NJ-2023-001

NJDOT Highway Safety Manual Predictive Safety Tool Research

FINAL REPORT

January 2023

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In cooperation with

New Jersey Department of Transportation
Bureau of Research
And
U.S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NJ-2023-001		

4. Title and Subtitle	5. Report Date
NJDOT Highway Safety Improvement Program Implementation Plan	January 2023

7. Author(s)
Cory Hopwood, Megan Motamed, Daniel Forbush

9. Performing Organization Name and Address	10. Work Unit No.
Cambridge Systematics, Inc. 38 East 32nd Street, 7th Floor New York, NY 10016	**11. Contract or Grant No.** **18-PROSV-00633EMS**

12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered
New Jersey Department of Transportation (SPR) 1035 Parkway Avenue, P.O. Box 600 Trenton, NJ 08625.0600	Federal Highway Administration 1200 New Jersey Ave. SE USDOT Washington, D.C. 20590	Final Research Report, July 2021 - June 2022 **14. Sponsoring Agency Code** NJDOT

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The New Jersey Department of Transportation (NJDOT) researched the predictive safety analysis tools available in the market and how they are being used by State Departments of Transportation (DOT). These tools have proliferated since the American Association of State Highway and Transportation Officials (AASHTO) released the Highway Safety Manual (HSM) in 2010. NJDOT sought to understand the benefits, limitations, and paths to implementation for the tools currently in use.

This research was conducted in two phases. The first phase consisted of a desk scan of predictive safety tool best practices. This phase reviewed nine types of tools. These tools were generally defined by what part of the HSM they address. They include national tools, which cover the most common roadway and safety elements, or statewide tools which are customized to the specific data collected by each DOT. Some agencies devote significant resources to creating their own tools, while other tools are made by external partners that provide specialized knowledge.

The second phase reported on practitioners' experience implementing HSM predictive safety tools through a survey and six follow-up interviews. This phase found that data needs are more intensive for network screening processes compared with project-level predictive safety analyses. Additionally, the absence of traffic volumes, especially along minor roads, are a common data gap. Finally, this research documents approaches to circumventing technical limitations of HSM predictive safety data.

17. Key Words	18. Distribution Statement
Safety, Highway Safety Improvement Program, Implementation Plan, Fatalities, Serious Injuries, Bicycle, Pedestrian, Planning, Performance Targets	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37	$36,420.00

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors of this report wish to thank, in particular, the staff of the New Jersey Department of Transportation (NJDOT), without whom completion of this report would not have been possible.

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EXECUTIVE SUMMARY

The New Jersey Department of Transportation (NJDOT) engaged Cambridge Systematics (CS) in learning what predictive safety analysis tools are available in the market and how they are being used by State Departments of Transportation (DOT). These tools have proliferated since the American Association of State Highway and Transportation Officials (AASHTO) released the Highway Safety Manual (HSM) in 2010. NJDOT sought to understand the benefits, limitations, and best practice paths to implementation for the tools currently in use as it plans its next phase of its predictive safety planning process.

This research was conducted in two phases. The first phase consisted of documenting best practices from a desk scan of predictive safety tools offered by AASHTO and the Federal Highway Administration (FHWA) and those developed by State DOTs. This includes documenting an overview of predictive safety tools and the HSM process that each of those tools support. Then, it catalogues nine types of tools, including tools offered by AASHTO, tools created by DOTs to conduct different HSM analyses, and tools that create specific inputs into the HSM process.

This desk review of predictive safety tools indicates the depth and complexity of safety analysis calculations made possible by the HSM. The HSM has laid out a complex mathematical methodology that requires significant data needs, technical capacity, and flexibility to customize safety analyses to specific conditions. The tools that federal and state agencies have created to implement the HSM reflect that the methodology is challenging and intensive. The main purpose of these tools is to reduce the technical barriers to completing these analyses and to standardize processes so that analysis results can be comparable to each other.

This second phase of this research reports on practitioners' experience implementing the HSM predictive safety process and using HSM predictive safety tools. This includes discussing the results a survey sent to state DOTs and conducting six follow-up interviews with predictive safety practitioners at different DOTs.

The survey and interviews documented several important findings. First, it found that data needs are more intensive for network screening processes compared with project-level predictive safety analyses. It also found that missing traffic volumes, especially along minor roads and along roadways that are not within the jurisdiction of State DOTs, is a common data gap. Some agencies user existing infrastructure, such as radar or cameras, to augment traffic counts. Additionally, it found that adapting to a state's Linear Referencing System (LRS) can be challenging but there are technical workarounds. Finally, in general, the survey and interview findings demonstrate the value that safety practitioners see from investing in HSM predictive methods and tools.

There are several steps that NJDOT can take to follow-up on this research, including working with specific peer DOTs on common issues they face. There are also additional research projects that NJDOT can pursue to further investigate how to handle data gaps, how to implement specific portions of the HSM process, and how to overcome technical limitations.

INTRODUCTION

The purpose of this research report is to assist the New Jersey Department of Transportation (NJDOT) in learning what predictive safety analysis tools are available in the market and how they are being used by State Departments of Transportation (DOT). These tools have proliferated since the American Association of State Highway and Transportation Officials (AASHTO) released the Highway Safety Manual (HSM) in 2010. The NJDOT presently has the data and capabilities to make use of the predictive methods in the HSM to quantify safety performance, prioritize locations for safety investments, and select the most efficient countermeasures. However, there is a need to understand the benefits, limitations, and best practice paths to implementation for the tools currently in use. This research is being compiled to review the different approaches that States have taken to implement the HSM methodologies and will be used to inform the NJDOT as it completes the next phase of its predictive safety planning process.

This report starts with the results from a desk scan of best practices of predictive safety tools offered by AASHTO and the Federal Highway Administration (FHWA) and those developed by State DOTs. This section includes an overview of predictive safety tools and the HSM process that each of those tools support. Then, it catalogues common tools available for use in predictive safety analysis, discussing their context, purpose, and data needs. It concludes with main takeaways from the desk scan and a summary of information that has not been gleaned by this desk scan.

This second section compiles the results from a survey and series of interviews of safety practitioners at State DOTs. This section builds on the first section by reporting on the practitioners' experience implementing the HSM predictive safety process and using HSM predictive safety tools. This includes an overview of the survey results sent to State DOTs and the findings from follow-up interviews conducted with six State DOTs.

The report concludes with main findings from this research, highlighting takeaways from the desk scan, survey results, and interview findings. It also suggests additional research that may be carried out to further address gaps in knowledge in the use and implementation of HSM predictive safety tools.

PREDICTIVE SAFETY TOOL BEST PRACTICES

Overview of Predictive Safety Tools

The AASHTO HSM represents a significant milestone in developing a rigorous highway safety analysis for use by transportation agencies. First published in 2010 with a freeways supplement being published in 2014, the HSM created a standard for safety analysis that is based on data analysis, quantitative reasoning, and research-based interventions. From this standard, a number of tools have been developed to economize different parts of the analysis and increase transportation agency capacity to conduct more in-depth safety analyses.

The general process of the HSM relies on four parts:

- **Part A – Human Factors and Safety Fundamentals** – this section covers the general context of highway safety and fundamentals of the analysis.

- **Part B – Roadway Safety Management Process** – this section covers the process of monitoring and reducing crashes on entire roadway networks. In general, this section of the HSM is focused on higher-level safety planning and policy. Within this section are six main processes:

  1. Network Screening – identify and rank sites based on potential for reducing average crash frequency and/or crash severity;
  2. Diagnosis – identify contributing factors to crashes;
  3. Countermeasure Selection – select countermeasures to reduce crashes or crash severity based on contributing factors in observed crash patterns or types;
  4. Economic Appraisal – determine whether a project is economically justifiable and which projects or alternatives are the most cost-effective;
  5. Priority Ranking – review potential projects and sort them based on ranking and optimization processes; and
  6. Countermeasure Evaluation – assess how crash frequency or severity changes because of specific treatments, safety countermeasures, projects, and other funds invested in reducing crashes.

- **Part C – Predictive Methods** – this section focuses on calculating the predicted or expected average crash rate at individual sites using statistical models that take roadway characteristics and traffic volume as inputs and also account for the inherent randomness of crashes. This can include metrics such as:

  - Expected Excess Crash Rate – The difference between the adjusted observed crash frequency and the expected crash frequency for that location based on its site type and characteristics.

  - Potential for Safety Improvement – An estimate of how much the long-term crash frequency can be reduced at a particular site.

- **Part D – Crash Modification Factors (CMF)** – this section is concerned with how effective different roadway characteristics and operational characteristics are at reducing crashes at a specific location. CMFs themselves are indices which reflect the number of crashes after a modification; as such, CMFs greater than one are expected to increase the crash rate, and CMFs less than 1 are expected to decrease the crash rate.[1]

As a pre-requisite to the HSM process, states must first collect a significant amount of data about their roadway characteristics, the volume of traffic, and the crashes that occur on those roadways. To assist in identifying and collecting the data required for a robust safety analysis, the FHWA, National Highway Traffic Safety Administration (NHTSA), and

[1] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP17-50_UserGuide.pdf

Governors Highway Safety Association (GHSA) have together promulgated two sets of model data.

The first, the Model Inventory of Roadway Elements (MIRE), includes the recommended attributes for roadway characteristics and traffic volumes. Data collection is specific to the type of roadway. Roadway segments should include identifying information (such as route number or road name), surface type, geometry, owner, functional class, data about medians and shoulders, and Average Annual Daily Traffic (AADT) counts. Intersections include additional information about geometry and AADT for each intersection road. Interchanges or ramps also require data specific to their geometry and design.[2]

The second, the Model Minimum Uniform Crash Criteria (MMUCC), includes the recommended attributes to collect for motor vehicle crashes. The first set of data to collect involves crash elements, including location information, weather and roadway conditions, number of people involved in the crash, and contributing factors. The second set of data collects information on the vehicles involved in the crash, while the third set of data collects information on the people involved in the crash. There are additional fields for specific roadway elements, large vehicles, hazardous materials, and non-motorists involved.[3]

Each of these models have undergone significant development and maturation over the past few decades and have been integrated with other data collection requirements, such as the Highway Performance Monitoring System and National Bridge Inventory.

Once DOTs have collected roadway inventory, traffic volume and crash data, the HSM process uses this data to create mathematical models that reflect base crash conditions and can be used to predict future crashes. To support DOTs in creating and using these models, a number of predictive safety tools have been created to assist with the HSM process under Parts B, C, and D. These tools have been created by AASHTO, the FHWA, individual State DOTs, and private organizations.

A complete review of the different mathematical calculations used in the HSM process is beyond the scope of this memorandum.[4] However, a key part of this process is that it is predictive and not just historical. HSM predictive methods go beyond a traditional hot spot analysis, which focus on analyzing recent crash history only. The predictive process attempts to review crash frequency and performance based on similar peer sites, incorporate alternative or planned changes, and analyze future conditions to determine the expected performance and potential for safety improvement in the future.

