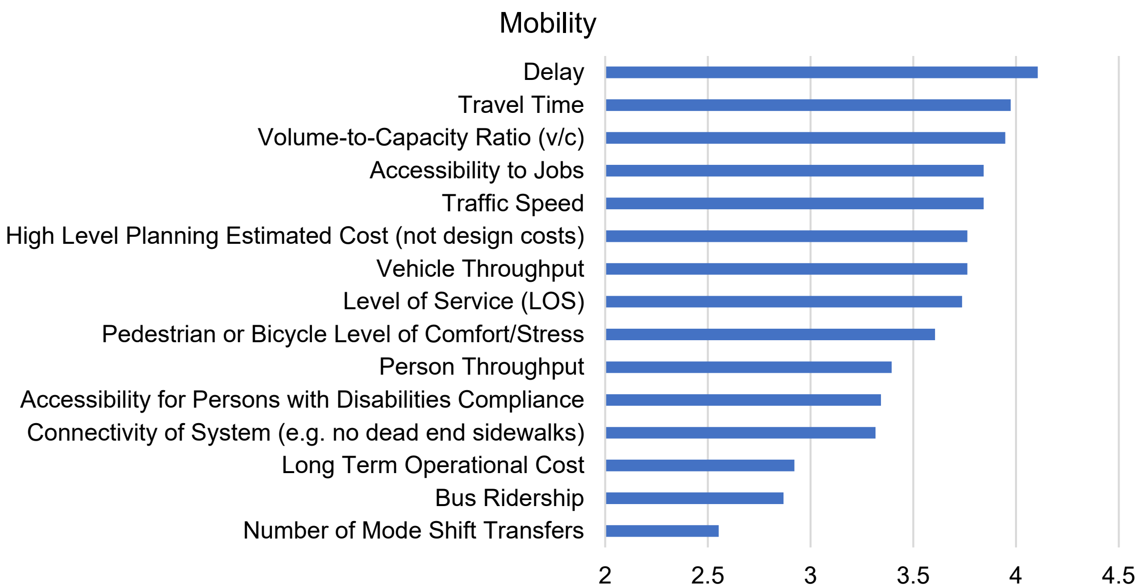


Figure A3. Mobility Metrics Average Scores

Respondents also recommended the following mobility metrics not mentioned in the survey:

Total Score	Metrics	# of Respondents
16	Government Operations (e.g., Equipment availability, Master plan comformance, Resource allocation)	4
15	Multimodal Mobility (e.g., Mode share, Transfer Time, Bicycling network, Frequency at key stops, Accommodation of Amish buggies)	5
4	Average Vehicle Occupancy Destinations	1
4	Driver Expectancy	1
4	Diversion Off Local Facilities	1
3	Business Opening Times	1

For reliability-related projects, the most frequently used metric is Travel Time Index (3.42) and the least used metric is the level of travel time reliability (3.16).

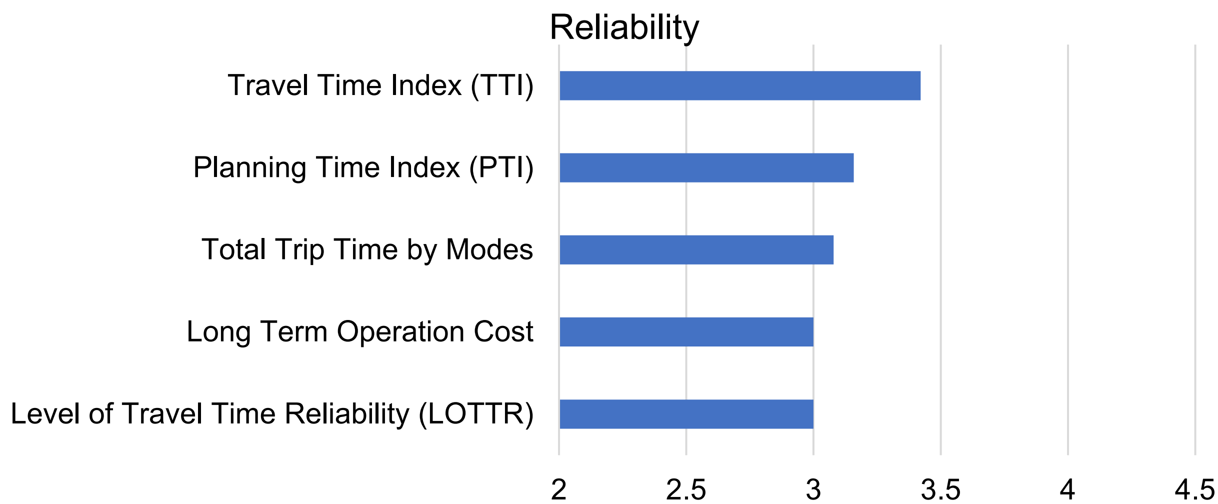


Figure A4. Reliability Metrics Scores

Respondents also recommended the following reliability metrics not mentioned in the survey:

