Overcoming Highway Safety Manual Implementation Challenges

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The AASHTO Highway Safety Manual (HSM) offers the potential for incorporation of high-quality quantitative safety analyses into transportation project development and decision-making.

Applying the HSM methods requires collecting and maintaining detailed and comprehensive data systems and implementing complex analysis methodologies for quantifying safety performance. The use and implementation of the HSM can be challenging given the complex processes and limited practical guidance on a variety of components.

This paper discusses the obstacles that agencies are currently encountering while integrating HSM-based analyses into standard practice and the strategies being used to overcome them. The discussion includes case studies of approaches for dealing with missing data, unclear analysis methodologies, and analyzing conditions that don’t fit exactly within the HSM’s parameters. Reviewing the experience gained by a variety of users provides insight into potential issues and enables the development of guidance and best practices for use by other agencies to aid in bridging information and knowledge gaps during HSM implementation.

The ability to quantify safety effects of design facilitates better project decision making, improves the understanding of tradeoffs, and encourages the most efficient use of resources. The paper provides guidance on overcoming implementation challenges so jurisdictions can, at a minimum, implement pieces of the HSM methods as opposed to not at all. This will help to progress the use of quantitative safety analyses in the planning and design processes, guide the development of future editions of the HSM, and encourage continued use of quantitative-based safety in transportation decision-making.
INTRODUCTION

The AASHTO Highway Safety Manual (HSM) is a compendium of current knowledge and accepted best practices representing the culmination of many years of effort dedicated towards the compilation of a definitive and authoritative source of information related to roadway safety management. The HSM offers transportation professionals the ability to incorporate high-quality quantitative safety analyses into transportation project development and decision-making. This is done through a focus on substantive safety that characterizes the frequency and severity of crashes as a function of design elements, characteristics, and context. As such, safety in the HSM is not subjective, but rather objective, data-driven, and science-based. This objectivity provides transportation professionals with the opportunity to quantify the effect on safety as a result of changes in design, as measured by crashes, and crash characteristics.

In order to take full advantage of the knowledge base and research documented in the HSM, users must collect and maintain detailed historical crash and roadway geometric design data. These data must use a common or compatible linear referencing and coordinate systems so that the relationships between crashes and roadway design elements can be accurately established. In addition, these data are used as inputs to complex statistical models that allow for the estimation of crashes and predicted safety performance for various roadway types.

The HSM Part C presents a quantitative analysis method for predicting crash frequency. The facility types that can be analyzed include rural two-lane roads, rural multilane highways, and urban/suburban arterials. Additionally, subsequent to the publication of the HSM first edition, analytic methods and tools were released for estimating crash frequency and safety performance for freeways and interchanges.

This predictive method analysis process for estimating crash frequency consists of three basic elements: safety performance functions (SPFs), crash modification factors (CMFs), and calibration factors:

- **SPFs** are regression models developed from observed crash data and roadway inventory that predict the average crash frequency of a roadway based on a set of ‘base’ geometric and traffic conditions, with average annual daily traffic (AADT) and segment length, where applicable, as explanatory variables. Safety performance functions vary by roadway type, site type (segment vs. intersection), and location (rural vs. urban).

- **CMFs**, within the context of the predictive method, use the same data and are developed in conjunction with the SPFs. They are used to adjust the predicted average crash frequency estimated by the SPF for a site with given base conditions to specific site conditions.

- **Calibration factors** are applied to adjust for jurisdictional differences in the models that may exist between the analysis location and the models within the HSM; the HSM models for crash prediction were developed based on data from a select group of states and may not be directly applicable to other states without calibration.

Calibration factors can be applied to the SPFs to account for differences in state reporting thresholds, terrain, driver demographics, climate, and other unique crash attributes so that the models can better predict safety performance for these specific areas. In some cases, calibration factors cannot adequately adjust the HSM models, generally due to fundamental differences in roadway operations/conditions between the roads used to develop the models and the roads of the specific jurisdiction. When this occurs, the modeling of jurisdiction-specific SPFs for these roadway/site types is needed to adequately account for the regional or jurisdictional differences that could not otherwise be addressed through calibration. Where site types exist within an
agency’s roadway system that are in addition to those within the HSM, jurisdiction-specific SPFs may also be appropriate.