An important component of the HSM process is Safety Performance Functions (SPF), which are regression models that predict the number of crashes given different traffic volumes and roadway characteristics at specific site types. SPFs can become very complex depending on the number of variables that account for the wide variety of different

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[2] https://safety.fhwa.dot.gov/rsdp/mire.aspx

[3] https://www.nhtsa.gov/mmucc-1

[4] Resources to learn more about the HSM process include the FHWA's Road Safety Fundamentals program, the FHWA's Roadway Safety Analysis Training videos compiled by the Michigan DOT, and the HSM User Guide.

observable features. Their development is a rigorous process that requires significant data collection and validation of their calculations. SPFs can be customized and enhanced through the addition of CMFs and calibration factors that adjust the models for roadway features at specific sites and local conditions.

Due to the complexity of the HSM process, predictive safety tools are used to standardized procedures and increase agency capacity to conduct different parts of the analysis. These tools can serve the following purposes:

- Managing roadway inventory data, including roadway segment and intersection characteristics, crash data, and volume data, and allowing for easy application of that data into HSM processes. This can also include automating integration of safety data with other departments such as the Department of Motor Vehicles;

- Processing of data for all six phases of HSM Part B and integrating that data into mapping software using external programs like Tableau or Esri products;

- Facilitating selection of appropriate SPFs for intersections or roadway segments with given characteristics; applying adjustment factors to account for roadway characteristics not accounted for in the chosen SPFs; and applying calibration factors to adjust SPFs for observed crashes;

- Calculating safety performance metrics, such as excess expected crash rate or potential for safety improvement; or the Level of Service of Safety (LOSS), which categorizes the observed and expected crash frequency across a population of different sites into four classes of level of service;

- Investigating the predicted crash rates at individual project sites, comparing different treatment options for a project, and converting those options into an economic analysis; and

- Evaluating the efficacy of different CMFs, both in terms of finding the appropriate CMF to apply to a project and in terms of the statistical reliability in how that CMF was calculated.

Overall, according to NCHRP 20-68A, which reviewed leading practices in the use of the HSM, the goal of safety tools is to make it “easier for personnel to understand, implement, and apply HSM methods and [performance-based, advanced safety analysis procedures] as part of their job responsibilities.”[5]

Finally, a second edition of the HSM is currently in process of being developed and is expected to be published in 2022. It is not a rewrite of the first edition of the HSM but will

[5] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_16-01.pdf

expand upon many of the topics and will incorporate new research and analysis features.[6] The new HSM is expected to include:

- An expanded explanation of how human factors affect safety in HSM Part A,
- The addition to HSM Part B of topics related to pedestrians and bicyclist safety and systemic safety,
- An additional chapter in Part C related to calibrating SPFs,
- A new HSM Part D focused more on selecting and applying CMFs,
- Expanded tools for roundabouts, and
- More in-depth prediction models for intersections.

Predictive Safety Tool Options

This section covers the different predictive safety tools available for State DOTs to use, focusing on:

- What data required as inputs,
- Which phase of a safety analysis the tools apply to,
- What the output of each tool is, and
- Key strengths or drawbacks to note.

These tools are also documented in the accompanying Excel spreadsheet summarizing the various tools available for use, which DOT or Agency is using each tool, DOT/Agency contact information, approximate percentage of implementation, which HSM phase the tool applies to, key data, lessons learned/hurdles (positives/negatives), and considerations to make when gathering specific details from each individual state in Task 2.

AASHTOWare Safety Analyst

AASHTOWare Safety Analyst software was developed beginning in 2001 and completed in 2010. It is used to conduct network analyses under HSM Part B. It is specifically designed with modules that reflect the six steps of Part B: Network Screening, Diagnosis, Countermeasure Selection, Economic Analysis, Priority Ranking, and Countermeasure Evaluation. Users may work through them sequentially or may pick individual modules to run. The ultimate output of this tool is a list of potential sites, like road segments or

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6 http://www.tampabaytrafficsafety.com/LATSA/LATSA%20Presentations/FDOT%20LATSA%20VIII%202020%20S02%20Highway%20Safety%20Manual%20v2%20-%20Jack%20Freeman.pdf

intersections, to target for safety improvements. Site selections are based on the user calibration factors like crash type or severity.

AASHTO has scheduled the sunset of the Safety Analyst program, setting June 30, 2022 as the date when this software will no longer be supported. This decision was made based on a decreasing level of adoption and use by DOTs.[7] Safety practitioners have also noted that the Safety Analyst program is difficult to collect data for and that the results it produces are not necessarily predictive or improve upon historical hotspot analyses that can be done to identify sites for safety improvements.[8] For these reasons, a number of State DOTs have begun to invest in their own tools to conduct HSM Part B network screening.

AASHTOWare Safety Powered by Numetric, Inc.

AASHTOWare Safety, powered by Numetric, Inc., is the next set of AASHTO tools to replace the Safety Analyst software used to conduct HSM Part B analysis.[9] Agencies are required to, at a minimum, provide crash, segment, AADT, and intersection data with specific attributes. This tool includes three modules:

- **Segment Analytics** – This module analyzes roadway segments, allowing users to query crash data and generate an analytical report, conduct network screening and rank segments by customized attributes, and translate a safety analysis into a benefit-cost ratio of any countermeasure. Additionally, this module has SPF management features that allow users to either incorporate automatic SPFs or create customized SPFs, and then identify and compare under-performing or over-performing roadway segments.

- **Intersection Analytics** – This module provides the analogous analysis for intersections that the Segment Analytics provides for roadway segments. In addition to Segment SPF management features, this module allows users to create collision diagrams that categorize crashes by the manner of collision and the first harmful event.

- **Trend Analytics** – This module facilitates the presentation and transparency of crash data. Users can create dashboards and public portals that can be used to search through crash data and follow progress on Key Performance Indicators related to safety.

When agencies sign up for an AASHTOWare Safety license, they are also provided with the data management services of Numetric, Inc. Numetric, Inc. has the capabilities to adapt the data maintained by State DOTs to the AASHTOWare Safety software. States send their existing databases to Numetric who conducts an Extract, Transform, and Load (ETL) process to load data into the AASHTOWare Safety platform. Furthermore, Numetric, Inc. provides agencies with access to customizable default data values for

[7] https://www.aashtoware.org/products/safety/safety-overview/

[8] See the AASHTO Network Screening Webinar #1, https://www.youtube.com/watch?v=5sJEs5SAX9Q&ab_channel=AASHTOWebinarRecordingArchive

[9] https://www.aashtoware.org/products/safety/safety-overview/

countermeasures, CMF values, calculations, costs, discount rate, and calibrated SPF values. [10]

DOT Network Screening Tools

After AASHTO's announcement, around April 2020,[11] to sunset the Safety Analyst software, many State DOTs invested in creating customized network screening tools. These tools can be sponsored by programs from agencies such as the FHWA's Every Day Counts initiative.[12] The program supports states to create customized network screening tools that meet specific needs or explore specific issues.

Recently, AASHTO has been hosting a series of webinars where different agencies can showcase their work in developing these screening tools.[13] In general, these tools are created and customized by individual states to integrate their unique data sources and facilitate HSM calculations using those sources. The following tools had been covered in AASHTO's webinars:

- **Connecticut DOT – Connecticut Roadway Safety Management System (CRSMS) Tool:** CTDOT's web-based application fully implements the six steps of the Part B HSM process. It allows for updating of SPFs and CMFs as well as the calculation and visualization of performance measures such as LOSS and Critical Crash Rate.

- **Florida DOT – System Analysis & Forecast Evaluation (SAFE) Tool:** FDOT's SAS-based tool was created to first meet the state's need to conduct a detailed analysis of signalized intersections. It allows for annual calculation of state-specific SPFs. This tool also integrates all their datasets and allows it to interface with other systems, such as Department of Motor Vehicle data.

- **Kentucky Transportation Cabinet (KYTC) – Crash Data Analysis Tool:** KYTC's web-based application uses state-specific SPFs and can perform queries and generate maps to display crashes. Part of the intention of this tool is to promote highway homogeneity. They have also incorporated an open-source R Programming-based package, SPF-R, that can be used to generate and analyze SPFs.[14]

- **Illinois DOT – Safety Tiers:** IDOT developed a methodology that calculates tiers of need for roadway segments and intersections based on the Potential for Safety Improvement values calculated from SPFs. IDOT's methodology was created based on the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)'s requirement to submit the five percent of highway locations with the most pressing needs to FHWA.

[10] https://www.aashtoware.org/wp-content/uploads/2021/05/FY-2022-AASHTOWare-Catalog_Final.pdf

[11] https://numetric.com/news/press-release/aashtoware-and-numetric-announce-major-alliance/

[12] https://safety.fhwa.dot.gov/rsdp/ddsa.aspx

[13] http://www.highwaysafetymanual.org/Pages/Implementation.aspx

[14] https://github.com/irkgreen/SPF-R

- **Colorado DOT – DiExSys – Vision Zero Suite:** CDOT's tool performs network screenings by taking a crash history query and state-specific SPFs, applying an Empirical Bayes correction and categorizing roadway segments and intersections into four LOSS levels. The state-specific SPFs are updated through a separate effort along a rolling five-year time scale based on 74 different models. The software facilitates exporting results in batches for mapping and reporting purposes.

- **Wyoming DOT – OnSafety Portal:** WYDOT's portal maintains an inventory of roadways and intersection data along with component modules such as an HSM Network Processor, a safety management system, and a report engine. They screen for segments by dividing roadways into one-mile segments and looking for the highest concentration of fatal or serious injury crashes.

State-Specific SPFs

SPFs are a foundational element of the HSM predictive methodology. SPFs are the basic equations that quantify crash rates as a function of traffic volumes and roadway characteristics.

The HSM provides a set of SPFs for different roadway segments and intersections with common characteristics. However, many agencies maintain datasets specific to their network that can be used to develop either calibration factors for HSM-provided SPFs or to calculate their own jurisdiction-specific SPFs. This can be advantageous in increasing the predictive capability and accuracy of safety analyses.

In 2013, the FHWA released a Safety Performance Function Development Guide on how jurisdictions can calculate their own SPFs. The SPF calculation process recommended by the FHWA requires data that is typical of the HSM process, including observed crash, traffic volume, and roadway characteristic datasets. [15]

To provide the best results and avoid statistical issues that may arise during calculation, these datasets must be accurate and comprehensive. The FHWA also released a Safety Performance Function Decision Guide that can help transportation professionals determine whether it is better to calibrate HSM-provided SPFs or to develop their own SPFs.[16] Should a state or regional jurisdiction decide to proceed with producing their own SPFs, they would take the following steps:

1. Determine their intended purpose of the SPF.
2. Identify the facility type which the SPF will be applied toward.
3. Compile necessary data specific to the intended purpose of the SPF.
4. Prepare and clean the data collected.