Total Score	Metrics	# of Respondents
16	Congestion Impact (e.g., Duration of congestion (compared to similar periods, Transit on-time performance, Wait times, delays, buffer index)	5
9	Safety Impact (e.g., Level of comfort/safety, % days with incidents (subdivided by impact))	2
5	Average Travel Speed	1
4	Interconnectedness	1

For safety-related projects, the most frequently used metric is Crash Reduction (3.76) and the least used metric is Long Term Operational Cost (3.18). The scores of the four safety metrics are very close, indicating that the survey respondents rated these metrics with a similar level of importance.

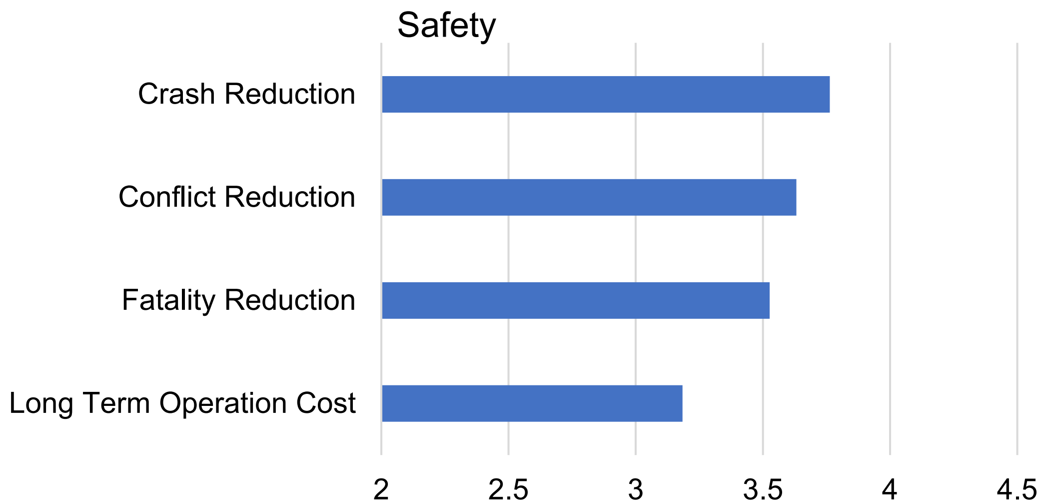


Figure A5. Safety Metrics Scores

Respondents also recommended the following safety metrics not mentioned in the survey:

Total Score	Metrics	# of Respondents
12	Pedestrian and Bicyclist Safety (e.g., Location of trails/bike lanes, pedestrian movement, safety parameters per mode)	3
8	Incident Rate (e.g., Incident rate per mile, Goal of "no longer significantly higher than statewide average")	2
8	Speed Limits & Speed of Nearby Traffic	2
4	Visibility / Lighting	1

For environment-related projects, the most frequently used metric is Natural Resource Impact (3.39) and the least used metrics is Vehicle Fuel Savings (3.10).

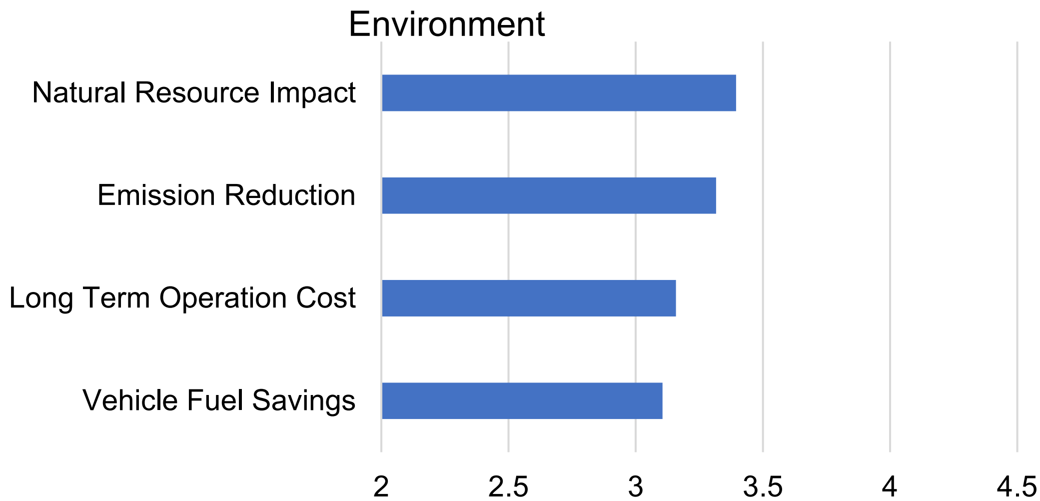


Figure A6. Environment Metrics Scores

Respondents also recommended the following environment metrics not mentioned in the survey:

Total Score	Metrics	# of Respondents
16	Hazardous Impacts (e.g., Flood planning, Stormwater planning, Draining)	5
11	Environmental Exposure (e.g., Noise impacts, Exposure per person to emissions)	3
8	Cost of Environmental Testing (e.g. Rural preservation)	2
5	Indirect/Cumulative Effects	1
3	Development Control	1

For socio-economic-related projects, the most frequently used metric is Land Use (3.76) and the least used metric is Health (2.60).

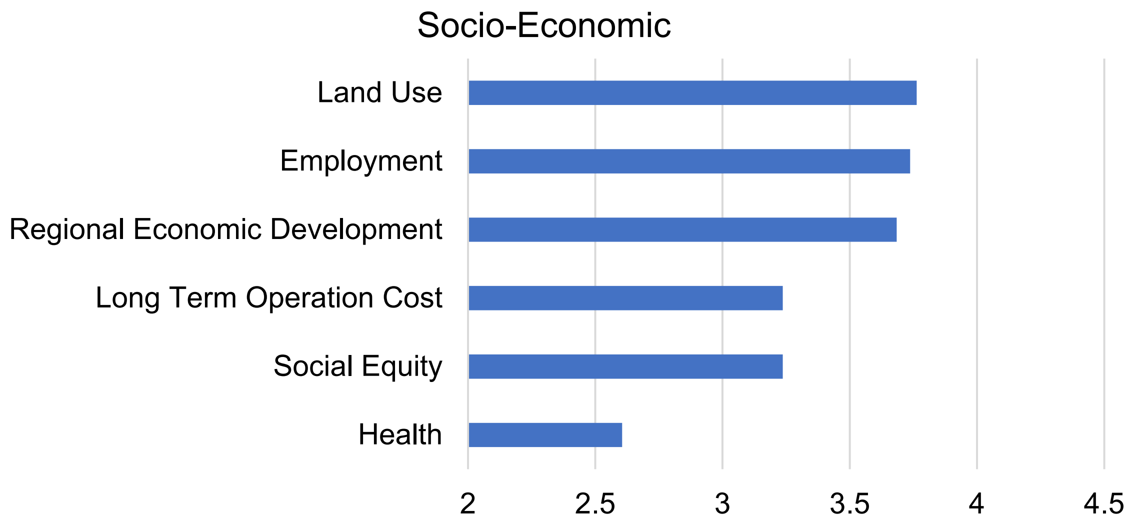


Figure A7. Socio-economic Metrics Scores

Respondents also recommended the following socio-economic metrics not mentioned in the survey:

Total Score	Metrics	# of Respondents
13	Community Impact (e.g. Community revitalization, Community/Historic resources, Older adult demographic)	3
5	Access to Public Transportation	1
5	Noise	1
5	Indirect/Cumulative Effects	1

For recreation-related projects, the most frequently used metric is Number of Trail Users (3.24) and the least used metrics are Shelter Reservations (2.42).

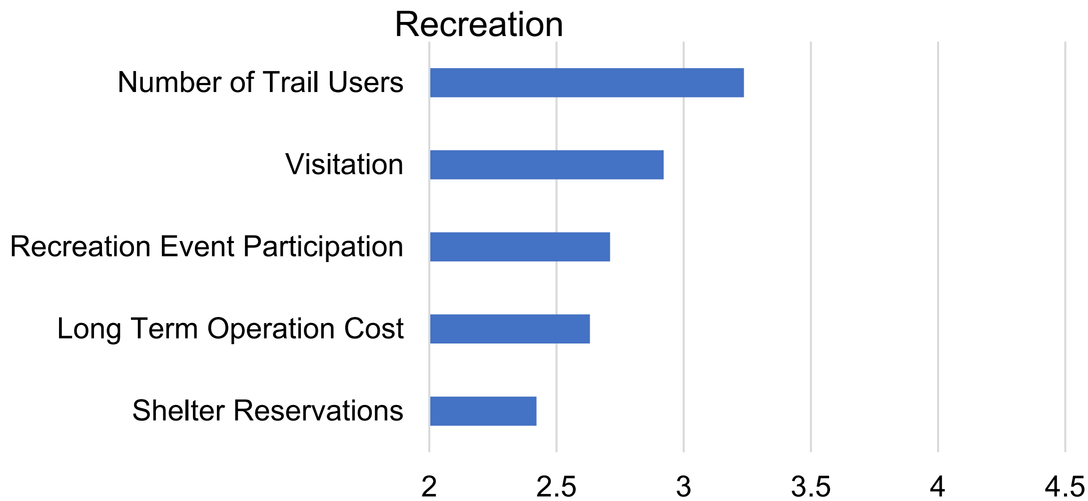


Figure A8. Recreation Metrics Scores

Respondents also recommended the following recreation metrics not mentioned in the survey:

Total Score	Metrics	# of Respondents
18	Trail Conditions (e.g., Widths of crossing/sidewalks/trails, Nexus to other trails / bike networks, Barrier separate)	4
5	ADA Purpose Built	1
5	High Accident Locations	1
3	Open Space Program Implementation	1
3	Social Equity	1

The following figure ranks the various reasons for why projects were not moved forward. The lower the score the more important the reason is in decisionmaking. For most projects, we can see that the "Cost Generally Too High" is the number-one reason.

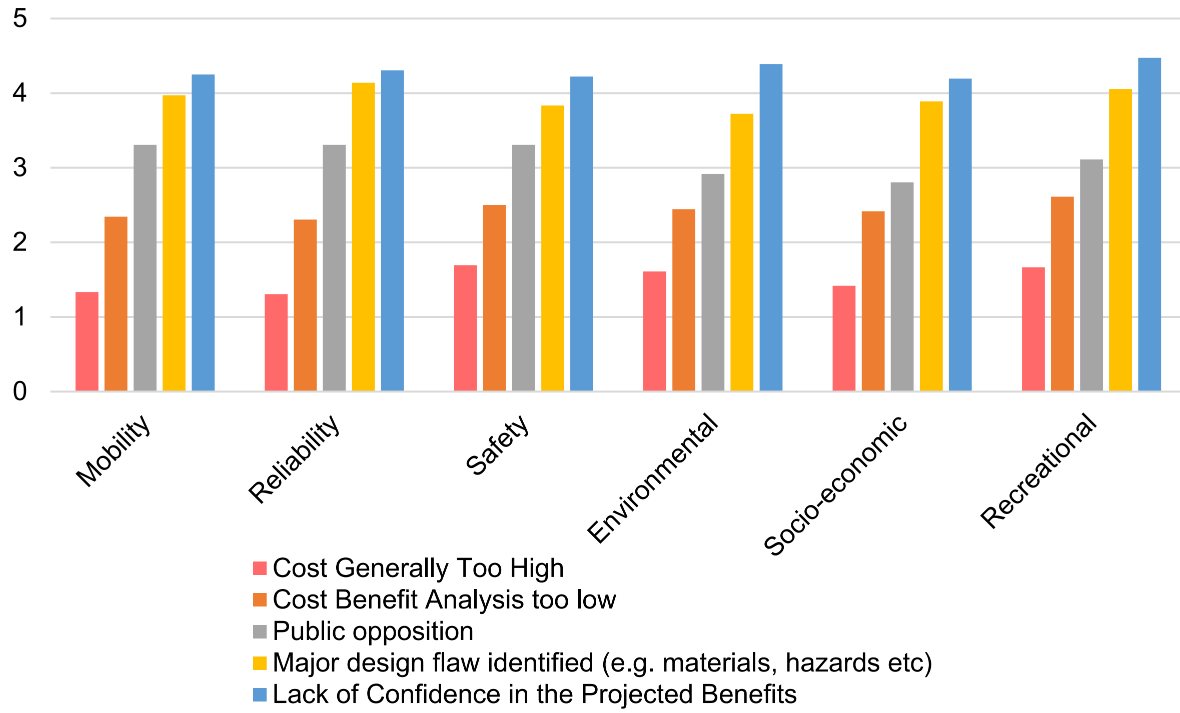


Figure A9. Rankings of why the Project did not Move Forward (the Lower the Score, the Higher the Average Ranking)

Respondents also provided some standard performance metrics during the design and construction state:

Metrics
Is the project still within the anticipated cost?
Is the mix of projects to be funded annually a reasonable distribution across modes?
Department of Public Works staff/engineers reviews such metrics. Adequate Public Facilities Ordinance APFO is also in place which requires such an assessment.
Travel Time, Volume/Capacity, Level of Service (LOS), Delay, 95% queue, Throughput, Hours of congestion, Bike and Ped Connectivity, etc.
Cost and O&M projections versus use

During the maintenance and operations phase, respondents recommended "on-time performance", "alternative routes", "bridge condition", "state of good repair", "age of transit flee", "surface condition", "signage availability", "sufficient funding", "clear marking (e.g., marking for crosswalks, travel lanes)", "reporting issues", and "priority lists".