When available, historical crash data can be combined with the results of the model analysis by application of the Empirical Bayes (EB) method which combines the results of model output with historical crash data via an approach that considers the strength of the model. This approach further improves the crash frequency estimate but is only applicable for situations where the historical crashes can be directly related to the conditions to be analyzed and is not appropriate for locations where volume or geometric conditions are significantly different than the condition under which the crashes occurred.

Addressing Gaps: Overcoming Challenges in HSM Implementation

The predictive method for estimating crash frequency presented in the HSM can be extremely useful information for DOTs and other agencies for purposes of funding, project planning, and other applications. The ability to quantify safety effects of design facilitates better project decision making, improves the understanding of tradeoffs, and encourages the most efficient use of resources.

The current knowledge base in safety is broad with much research and guidance available for practitioners to draw from to quantitatively evaluate safety as part of transportation decision-making. However, there are knowledge gaps in areas where tools and best practices may not yet exist for conducting a substantive or quantitative safety analysis. These gaps include approaches for dealing with missing data, unclear analysis methodologies, and methods for analyzing conditions that do not align with the current set of HSM definitions.

These gaps are not discouraging some practitioners from applying the methods presented in HSM. Instead, they are encouraging the application of engineering judgment, professional knowledge, and experience in the area of substantive safety, and inspiring innovative thinking to help bridge the gaps. As agencies choose to face the challenges of overcoming limitations in knowledge and experience, they are gaining valuable experience that will help shape the direction of future research in quantitative safety and guide the development of future HSM editions and implementation resources.

This paper presents, in the form of case studies, the obstacles that agencies are facing while integrating HSM-based analyses into standard practice and strategies that are being used to overcome them. These experiences of implementing the HSM methods from a variety of users across the U.S. provides insight into common and potential issues. In addition, this documents guidance and best practices for use by other agencies to aid in bridging information and knowledge gaps for HSM implementation.

Literature Review

Many documents identify the need for more research, but there is limited, if any, information available to guide the practitioner through the practical application of the methods in the HSM; nor is there any guidance on what flexibility, if any, exists within the limits of these models in applying them to situations that aren’t a ‘perfect fit’ to the model definitions.

The HSM (1) acknowledges that the predictive method incorporates “the effects of many, but not all, geometric designs and traffic control features of potential interest” and presents four methods for estimating safety effectiveness of a proposed project based on availability of data and applicable models. However, it does not specifically discuss the application of the HSM models when: only partial or limited data is available; a site to be studied does not fit the
available site types; and a site fits the parameters of a SPF, but does not necessarily meet all of
the base conditions or design criteria for the specific site type covered by the SPF.

The reference materials developed in conjunction with the initial development of the
HSM refer to gaps in either data or models and provide recommendations for future
enhancements to crash prediction models and expanding the scope of the conditions and types of
facilities that are addressed. Documents and resources developed and published post-publication
of the HSM reflect very similar recommendations.

A detailed search and review of published research, literature, and online resources
related to roadway safety management was performed. This review included: documentation
developed in association with research and activities conducted before or during the development
of the HSM (2-9); more recent documentation developed as part of initial implementation
activities after publication of the first edition HSM (10-12); and of websites wherein the most
current knowledge regarding ongoing implementation activities is being posted (13, 14).

A small number of documents developed post-publication or on the current HSM website
discuss data limitations, but focus primarily on data prioritization and management. The most
notable of these was prepared for the Florida Department of Transportation (15) to present an
improved process for meeting the HSM and Safety Analyst data requirements. In recognition of
the limited ability of many agencies to obtain all of the data variables required to implement
HSM methods and derive calibration factors, the process identifies and prioritizes the influential
variables for data collection, and presents a revised minimum sample size needed to estimate
reliable calibration factors.

CASE STUDIES

The following case studies highlight examples of the methods that practitioners are using to
overcome challenges and gaps encountered during implementation of the Highway Safety
Manual. These include examples of implementation for corridor studies, SPF development, SPF
calibration, and freeway and interchange analysis.