[15] https://safety.fhwa.dot.gov/rsdp/downloads/spf_development_guide_final.pdf

[16] https://safety.fhwa.dot.gov/rsdp/downloads/spf_decision_guide_final.pdf

5. Iteratively calculate the SPF, taking careful consideration of the different statistical issues that may arise and evaluating the validity (i.e. through goodness-of-fit statistics and cumulative residual plots).[17]

6. Develop the SPF for base conditions, if needed for the intended purpose of the SPF.

7. Develop CMFs for specific treatments, if needed for the intended purpose of the SPF.

8. Document results.

The Crash Modification Clearinghouse maintains a list of which states have calibrated HSM-provided SPFs for their roadway network and/or developed state-specific SPFs. According to that list, as of November 2020, 30 states have calibrated and/or developed state-specific SPFs. [18]

SPF Tool is a web-based application created by transportation engineers that many states use to enhance their HSM Part B analysis capabilities. It contains many features related to SPFs that help agencies manage the SPF databases from the standard SPFs that come with the HSM. This tool can help agencies calculate state-specific SPFs, apply them through network screening queries, visualize screening results and diagnostics, and convert the results to an economic analysis.[19] This desk scan did not identify thorough publicly available information about the specifics (such as data requirements) that states need to utilize this tool.

DOT and AASHTO Spreadsheets for Predictive Analysis

AASHTO maintains three HSM Part C spreadsheet tools developed out of National Cooperative Highway Research Program research studies. Each of these tools is named after HSM Chapters 10 – 12 (Rural Two-Lane Roads, Rural Multilane Highways, and Urban and Suburban Arterials) and are thus tools to implement the methodologies in those chapters. [20]

Each spreadsheet is similar in that it provides users with worksheets to enter up to eight roadway segments and/or up to eight intersections. The Rural Multilane Highway spreadsheet also differentiates between divided and undivided roadway segments. For segments, users must enter data for roadway type, length, traffic volume, and various roadway characteristics. For intersections, users enter data for intersection type, major and minor segment traffic volumes, and various intersection characteristics. These inputs are then used in predictive modeling calculations, and users may also enter locally-derived values to customize those modeling calculations.

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[17] The FHWA has published The Calibrator, a guide to help with calibration: https://safety.fhwa.dot.gov/rsdp/downloads/fhwasa17016.pdf

[18] http://www.cmfclearinghouse.org/resources_spf.cfm

[19] http://spftool.com/about-spf-tool

[20] See "HSM Spreadsheet Tools" under "PART C – Predictive Method" at http://www.highwaysafetymanual.org/Pages/Tools.aspx

Several DOTs have modified or expanded the Part C Spreadsheet tools maintained by AASHTO to suit the needs of their jurisdictions. Examples of those spreadsheets include:

- **Pennsylvania DOT – Part C Tools:** Pennsylvania's DOT offers several different calibrated tools specific to their state. Specific to HSM Part C predictive analysis, there are two tools that have been designed for existing conditions analysis and alternatives analysis. These are enabled with macros and a user interface and allow users to select SPFs that have been calibrated for Pennsylvania districts or counties. Additionally, the Pennsylvania DOT has a BCA tool and a version of Enhanced Interchange Safety Analysis Tool (ISATe) that have both been calibrated to Pennsylvania. 21

- **Ohio DOT – Economic Crash Analysis Tool (ECAT):** The ECAT is a version of the spreadsheet calibrated specifically for Ohio. It significantly augments the user interactivity with the spreadsheet, the ability to enter detailed project data, and then produce reports from the spreadsheet's calculations. It has been tailored to meet the requirements under ODOT's Highway Safety Program and utilize input from Ohio's other crash data analysis tools. 22

- **Louisiana Department of Transportation and Development's (DOTD) – Highway Safety Analysis Toolbox:** The Louisiana DOTD has catalogued several tools within the Highway Safety Analysis Toolbox. This includes a Crash Analysis Tool that incorporates state-specific SPFs for HSM Part C Analysis as well as a number of screening and triage tools for network screening. 23

The Crash Modification Clearinghouse maintains a spreadsheet summarizing which states have adapted HSM Part C Spreadsheet tools to their jurisdictions. This spreadsheet was last updated in June 2016 and compiled seven states who have adapted HSM Part C Spreadsheets.[24]

Crash Modification Factors Clearinghouse

CMFs are factors applied to crash rate prediction algorithms to reflect changes to the crash rate due to specific roadway treatments. These factors can either be applied because of existing roadway treatments that change the predicted crash rate or to compare the effectiveness of roadway treatment options to be applied in the future. CMFs can either be below 1.0, indicating that they decrease the predicted crash rate, or above 1.0, indicating that they increase the predicted crash rate.

[21] https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx

[22] https://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx

[23] http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Highway_Safety/Pages/Highway_Safety_Analysis_Toolbox.aspx

[24] http://www.cmfclearinghouse.org/resources_spf.cfm

From a national perspective, the central resource for CMFs is the Crash Modification Factors Clearinghouse (CMF Clearinghouse).[25] The CMF Clearinghouse provides a centralized, searchable repository of CMFs that have been published. Each CMF includes an expected change in the crash rate, which crashes it applies to, and a source for how it was determined. [26] Using the Clearinghouse, safety practitioners can search through different roadway treatment options, decide which CMF(s) most appropriately fits the roadway characteristics and local conditions being investigated, and compare the effects of different treatment options. The CMF Clearinghouse is a central resource that State DOTs use regularly to locate information regarding CMFs.

One key element of the CMF Clearinghouse is the rating system, which was recently updated in February 2021.[27] This system helps users understand the rigor and validity used to calculate a CMF value. The new rating system calculates points (out of a maximum of 150) based on different factors. The factors applied differ depending on whether the CMF was calculated as part of a before/after and cross-sectional study, meta-analysis study, or meta-regression study. In general, the factors consider the data used to calculate the CMF, study design and statistical methodology, and statistical significance of the CMF.

In addition to the CMF Clearinghouse, many states develop CMFs.[28] This allows CMFs to be tailored to local conditions and ensure consistency for state-specific roadway treatment designs.

Interactive Highway Safety Design Model (IHSDM)

The IHSDM is a suite of software analysis tools by the FHWA to evaluate safety and operational effects of geometric design on highway segments, intersections, interchanges, and roundabouts. It is an implementation of the Part C methodology of the HSM, thereby providing a standardized way of analyzing the safety impacts of individual sites or projects. [29] Several State DOTs, including Pennsylvania, North Dakota, Louisiana, Kansas, Nevada, Arizona, California, and Idaho, have used the IHSDM and presented their findings at conferences such as the Transportation Research Board Annual Meeting.[30]

The IHSDM contains five modules, the most prominent of which is the Crash Prediction module. This module quantifies road safety performance based on the expected and predicted crash rates given a set of roadway, intersection, or interchange characteristics and traffic volume data. To achieve that:

[25] http://www.cmfclearinghouse.org/index.cfm

[26] http://www.cmfclearinghouse.org/userguide.cfm

[27] http://www.cmfclearinghouse.org/changes.cfm

[28] http://www.cmfclearinghouse.org/stateselectedlist.cfm

[29] https://highways.dot.gov/research/safety/interactive-highway-safety-design-model/interactive-highway-safety-design-model-ihsdm-overview

[30] https://www.ihsdm.org/wiki/Documented_IHSDM_Applications

- Start with an SPF for one of five roadway types (rural two-lane highways, rural multilane highways, urban and suburban arterials, freeways and interchanges, and roundabouts).

- Then, apply CMFs for a range of site-specific elements, such as shoulder width or intersection features that customize the SPF to site-specific features.

- Next, incorporate calibration factors that adjust the expected crash rate to be consistent with observed crashes.

Users of the IHSDM can use these different elements to quantify the effects that specific treatments might have on future crash rates.

In addition to the Crash Prediction module, the IHSDM contains several other modules that help analyze specific project issues:

- The Policy Review module can compare the design elements of rural two-lane highways and rural multilane highways with policy documents such as The Green Book;

- The Design Consistency module evaluates crashes along curved roadway segments;

- The Driver/Vehicle module models vehicle behavior and vehicle dynamics;

- The Traffic Analysis module estimates the operational quality of service under current or future traffic volumes. (The Design Consistency, Driver/Vehicle, and Traffic Analysis modules are only applicable to rural two-lane highways); and

- The economic analysis tool converts results from the Crash Prediction module into cost-benefit analysis results.

The exact data requirements depend on which safety module(s) will be used. In general, data requirements may include highway segment geometry (horizontal alignment, vertical alignment, and cross section), roadside geometry, intersection geometry, traffic volume data, and crash data.[31]

Enhanced Interchange Safety Analysis Tool (ISATe)

The Enhanced Interchange Safety Analysis Tool (ISATe) specifically evaluates the safety performance of freeway interchanges and entrance ramps. It was created as a supplement to Part C of the HSM to enhance the ability to evaluate safety at these specific sites. Interchanges, ramp terminals, and freeway entrance ramps are unique from other intersections covered in Part C of the HSM, as they have more facility components such as limited access sections, ramps, and crossroad ramp terminals. The ISATe software is specifically designed to evaluate these components alone or in any combination that reflects the multiple possible designs of these facilities. Additionally, the software contains

[31] https://www.ihsdm.org/wiki/Highway_Data

procedures to calibrate the predictive model variables, distribution values, and severity distribution functions used to calculate expected crashes.[32]

Data requirements for the ISATe tool are similar to other tools in that they require traffic volume, observed crash, and roadway characteristic data. However, these data needs are tailored to the specific features of freeway interchanges. There are specific parameters that need to be collected to reflect the many characteristics related to ramps and crossroad ramp intersections, such as the length of the speed-change lane, length of the ramp, curve of the roadway and/or the ramp, presence of any median barriers, etc.[33]

The ISATe tool has been used in the state of Florida to evaluate five interchanges using a before-and-after safety analysis. This study found that the ISATe tool overpredicted for property damage only crashes and overpredicted crashes along crossroad ramp terminals.[34] Aside from this, no other documented use cases of the ISATe tool were found in this desk review, although the tool is used by practitioners in many states.

Crash Modification Factors Clearinghouse

CMFs are factors applied to crash rate prediction algorithms to reflect changes to the crash rate due to specific roadway treatments. These factors can either be applied because of existing roadway treatments that change the predicted crash rate or to compare the effectiveness of roadway treatment options to be applied in the future. CMFs can either be below 1.0, indicating that they decrease the predicted crash rate, or above 1.0, indicating that they increase the predicted crash rate.

From a national perspective, the central resource for CMFs is the Crash Modification Factors Clearinghouse (CMF Clearinghouse).[35] The CMF Clearinghouse provides a centralized, searchable repository of CMFs that have been published. Each CMF includes an expected change in the crash rate, which crashes it applies to, and a source for how it was determined.[36] Using the Clearinghouse, safety practitioners can search through different roadway treatment options, decide which CMF(s) most appropriately fits the roadway characteristics and local conditions being investigated, and compare the effects of different treatment options. The CMF Clearinghouse is a central resource that State DOTs use regularly to locate information regarding CMFs.

One key element of the CMF Clearinghouse is the rating system, which was recently updated in February 2021.[37] This system helps users understand the rigor and validity used to calculate a CMF value. The new rating system calculates points (out of a maximum of 150) based on different factors. The factors applied differ depending on whether the CMF was calculated as part of a before/after and cross-sectional study, meta-

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[32] Downloaded from http://www.highwaysafetymanual.org/documents/NCHRP-1738_XLS.zip

[33] See a list of data requirements here: https://safety.fhwa.dot.gov/rsdp/toolbox-content.aspx?toolid=62

[34] https://trid.trb.org/view/1667717

[35] http://www.cmfclearinghouse.org/index.cfm

[36] http://www.cmfclearinghouse.org/userguide.cfm

[37] http://www.cmfclearinghouse.org/changes.cfm

analysis study, or meta-regression study. In general, the factors consider the data used to calculate the CMF, study design and statistical methodology, and statistical significance of the CMF.

In addition to the CMF Clearinghouse, many states develop CMFs.[38] This allows CMFs to be tailored to local conditions and ensure consistency for state-specific roadway treatment designs.

Key Considerations for Predictive Safety Tools

This desk review of predictive safety tool best practices indicates the depth and complexity of safety analysis calculations made possible by the HSM. The HSM has laid out a complex mathematical methodology that requires significant data needs, technical capacity, and flexibility to customize safety analyses to specific conditions. It is clear that the development of these methodologies over the last two decades has greatly expanded the ability for State DOTs to conduct safety analysis and quantify safety benefits using a data-driven process.

The tools that federal and state agencies have created to implement the HSM reflect that the methodology is challenging and intensive. The main purpose of these tools is to reduce the technical barriers to completing these analyses and to standardize processes so that analysis results can be comparable to each other. This desk review reveals several themes:

- **HSM Process Component** – The types of tools available are defined by which process of the HSM they address. Broadly speaking, that includes HSM Part B (Roadway Safety Management), HSM Part C (Predictive Methods), SPF management, and CMF management.

- **National vs. State** – National tools attempt to cover the most common roadway and safety elements. State tools are more customized to the specific data collected by each DOT, as well as specific circumstances such as weather conditions or design guidelines.

- **In-House vs. Outsourced** – Many agencies devote significant resources to creating their own tools using their own staff members and internal capacity. Several also utilize consultant support for aspects of development, testing and calibration. Other tools are made available by outside firms (such as Numetric, Inc.) that provide specialized knowledge of data-handling and tool customization.

- **Data Specificity** – The categories of data required for HSM processes are broadly the same: roadway characteristics, traffic volume, and observed crashes. However, there is variability among the specific attributes collected by States and the information required to complete an analysis with each tool.

[38] http://www.cmfclearinghouse.org/stateselectedlist.cfm

PREDICTIVE SAFETY TOOL SURVEY AND INTERVIEW FINDINGS

This section builds on the first by reporting on the practitioners' experience implementing the HSM predictive safety process and using HSM predictive safety tools. The first subsection outlines the survey results sent to State DOTs and the second subsection documents the follow-up interviews conducted with six State DOTs.

Survey Findings

Survey Design

The survey is divided into two broad sections. The first section collected information about the participants' specific experience with eight different HSM predictive tools, which are detailed in the first section of this report:

- AASHTOWare Safety Analyst.
- AASHTOWare Safety powered by Numetric, Inc.
- A State-Specific Network Screening Tool.
- AASHTO HSM Part C Spreadsheets.
- State-Specific HSM Part C Spreadsheets.
- SPFTool.
- Interactive Highway Safety Design Model (IHSDM).
- Enhanced Interchange Safety Analysis Tool (ISATe).

The second section collected information about the HSM process more broadly, including issues related to roadway characteristic and traffic volume/Average Annual Daily Traffic (AADT) data (e.g., MIRE), crash data (e.g., MMUCC), HSM training, SPFs and CMFs, and performance measures. In addition, the survey introduction asked participants about how much experience they have with HSM predictive methods, and the conclusion asked participants about their willingness to participate in the follow-up interviews.

The survey contained embedded logic that asked more detailed questions about the topics that participants claimed to have experience with. For instance, if the respondent answered that they have experience with the IHDSM tool, they were then asked specific follow-up questions about that specific tool. If they answered they did not have experience with the IHDSM tool, those questions were skipped. This design keeps the survey targeted and the response time shorter while still collecting a broad set of information from participants.

In addition, the survey asked specific questions of particular interest to NJDOT, including questions related to data collection, data gaps, roadway segmentation, training and staff turnover, and Information Technology (IT) challenges.

Tool-Specific Survey Findings

The first set of questions focused on eight HSM tools and specific issues with using those tools. Figure 1 shows how many respondents have experience using each of the eight tools. **Overall, most respondents have experience with a state-specific network screening tool (18 of 26) and the IHDSM (16 of 26 respondents).** Many respondents also have experience working with HSM Part C spreadsheets, either those maintained by AASHTO (12 of 26 respondents) or those calibrated to their State (13 of 26 respondents). **Respondents had the least experience with two proprietary software tools**, AASHTOWare Safety by Numetric, Inc. (3 of 26 respondents) and SPFTool (2 of 26 respondents).

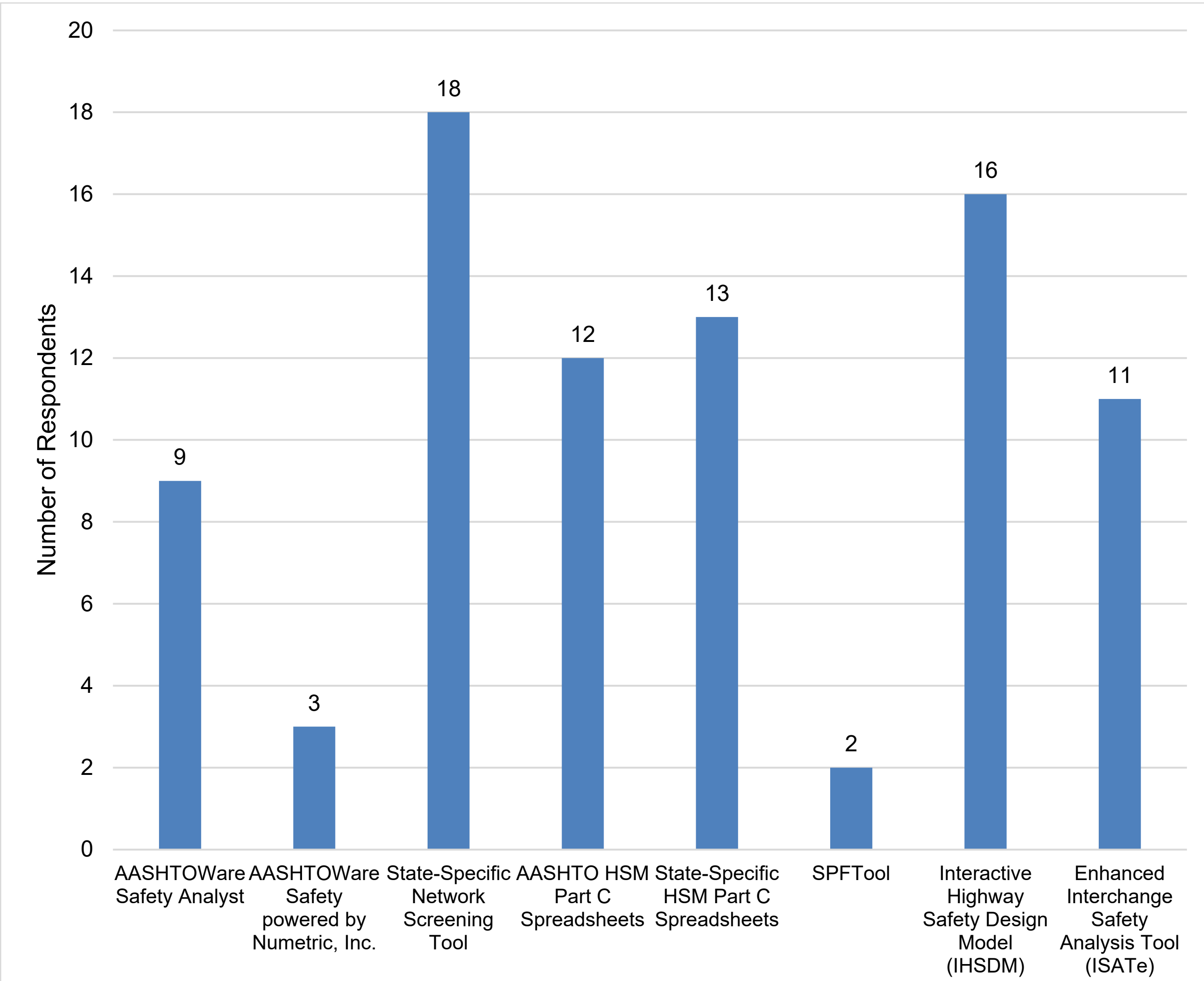


Figure 1. Number of Respondents Using Each HSM Tool

For each tool that respondents had experience with, the survey asked follow-up questions about issues specific to their experiences. The first question explored is how much effort it takes to upload data to each tool. Figure 2 shows the amount of time users anticipate it takes to adapt their data to each tool.

In general, it takes less time to adapt data for HSM Part C tools compared with HSM Part B tools, likely reflecting that the latter types of tools have more intensive and complex data needs. Among HSM Part B tools, it takes the longest to upload data to AASHTOWare Safety Analyst. It takes comparatively less effort to upload data to both AASHTOWare Safety powered by Numetric, Inc. and a state-specific network screening tool, with half of respondents reporting it takes less than two weeks to upload data for both of those tools. Among HSM Part C tools, IHDSM takes the longest to upload data and it is comparatively faster to upload data to HSM Part C Spreadsheets (both those maintained by AASHTO and those calibrated to each State) and the ISATe.

Note: Tools marked with an asterisk (*) had a low survey response rate. SPFTool is excluded from this figure because no responses were received for this question for that tool.

Figure 2. Length of Time to Upload Data to the Tool

The second follow-up question relates to data gaps experienced when using each tool. Table 1 shows how many users experience data gaps related to missing roadway characteristic data, missing traffic volume data, missing crash history data, and/or other missing data. The table also contains a column that summarizes user responses for the other missing data that users encounter.

The most common response, except for AASHTOWare Safety Analyst and AASHTOWare Safety powered by Numetric, Inc., was that users experienced no data gaps for the tools they used. When users experienced data gaps, the most common gap was missing roadway characteristic data, followed by missing traffic data, and followed by missing crash history data. Some insight from the comment responses include:

- For other missing data, users report various gaps for HSM Part B tools, notably missing intersection data and missing local road data.