Case Study 1: Wyoming US Highway 89

Project Description
The Wyoming Department of Transportation intended to provide improvements along a 9-mile
stretch of US Highway 89, between Etna and Alpine, Wyoming, in order to improve safety
performance and traffic operations. Initially, a no build alternative and a five-lane section were
considered. Based on public comments, however, an additional build alternative was proposed
that would include four lanes – one lane in each direction with a center turn lane and alternating
passing lanes. While the proposed alternatives both minimized right-of-way impacts and
maintained existing access to adjacent land uses, additional evaluation was necessary to
determine the difference in safety performance between the alternatives. These two build
alternatives are shown in Figure 1.

This project consisted of conducting safety analyses for the three designated alternatives.
The safety analysis utilized predictive models contained in the HSM. The technical tasks
included: obtaining crash data, traffic volumes, and roadway data; analysis of alternatives using
the HSM; and development of a technical memorandum documenting the analysis and findings
which included specific safety strategies for the two build alternatives. The analysis tasks were
consistent with the methods of the HSM and other industry best practices. The alternative
analysis looked at the safety performance of the two proposed build alternatives and the existing no-build condition using available crash data, traffic volumes, geometric, and plan data. The primary performance measures analyzed for the safety analysis were the future expected crash frequency (Part C, Chapters 10-12 of the HSM), and an evaluation of the potential safety benefits using a benefit-cost analysis (Part B, Chapter 7 of the HSM).

FIGURE 1 Wyoming US 89 alternate designs.

Challenges and Strategies

HSM Models and Site Types  During the scoping of this safety analysis task, the team recognized that analyzing US 89 using the HSM methods would require a creative approach to using the analysis tools available in the HSM. The ability to model some elements of design can be limited by the availability of models that are specific to the design details and/or site types. The project entailed the use of existing HSM data to model design alternatives for both traditional and non-traditional design elements with no exact matches within the HSM.

The primary issue with the US 89 project was the combination of geometric cross-sections of the alternatives and the area type of the project. Although the surrounding area was rural, there were components of the geometry (existing and proposed) that resembled both rural and urban cross-sections. For example, some sections had frequent access points and a two-way left-turn lane (typically urban/suburban characteristics) as well as shoulders with no curbs (typically a rural characteristic). The HSM does not provide a model for this rural/urban hybrid
facility type so it was unclear which facility type and corresponding model to use for the
alternative analysis.

The geometric base conditions were also a problem, primarily when trying to determine
the effects of the two-way left-turn lane. The rural multilane facility type does not include the
consideration of a two-way left-turn lane in the HSM analysis; therefore, analyzing the five-lane
section alternative as a rural multilane highway excluded a primary component of the design for
that alternative. (The exclusion of a particular geometric characteristic from any of the models
may mean that it was found to be statistically not significant or that there was not enough data to
adequately evaluate that feature. It cannot be concluded definitively that it has no effect on safety
performance.)

Strategies using HSM methodologies were developed to overcome the gap in available
model types for each build alternative by using a combination of analyses to evaluate the
alternatives. The five-lane alternative was modeled three different ways in order to assess the
safety performance:
1. A rural two-lane road with a center turn lane and passing lanes on both sides.
2. A rural multilane road with four lanes and an added CMF for a center turn lane.
3. An urban/suburban arterial analysis of a five-lane facility.

Considering the results of this analysis, along with the historical crash data and intended function
of the facility, the urban/suburban arterial analysis was selected as the most appropriate model.
By accounting for the higher speeds of the road and expected changes in land use (based on
number of access points), this option fit the proposed design of the facility and the expected
increase in commuter and recreational volumes.

The four-lane alternative was modeled two different ways in order to assess the safety
performance:
1. A rural two-lane road with a center turn lane and alternating passing lane.
2. A hybrid between a rural two-lane road with a center turn lane (three lanes) and a rural
   multilane road with an added CMF for a center turn lane.

The predicted crash performance of each analysis was averaged to develop the hybrid
analysis. For similar reasons as the five-lane alternative, the hybrid model was selected as the
most appropriate.