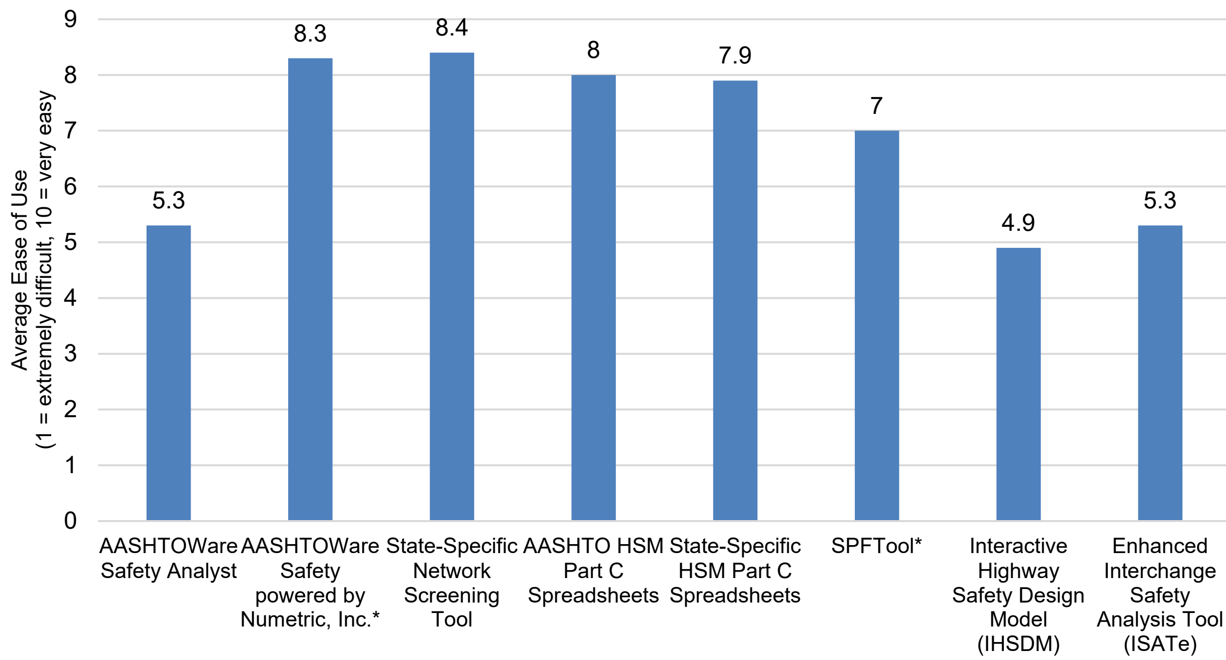
- For Part C Tools, users report data missing at the planning stages of projects, inaccurate crash location data, and missing detailed roadway characteristic data.

Table 1 – Summary of Data Gaps Per Tool

Tool	Number of Responses	No Missing Data	Missing Roadway Characteristic Data	Missing Traffic Volume Data	Missing Crash History Data	Missing Other Data	Comments on Other Missing Data
AASHTOWare Safety Analyst	6	1 (17%)	1 (17%)	2 (33%)	0 (0%)	2 (33%)	• Respondents reported various gaps, including inaccuracies for traffic data, intersection data, crash severity, and imported local data
AASHTOWare Safety powered by Numetric, Inc.	3	1 (33%)	1 (33%)	0 (0%)	1 (33%)	0 (0%)	N/A
State-Specific Network Screening Tool	16	7 (44%)	3 (19%)	1 (6%)	2 (13%)	3 (19%)	• Some tools use only crash data • Some intersection data (such as left-turn lanes) may be missing • Some missing local road data
AASHTO HSM Part C Spreadsheets	11	4 (36%)	3 (27%)	3 (27%)	0 (0%)	1 (9%)	• Some missing more detailed roadway characteristic data (ex: driveway density, curve radii, skew angel, etc.)
State-Specific HSM Part C Spreadsheets	11	5 (45%)	1 (9%)	1 (9%)	1 (9%)	3 (27%)	• Data may not be available at planning design stages • Crash location data may be inaccurate
SPFTool	1	1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	N/A
Interactive Highway Safety Design Model (IHSDM)	14	6 (43%)	2 (14%)	2 (14%)	1 (7%)	3 (21%)	• Difficult to keep the tool calibrated • Had issues importing CAD files
Enhanced Interchange Safety Analysis Tool (ISATe)	11	5 (45%)	2 (18%)	1 (9%)	0 (0%)	3 (27%)	• Data may not be available at planning stages • Crash location data may be inaccurate • Need more precise measurements for roadside elements

The third follow-up question related to each tool's ease of use. Figure 3 shows the average ease of use for each tool on a scale from 1 to 10, with 1 being extremely difficult to use and 10 being very easy to use.

In general, the tools with more customization capability show greater ease of use. For instance, users find AASHTOWare Safety Analyst relatively difficult to use but find AASHTOWare Safety powered by Numetric, Inc. much easier to use. Likewise, both AASHTO-maintained and state-specific HSM Part C spreadsheets are comparatively easy to use, but IHDSM and ISATe are harder to use. State-specific network screening tools are rated the easiest to use among all the tools while the IHDSM is rated the hardest to use.



Note: Tools marked with an asterisk (*) had a low survey response rate.

Figure 3. Average Ease of Use for Each Tool

The fourth follow-up question asked about the geographic scope used with each tool. Figure 4 shows how many respondents use each tool at the statewide, regional/district, MPO, local, or other geographic scale.

For network screening tools, almost all respondents note using them at the statewide level but many report using them at all other scales as well. Other comments note that the level of analysis was the State highway network for network screening tools. HSM Part C tools tend to be used at the project level, with many respondents leaving a comment to specify that as the geographic scope of use. For analyses at the MPO level, respondents report using AASHTOWare Safety powered by

Numetric, Inc., state-specific network screening tools, and AASHTO HSM Part C Spreadsheets.

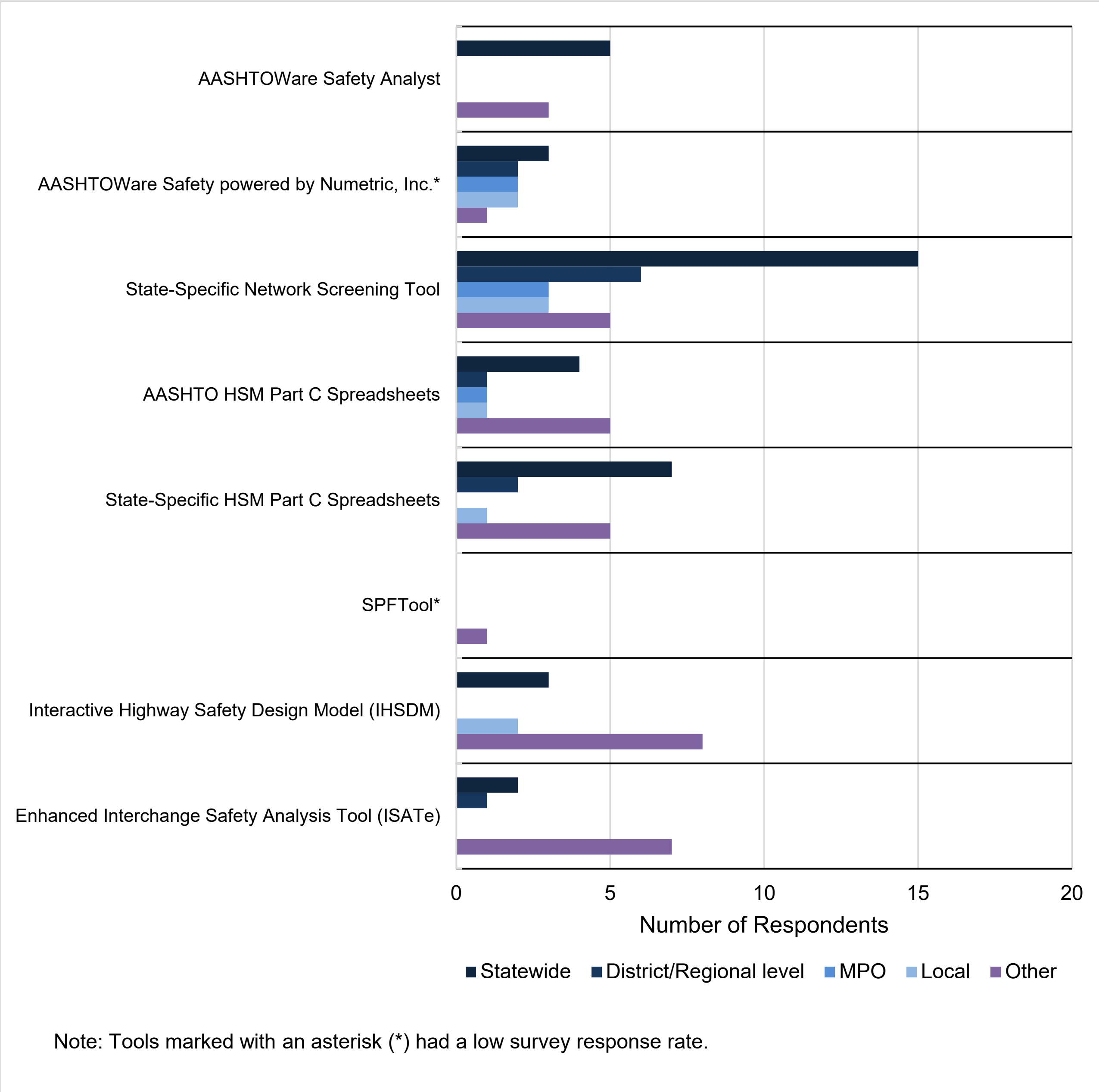


Figure 4. Geographic Scope of Use for Each Tool

The final follow-up question in the first part of the survey relates only to AASHTOWare Safety Analyst, AASHTOWare Safety by Numetric, and SPFTool. These proprietary tools require licensing and technical support, so the survey asked respondents about their experience with these parts of the tools. Insights include:

- For the most part, respondents could not extend their license to MPOs or localities with AASHTOWare Safety Analyst or SPFTool, but two of three respondents were able to with AASHTOWare Safety by Numetric, Inc.

- Most respondents did not have issues with technical support.

- Respondents who work with AASHTOWare Safety by Numetric, Inc. note that trainings and support have been generally good, though the technical support teams sometimes do not understand the details of specific safety analyses.

HSM Process Survey Findings

The second half of the survey focused on HSM processes more broadly. It started with questions related to data collection, specifically those related to MIRE data (for roadway characteristics and traffic volume) and MMUCC data (for crash data). Next, the questions transitioned to training staff on HSM methods and tools. After that, it asked respondents about their experience with safety performance measures used in their analyses. Finally, the survey asked respondents about their experience developing or calibrating SPFs or CMFs.

As with the first half of the survey, the respondents were only asked questions regarding HSM methods that they have experience with. So, for instance, if a user does not have experience with MMUCC data collection, those follow-up questions are skipped.

MIRE/MMUCC and Safety Data Integration

The initial category of general HSM process questions relate to the collection of roadway characteristic and traffic data (MIRE) and crash data (MMUCC). 18 respondents had experience with MIRE, and 17 respondents had experience with MMUCC. The first question asked respondents to agree or disagree with the following statements:

- Our department can easily collect and maintain [MIRE or MMUCC data] on our roadway network.

- Our department can readily access our [MIRE or MMUCC data] in HSM predictive methods and tools.

- It is common that we face significant data gaps regarding [MIRE or MMUCC data] when using HSM predictive methods or tools.

Figure 5 shows the average response score to these three statements, where 1 = Strongly Disagree, 2 = Somewhat Disagree, 3 = Neither Agree nor Disagree, 4 = Somewhat Agree, and 5 = Strongly Agree**. In general, respondents find it easier to collect, maintain, and access MMUCC data compared to MIRE data, and have fewer data gaps for MMUCC data compared to MIRE data.** For MIRE data, respondents find it more challenging to collect and maintain that data as opposed to access it in HSM predictive methods and tools.

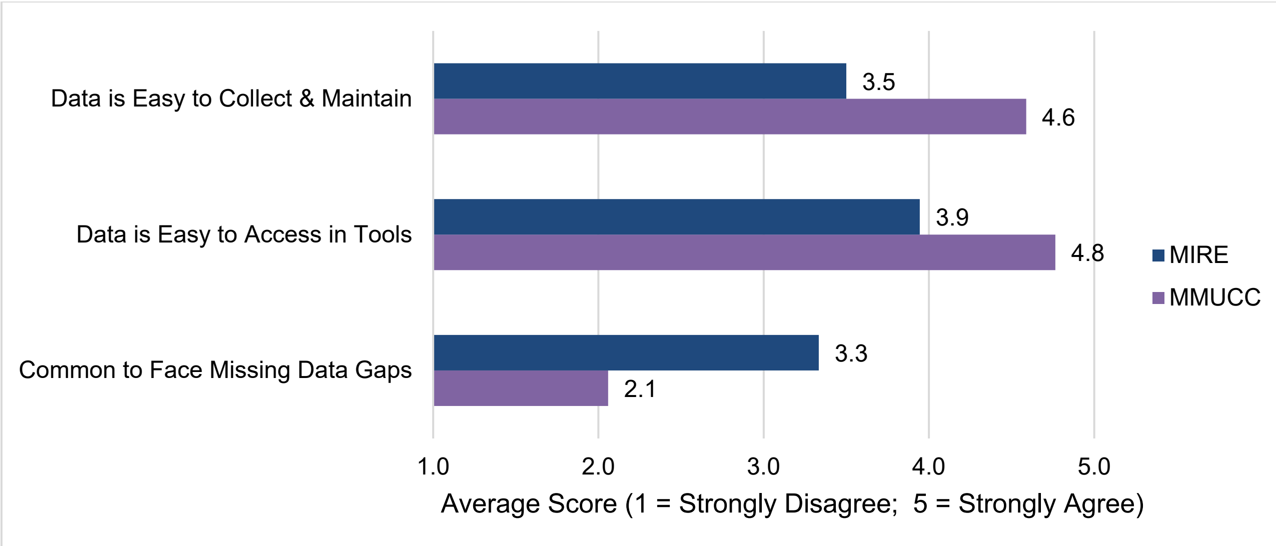


Figure 5. Average Responses for Data Accessibility and Availability for MIRE and MMUCC Data

The second question asked about supplemental programs that agencies use to address two specific topics of interest to NJDOT. First, for MIRE data, the survey asked if respondents use any program(s) to supplement traffic volume collection efforts, especially along minor roads. Some respondents use such program(s), but most do not know the details of those programs or those efforts. One respondent believes that their department uses models to predict or estimate volumes on minor roads; one respondent knows of a traffic data collection process using yearly tube counts or permanent stations; one respondent cited on-demand contracts with consultants to collect traffic counts; and one respondent said minor roadway traffic volumes are estimated based on nearby generator counts.

For MMUCC data, the survey asked what program(s) are used to visualize crash data. **The most common answer is GIS software, such as ArcGIS.** Several respondents also list Microsoft Power BI. Several other respondents note that they use in-house or internal-only tools to access crash data. Other respondents list programs that are publicly available, including IMPACT,[39] the Pennsylvania Crash Information Tool (PCIT),[40] the Nebraska Transportation Information Portal (NTIP),[41] and Community Maps.[42]

Finally, the survey asked if respondents have segmented their roadway line data for network analysis or determined buffer distance for attributing safety data at

[39] https://apps.impact.dot.state.ma.us/cdp/home

[40] https://crashinfo.penndot.gov/PCIT/queryTool.html

[41] https://ntip.nebraska.gov

[42] https://transportal.cee.wisc.edu/partners/community-maps/

intersections. **83 percent (15 of 17) had done the former and 67 percent (12 of 17) had done the latter; only 11 percent (2 of 17) had done neither of these**.

HSM Training

The next category of general HSM questions relate to the training that respondents receive in HSM predictive methods and tools. **12 of 26 respondents work in departments that provide their own training on this subject.** Of the employees that are required to attend, engineers are most often required to attend (5 of 12 responses), followed by planners (3 of 12 responses) and DOT leadership (2 of 12 responses). However, 5 of 12 responses also said that no one was required to attend these trainings. These trainings take place no more than 1-2 times per year and often even less. For the most part (7 of 12 responses), these trainings occur either one time only or as needed based on staff requests.

Of the methodologies, tools, or resources covered at HSM predictive methods and tools trainings, the most common topics include the overall HSM process (9 of 12 responses) and HSM Part C predictive methods (9 of 12 responses). Also common are HSM Part D crash modification factors (7 of 12 responses). Less common topics include HSM Part B network screening (3 of 12 responses) and SPF development and use (3 of 12 responses).

Respondents were asked to agree or disagree with the following statement: "I have learned a lot from the trainings on HSM tools and methodologies provided by my department and they have helped me conduct a more thorough crash analysis." **No respondents disagreed with this statement, and most (8 of 12) either strongly or somewhat agreed with it**; the remainder answered they neither agree nor disagree or they do not know.

Performance Measures

The next category of general HSM questions relate to which performance measure respondents use to evaluate the potential to reduce crashes at different sites. In particular, the survey asked about the following performance metrics:

- *Crash Rate* – the number of crashes per unit of exposure.
- *Excess Expected Crash Rate* – The difference between the adjusted observed crash frequency and the expected crash frequency for that location based on its site type and characteristics.
- *Potential for Safety Improvement (PSI)* – An estimate of how much the long-term crash frequency can be reduced at a particular site.
- *Level of Service of Safety (LOSS)* – categorizes the observed and expected crash frequency across a population of different sites into four classes of level of service.

Figure 6 shows how many respondents use each of those four metrics. **Of those four, the most used is PSI,** followed by the Crash Rate, LOSS, and Excess Expected Crash Rate.

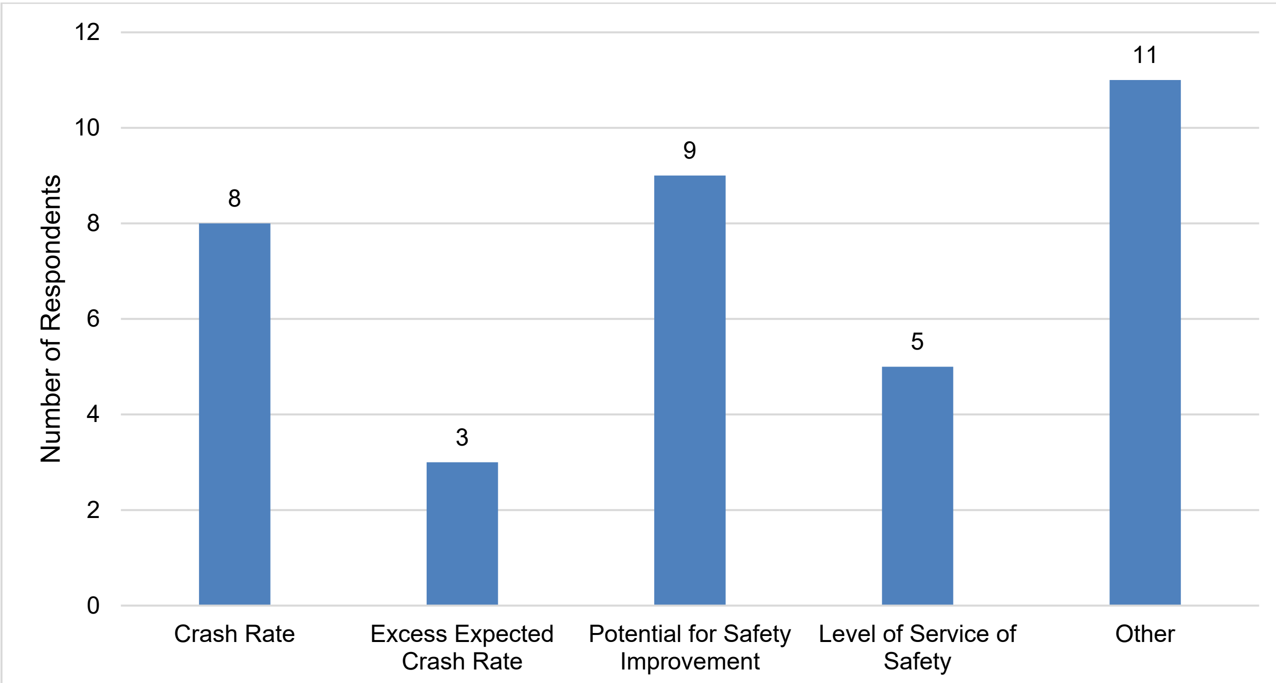


Figure 6. Performance Metrics Used to Evaluate Potential to Reduce Crashes

The most common response, however, is "other," and respondents list a variety of other performance metrics that they use. These include metrics related to benefit-cost analysis (i.e., benefit-cost ratio), crash rates for fatal and serious injury crashes, excess yearly crash frequency, predicted or expected crashes, and Empirical Bayes average excess crashes.

SPFs and CMFs

The remaining two sections of the survey relate to respondents' experience with SPFs and CMFs. A common element between SPFs and CMFs is that States can either calibrate HSM-provided SPFs or national CMFs to their jurisdiction or they can develop their own. Among survey respondents, **a roughly equal number** calibrate HSM-provided SPFs to their jurisdiction (11 respondents) as develop their own state-specific SPFs (12 respondents). For CMFs, **more respondents** are involved in evaluating national CMFs (20 respondents) compared to those who develop their own CMFs (12 respondents).

Figure 7 shows respondents' experience with data gaps when developing SPFs and CMFs. **Data gaps are most common for calibrating HSM-provided SPFs.** Several respondents report missing traffic volume data. Many respondents report other missing data, such as not having a large enough sample size to calibrate SPFs or issues with matching crashes to interchanges. Data gaps are less common for developing state-specific SPFs, though some respondents report missing roadway characteristic or traffic volume data.

For calibrating national CMFs, most respondents report no data gaps. Those that did experience data gaps most commonly report missing roadway characteristic data or other missing data, such as national CMFs not matching their specific situation. For developing state-specific CMFs, the most common data gap is missing traffic volume data followed by other missing data. For both calibrating national CMFs and developing state-specific CMFs, other missing data most frequently refers to a lack of data or locations to develop statistically significant CMFs.