The results for all five of the analyzed configurations indicated that there would be a
reduction in crashes from the existing condition and that overall safety performance would
improve with implementation of the project. Using the selected analysis methods, the five-lane
alternative with the urban/suburban arterial analysis, had a slightly lower frequency of fatal and
injury crashes than the four-lane alternative. A cost-benefit analysis was also completed to better
quantify the impacts of each alternative. In recognition of the limitations with applying the HSM
methods to this particular corridor, WYDOT supported the hybrid analysis and are considering
the results as part of their desire to conduct a data-driven safety analysis.

Case Study 2: Pennsylvania Safety Performance Function Development for Rural Two-
Lane Facilities

Project Description
The Pennsylvania Department of Transportation desired to develop SPFs for rural two-lane road
segments and intersections in Pennsylvania. Agencies can either develop all of their own SPFs,
or replace some SPFs with jurisdiction-specific models and retain other SPFs from the HSM.
Jurisdiction-specific SPFs use an agency’s own data and can enhance the reliability of the Part C predictive method. This is particularly true where the potential exists for differing safety performance by roadway type or where there are parameters of the site type models that are unique or more predominant within the respective jurisdiction.

This project developed statistical models for total crash frequency and fatal/injury crash frequency using data from state-owned, two-lane rural roadways. This project used the same statistical methods as those in the HSM to ensure the models developed were compatible with the models presented in the HSM for rural two-lane roadways and maintained continuity in application to those presented for the other roadway types.

Development of the SPFs required data collection from the following sources:

- The PennDOT Roadway Management System (RMS): Information regarding roadway cross-section, traffic volume, access control, functional classification, posted speed limit, and intersection locations and traffic control.
- PennDOT online vehicle photo log system and Google™ Earth: Elements unavailable through the RMS files. Supplemental data elements were also collected to enable inclusion of additional roadway and roadside features not in the HSM model. This included roadside hazard rating, presence and radius/length of horizontal curves, presence of passing zones, and the presence of low-cost safety improvements (i.e. shoulder or centerline rumble strips, horizontal curve warning pavement markings, intersection warning pavement marking, and aggressive driving dot pavement markings). For the intersection data files, the additional elements included intersection skew angle, presence of exclusive lanes on intersections approaches (i.e. left- or right-turn lanes) and the presence of crosswalks on any intersection approach.
- Historical crash data: The most recent eight years of crash data. The data collected included information about the crash event, driver, and vehicle occupants for each reported crash.

While from different sources, the data needed to be on the same linear referencing system. Therefore, the crash data were merged with the roadway inventory data based on location (county, route, and segment) to obtain a singular dataset.

Methodologies that were compatible with HSM concepts were used to develop six statistical models for state-owned, two-lane rural roads and adjacent intersections. These models resulted in SPFs similar to those in the HSM but specific to PennDOT rural two-lane facilities and also added additional SPFs for intersection types specific to Pennsylvania that were not included in the HSM.

**Challenges and Strategies**

**Data Reliability** Data reliability became an issue for several elements of the roadway inventory data, specifically roadway width and speed limit. For roadway width, the values reported in the RMS system were determined to be unrealistically large. For speed limit, the values included operating speed or warning speed and not specifically the speed limit. Therefore, the data could not be consistently related to the regulatory speed of the respective roadway segment. Based on these factors, it was necessary to omit several of the roadway inventory data variables from the models because they were determined in these cases to be unreliable and the significance could not be determined. PennDOT proceeded with development of the SPFs, but with a smaller set of independent site characteristic variables.
Unreported Crashes and Severity Distribution  Comparing the jurisdiction SPF to the HSM SPF for rural two-lane roads highlighted one potential issue. The severity distribution was significantly different between the two models with property damage only (PDO) crashes accounting for more than half of the crashes in the HSM model, but less than half of the crashes in the PennDOT model. This suggests that PDO crashes are underreported in Pennsylvania. PennDOT developed separate models for total crash frequency and fatal and injury crash frequency as one method to offset the impact of unreported crashes. Regardless, this still identified the need for additional research on addressing underreporting of crashes and the impact on SPF development.