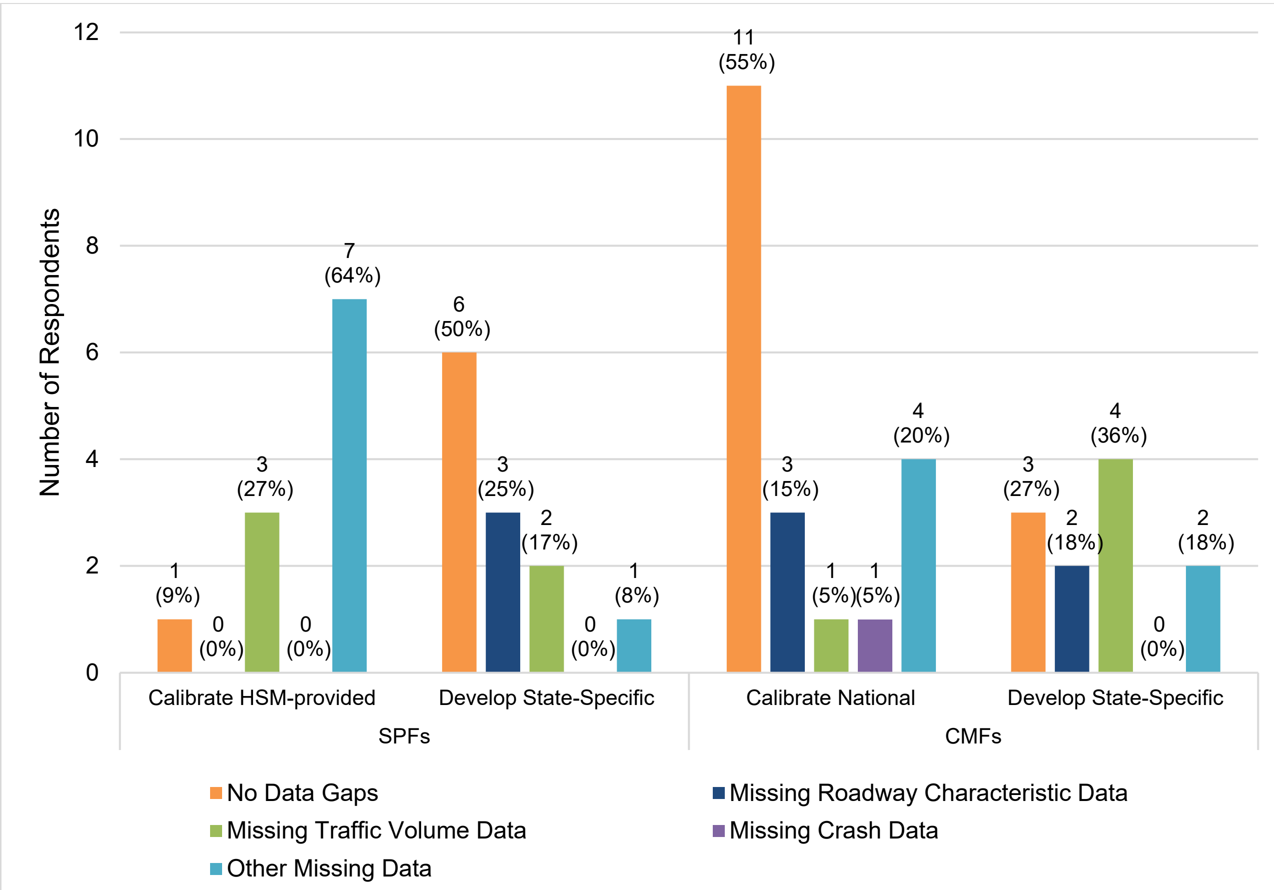


Figure 7. Data Gaps Experienced with SPFs and CMFs

The survey also asked respondents to share their opinion if it is worth the cost to calibrate HSM-provided SPFs or develop state-specific SPFs or CMFs. **Respondents overwhelmingly agree that it is worth the cost.** Additionally, the survey asked about their opinion of the CMF Clearinghouse. Respondents overwhelmingly agree that it is a worthwhile resource to find crash treatments and agree with less zeal that the CMFs found on it are accurate to the respondents' State roadway network.

Survey Conclusion

The conclusion of the survey asked respondents about whether they face certain issues when working with HSM predictive methods and tools, including:

- Missing AADT measurements on minor roads.
- Issues with seasonal changes to AADT affecting crash rates.
- Difficulties with roadway segmentation.
- Accessing data through your IT department.
- Not having the data or resources to implement specific tools.
- Difficulty using state-maintained intersection identifier (ID) numbers in specific tools.
- Issues maintaining HSM tools and methodologies due to staff turnover.

Figure 8 shows the number of respondents who face these issues. The most common issues faced include missing AADT measurements on minor roads, difficulties with roadway segmentation, not having the data or resources to implement specific tools, and issues maintaining HSM tools and methodologies due to staff turnover.

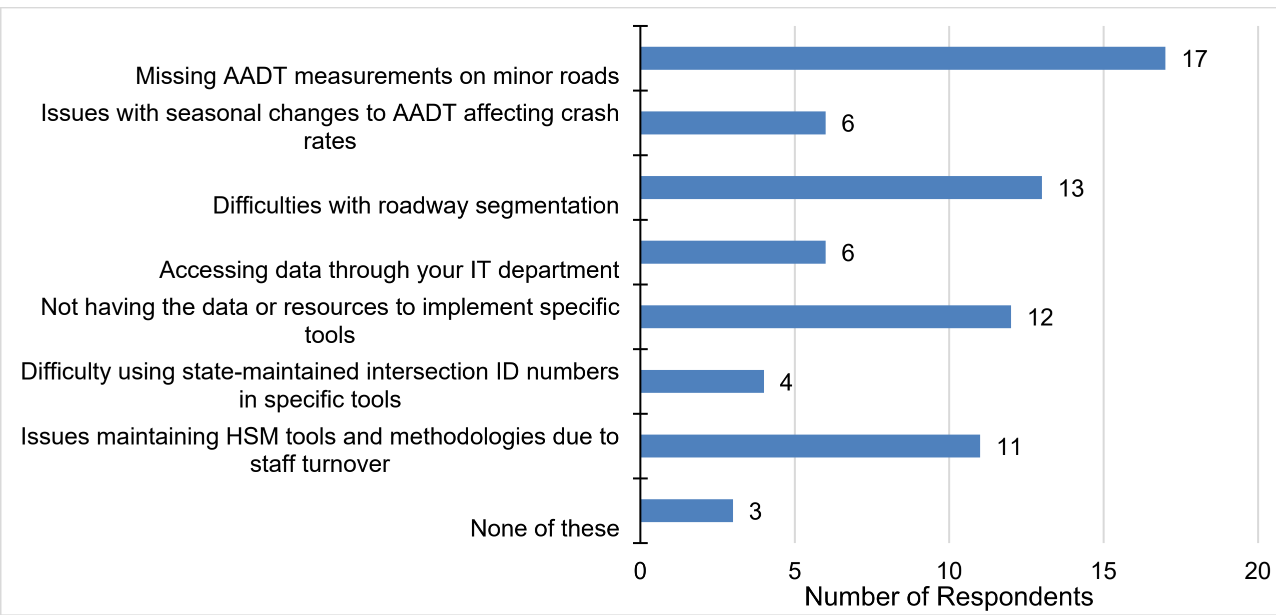


Figure 8. Number of Respondents Who Face Issues of Interest to NJDOT

Interview Results

The study team conducted six interviews following the survey to explore several topics of interest to NJDOT in greater detail. Interviewees were selected based their experience developing their own tools, addressing challenges related to data cleaning, processing, or importing, and/or identifying other solutions for data issues. Additionally, the interviews needed to cover a split of HSM Part B and HSM Part C experience and implementation.

Interviews were conducted with the following six agencies:

- Louisiana Department of Transportation and Development (DOTD).
- Missouri DOT.
- Vermont Agency of Transportation (AOT).
- Virginia DOT.
- Wisconsin DOT.
- Nebraska DOT.

The interviews covered several questions within three broad topics. Table 2 outlines those questions and topics, which were tailored to match the survey responses received from each agency.

Table 2 – Interview Topics and Questions

Topic	Questions
Experience with Developing Tools and HSM Processes	• What has your experience been with developing state-specific network screening and HSM Part C Tools? Did you use any programming languages and, if so, which ones? What has been the cost of developing this tool? What challenges did they face? • For developing state-specific SPFs or CMFs, what has your experience been? What data collection efforts went into developing these models? What challenges did they face? • For the different tools your agency has used, what has been the source of funding (state or federal) for these tools? What has been the cost in terms of staff hours? Do you feel that it has been worth the cost invested into each tool your agency uses?

Topic	Questions
Data Gaps	• Has your agency experienced data gaps in the past? How have you addressed such gaps? In particular, please let us know how you have faced data gaps about the following topics: – Missing AADT values on all streets and intersections and/or minor roads – Using existing infrastructure (such as cameras, radars, or other vendor software) to collect data – Issues with matching state-maintained roadway segment identifiers with the requirements of the tools
Technical Barriers	• Do you have experience using linear referencing systems (LRS) with the tools your agency has used? Is that done through contracting or in-house? How are you importing the LRS to conduct network screening and segment roadway networks? • If the interviewee answered that they had faced any of the issues listed below, discuss your experience with those issues in more details. – Difficulties with roadway segmentation – Accessing data through your IT department – Not having the data or resources to implement specific tools – Issues maintaining HSM tools and methodologies due to staff turnover • If your agency has used tools that require license agreements (such as SPF Tool or AASHTOWare by Numetric): – Have you had issues extending license agreements to MPOs and regional partners? – What has been your experience with the tool's technical support and the quality of guidance, support, and training provided by the vendor? – What has been your experience with your agency's IT department in regard to these tools?

Information learned within each of these topics is summarized below.

Experience with Developing Tools and HSM Processes

Network Screening Tools

Agencies have a varied experience developing their own state-specific network screening tools. Some agencies, such as Virginia DOT, have extensive experience developing such tools and propagating their methodologies for others to use. Other agencies, such as Vermont AOT, are following the ongoing evolution of HSM predictive methods and considered software such as AASHTOWare Safety Analyst prior to it being sunset.

In terms of data need and data access, state-specific network screening tools have intensive data needs to bring together the various data elements from other departments, and that requires a significant capacity in terms of staff hours and

technical skills. Additionally, the input data can be spread across multiple departments and/or vendors and it can be a challenge to get all those sources on the same page. For example, Virginia DOT's IT department hosts their roadway characteristic data, but the maintenance department is the business owner of the data, so its database is designed with maintenance as the primary operational consideration. This means that the safety group must work with both IT and the maintenance department to access and format the data required for HSM predictive methods and tools.

There are several initiatives that agencies can undertake that can complement the development of network screening tools:

- *Developing state-specific SPFs:* Both developing state-specific SPFs and a state-specific network screening tool require data cleaning of input sources, mathematical calculations, and calibration and analysis efforts. Some agencies, such as Missouri DOT, start their SPF network screening process on a specific type of roadway, such as rural two-lane highways, and then build other roadway and/or intersection types into their process.

- *Collecting the fundamental data elements of MIRE:*[43] This process can be designed toward creating or filling in gaps for inputs of network screening tools.

- *Compiling an intersection inventory:* This initiative can accompany an intersection-focused network screening tools, and some agencies, like Wisconsin DOT, use this inventory along with network screening SPFs and crash data to screen for intersections on the network.

- *Working with the processes of other departments:* Other departments are frequently responsible for data collection, and their processes can be leveraged during safety analyses. For instance, Nebraska DOT collects roadway characteristic data from their asset management department, who collect data after construction projects are completed.

Additionally, vendors can help DOTs with data collection. The most recent vendor available is Numetric, Inc., who have developed the AASHTOWare powered by Numetric, Inc. tool. Nebraska DOT has described Numetric, Inc., as having a philosophy to "meet agencies where their data is," reducing the burden of data collection and management.

Programming Language

In terms of a programming language, some network screening tools have been built on SQL queries combined with statistical software such as SASS, while other tools are created in Python and can leverage products like ArcGIS Online to provide mapping and visualizations. Other agencies, such as Wisconsin DOT, maintain spreadsheet-

[43] See 23 CFR §924.17 for a list of the Mire fundamental data elements: https://www.law.cornell.edu/cfr/text/23/924.17

based network screening tools in Microsoft Excel. Using a variety of programming languages can lead to issues with data maintenance. Wisconsin DOT has highlighted the creation of a data maintenance plan as a need to keep its spreadsheet and GIS based tools compatible and updated.

HSM Part C Tools

In terms of invested cost and common issue, HSM Part C tools have generally taken less effort to develop and are typically spreadsheet-based tools. One common issue that agencies have experienced with these tools is the accuracy of crash data, specifically the crash location. Several agencies have experience with crash locations being inaccurately mapped to intersection locations (for instance, when an intersection field is inaccurately checked upon data entry), and practitioners must manually correct for this. Another common issue is inaccurate measurements for roadway characteristics such as shoulders, medians, or turn lanes. Again, practitioners must manually correct for this, and these types of corrections are generally done at the project level.

Funding

The most common source of funding for these tools is Highway Safety Improvement Program (HSIP) funding, although some agencies cited that they use IT funding for hosting and preparing data inputs and State Planning and Research (SPR) funds for the research components of tool development. One common collaboration on developing these tools includes partnering with State universities to complete research projects or improve data collection. Missouri DOT, Vermont AOT, Wisconsin DOT, and Louisiana DOTD all cite experiences working with universities within their State to research components of their HSM predictive safety processes and tools.

Data Gaps

Data gaps remain one of the primary issues facing practitioners of HSM predictive safety methods, and **all interviewees have mentioned incomplete or potentially inaccurate data as a constant focus of their improvement efforts.** In general, practitioners recognize that for network screening, it is acceptable to work with incomplete or inconsistent data and then to ensure more detailed and accurate data at the project once priority locations have been identified. For instance:

- Louisiana DOTD notes that they have developed planning-level SPFs that contain only geometry and AADT.
- Missouri DOT says that it is likely that they have inaccurate data values in their databases at the network screening level, and that these inaccuracies can be corrected at the field level after initial screening, to further refine this analysis.

- New Jersey identifies missing AADT values on minor roads or on non-system roads as one of the main data gaps that it faces, and this is a common issue among interviewees.

In terms of data gap solution, agencies have taken a variety of steps:

- Louisiana DOTD stated that they are constant customers for AADT counts; they do counts in house, they purchase volumes from vendors such as INRIX, and they use their existing infrastructure and sensors when possible.

- Wisconsin DOT has cited work from their Department of Transportation Investment Management on interpolating and projecting missing AADT data.[44]

- Missouri DOT uses estimated values based off the closest or most recent count they have available to the missing AADT values on local systems.

- Virginia DOT notes that they maintain the State's full roadway network, aside from a few cities, towns, and counties. As a result, they have been able to invest in a robust traffic count program and can at least estimate traffic volumes when they are missing.

- Nebraska DOT has undertaken several initiatives to collect AADT volumes on minor roads, including being part of a pooled study to use mobile phone data. However, they have found that the more traditional methods, such as manual counts and hose counts, work best on minor roads.

As for using existing infrastructure to augment traffic counts, this appears to be an emerging area of development to improve data quality. Missouri DOT has seen a demonstration from a consultant that uses aerial imagery to get more refined data on urban area data gaps and gaps with driveway density. Wisconsin DOT contracts with a vendor who supplies equipment which is used to collect roadway characteristic data, such as lane widths, though they caution that they have run into formatting and compatibility issues with this data for safety analysis processes. Nebraska DOT has cited success in using machine learning to map crosswalk locations from van recordings for a specific cyclist and pedestrian safety analysis.

Consistent roadway segment identifiers are a data gap that New Jersey seeks to investigate. It appears that this data gap results from technical issues, which are discussed further in the next section.

Finally, an underlying theme in these data gaps is that they are largely dependent on systemic factors that are outside the control of safety units within DOTs. Safety units within DOTs face gaps largely because they do not have control over their complete roadway networks, including which roads they have ownership over, the

[44] See resources for continuous count data and traffic forecasting here: https://wisconsindot.gov/pages/projects/data-plan/traf-counts/default.aspx

competing resource needs of other departments, and which initiatives are invested in to collect data that is as accurate and comprehensive as possible. Safety units will likely continue to be in a reactive position to such circumstances regarding the completeness of their data.

Technical Barriers

Related to data gaps are technical issues that arise when conducting predictive safety analyses. These technical issues can result from using data generated from different systems, complications from the State's Linear Referencing System (LRS), or from staff turnover.

Linear Referencing System (LRS)

One issue of interest to New Jersey is how to deal with technical issues that arise from States' LRS, such as issues with how it interacts with roadway characteristics, mapping crash data to intersections, and how to deal with changes to the LRS due to things like construction projects. New Jersey cites that it has run into issues with its LRS changing year-to-year with new construction projects and with moving from a unidirectional to a bidirectional LRS.

These kinds of LRS challenges are a common complication at other agencies. Louisiana DOTD is undergoing an update to its LRS that is leading to a redevelopment of many of the tools and processes used by the safety unit. Wisconsin DOT has to join their LRS to the statewide network system inventory, which can be done with buffer zones and Python scripting yet can lead to cluttered results. Virginia DOT has also undergone a shift from a node based LRS to a directional edge line LRS,[45] and they continue to use both the old LRS in combination with the new LRS for intersections.

Changes to the LRS reflect how the technical aspects of the predictive safety methodology have developed over time and remain an evolving process. This evolution leads to inconsistencies, such as missing identifier (ID) numbers being used to identify unique roadway segments or intersections. The agencies interviewed have come up with various techniques to overcome these inconsistencies:

- Missouri DOT has identified traffic information segments to group together roadways such as Interstate segments between ramp terminals. Those can be rolled up to larger segments, and they have a particular process for breaking out curves.
- Louisiana DOTD uses a Python script to concatenate adjacent homogenous segments. This allows them to use their SPFs to calculate Level of Service of Safety (LOSS) on those segments.

[45] See https://arcg.is/1bnCHv for Virginia DOT's current LRS Release User Guide, updated May 2018.

- Nebraska DOT maintains an LRS that segments roadways based on both characteristics and at 10th-of-a-mile increments. They cite AASHTOWare Powered by Numetric, Inc., as being flexible in working with both types of roadway segmentation, though they prefer to conduct analyses based off of common roadway characteristics.

Staffing

Another critical aspect to the technical components of the HSM predictive safety methods is staff knowledge and possible disruptions from staff turnover. Virginia DOT notes the importance of staff knowledge of the technical specifics of the predictive analysis and the input data. They say that it can take months or years to understand the intricacies and specifics of the data and data systems, and they note the importance of maintaining detailed methodological documentation to keep up with the ever-evolving methodology and process for data preparation.

Virginia DOT has had relatively consistent staffing during the development of their predictive safety process. Louisiana DOTD also notes consistent staff in their core safety group, though has experienced significant turnover at the district level. Vermont AOT has also had a relatively stable safety team.

CONCLUSION

Main Takeaways

The first section, reporting on the results of the desk scan of HSM predictive safety tool best practices, summarized the complexity of the HSM predictive safety process and the intensive data needs required to conduct predictive safety analyses. It focused on how the different HSM predictive safety tools related to each component of the HSM process (primarily Parts B, C, and D), the purpose of national vs. State-specific tools and methods, the split between tools and methods developed in-house versus those that are outsourced, and the variability of data elements collected by States to use in HSM predictive analyses.

The second section, reporting on the survey and interview findings, validates New Jersey’s research need to investigate what other agencies are doing with their predictive safety programs. Many of the issues that New Jersey faces, such as missing traffic volumes, complications resulting from their LRS, and difficulties matching crash data to intersections are common issues among agencies implementing the HSM predictive safety methodology. The following are the main takeaways from the survey results and interview findings:

- **Data needs are more intensive for network screening (i.e., HSM Part B) processes compared with project-level predictive safety (i.e., HSM Part C) analyses.** Therefore, there may be more effort to collect and validate MIRE data compared with MMUCC data. This can be seen in both the survey results and the interview responses.

- **Missing traffic volumes, especially along minor roads and along roadways that are not within the jurisdiction of State DOTs, is a common data gap.** Agencies have a variety of methods to address this gap, including purchasing traffic volumes from vendors, investing in robust traffic count programs, using models to predict missing volumes, or develop methods to use similar roadways to predict missing volumes.

- **Using existing infrastructure, such as radar or cameras, is an emerging practice to augment traffic counts.** Some agencies have experimented with using such infrastructure but there is not yet a well-established methodology.

- **Adapting data to the LRS can be challenging but there are technical workarounds.** This generally involves concatenating like segments using scripting or analysis tools.

Finally, this research demonstrates the value that safety practitioners see from investing in HSM predictive methods and tools. In the survey, for instance, when asked whether efforts to develop state-specific SPFs or CMFs were worth the cost, all practitioners reported they were.

Several States, such as the Virginia DOT, mentioned in their interview that these types of efforts take dedicated effort over the long term to result in significant change. However, quantifiable evaluation of safety treatments and programs are key to prioritizing safety at all levels. They can shift pavement programs, capital funding, and safety projects to become more systemic, resulting in more stakeholders thinking about safety and supporting policy changes to improve safety outcomes. These efforts to invest in HSM predictive methods and tools have a significant impact on residents and help State DOTs accomplish their mission.

Follow-Up Actions

There are several follow-up conversations that New Jersey can pursue with the agencies interviewed. Those conversations include:

- **Virginia DOT** – Follow-up about their traffic count program, including the technologies they use, and which parts of their contracting process could be relevant to New Jersey. Additionally, they have implemented the eCrash program, which New Jersey is also implementing, and may have suggestions for that implementation.

- **Louisiana DOTD** – Follow-up about the changes to their LRS, how they are updating their system to include latitude/longitude and Light Detection and Ranging (LIDAR) methods, and what changes they are making to their HSM predictive methods and tools to adapt to those changes.

- **Missouri DOT** – Follow-up with a knowledge exchange. New Jersey can demonstrate its experience using Safety Voyager to do crash data queries and visualization. Missouri can then show its process for rural two-lane highways and how they combine segments into groups.

There also additional research projects that could be pursued:

- A research project could be developed to focus on the best methods and tools available to supplement missing traffic volume data. This research would likely need to involve other units at a DOT who may be tasked with collecting traffic data, such as maintenance or operation teams.

- Another research project could focus on the link between SPF development and the development of HSM predictive methods and tools. This research could highlight the common elements between both initiatives and suggest methods to integrate these two initiatives.

- Several agencies report technical difficulties resulting from the LRS, including changes to the LRS from things like construction activities. A research project could catalogue different approaches to overcoming these issues and share resources to address related challenges.

- New Jersey has indicated an interest in determining which elements of MIRE are most impactful to safety analyses. A study could be completed to prioritize which elements are most likely to impact the predictive accuracy of HSM methods and tools.

- In general, DOTs have an interest in collaborating further and exchanging knowledge on their HSM predictive methods and tools. Additional coordination could provide safety practitioners an opportunity discuss which processes are in development and what challenges they are facing.