HSM Model Compatibility and Analysis Capabilities  Upon completion of the modeling exercise, PennDOT desired to incorporate the results of the modeling into a customized analysis tool that combined both the jurisdiction-specific SPFs for rural two-lane roadways and the other models for rural-multilane and urban/suburban arterials from the HSM. The SPF modeling efforts yielded a basic SPF form similar to the HSM model format and CMFs corresponding to the design elements determined to be statistically significant for Pennsylvania’s existing state-owned, two-lane facilities.

Although similar, this model was not inclusive of all the variables present in the SPF reflected in the HSM (e.g. lane width). The effect of this would mean that while the variables that could be measured using PennDOT data would be represented in the analysis of the facility type, the other variables present in the HSM could not be directly evaluated using the PennDOT-specific SPF. While this would not be expected to present issues in evaluating the majority of existing roadway facilities, it would make evaluation of proposed facilities that included the wider range of variables difficult.

To address this issue, PennDOT opted to utilize both the SPF and CMF information estimated for the Pennsylvania two-lane rural roadway system and CMF relationships developed in the HSM for the remainder of the variables. This permits both the prediction of crashes for two-lane rural roadways based on the models developed from Pennsylvania data as well as the evaluation of potential design options that considered the additional variables provided for in the HSM.

Case Study 3: Ohio Safety Performance Function Calibration

Project Description
The Ohio Department of Transportation (ODOT) desired to incorporate HSM data collection and calibration procedures into their project development and decision-making processes. Several years ago, ODOT began collecting additional crash and roadway inventory data elements – beyond what they had historically collected – in order to meet the detailed input requirements for HSM predictive analyses. Additionally, to fully utilize the predictive method, ODOT also chose to calibrate the HSM SPFs for all segment and intersection types (18 total) included in Chapters 10, 11, and 12 of the HSM as well as most of the facility types included in the freeway and interchange chapters.

Challenges and Strategies
Data Inputs  While ODOT had taken significant strides to improve their roadway inventory data systems, the collection of some inputs for the predictive method was more detailed and/or time intensive than ODOT was capable of collecting on a statewide scale. This included driveways, two-way left-turn lanes, signal phasing, shoulder and lane widths, parking, and roadway lighting. Although ODOT’s system of locating and recording crashes is very robust, this effort also revealed some limitations for crash data usefulness in HSM analyses. Crashes attributed to intersections (for all roadway types) and ramps generally were not located to a detail sufficient to assign to the respective site types.

For the additional data required for calibration, all of the data was collected manually using Google™ Maps, Bing™ Maps, and the ODOT Pathways Video Log. Specifically for driveways, the data was only collected after the analysis sites were chosen to minimize the level of effort of counting and classifying driveways. Similarly for crash data, the crash records were reviewed in order to place each crash with their respective site type for use in the calibration process.

HSM Models and Site Types  The facility types included in the HSM proved to be the most challenging issue encountered during calibration because they do not address all of the roadway types and conditions in Ohio. This gap proved to be the most limiting for freeway ramp terminal intersections. Although the HSM includes seven types of ramp terminal intersections, many of the ramp terminal intersections in the Ohio database did not fit into one of these defined configurations. In addition, these facility type definitions are the most rigid throughout the HSM and do not allow for variations. Therefore, the sites eligible for calibration were limited and many ramp terminals across Ohio will not have a corresponding calibration factor, instead using the default 1.0 until applicable models are developed.

In addition, the freeway facility types do not take into account ramp merging or diverging points with crossroads. The historical crash data showed that these areas within the interchange had a clustering of crashes, but the facility types did not allow for further analysis of these intersection points. Since no models exist to specifically analyze the ramp merge/diverge points with the arterials/connecting roadway facilities, these locations were not separately considered.

Calibration  Applicable sites were used for each facility type to obtain a calibration factor. Due to the classification of facility types, some segments and intersections on Ohio’s network did not have associated calibration factors and cannot be modeled using the HSM methodologies. Similarly, there were some facility types that did not have enough sample sites to be calibrated even though the configuration is included in the HSM.

Upon completing calibration, another problem arose as there was no method outlined in the HSM for determining if the calibration factors developed were appropriate or fitting to adjust the HSM models. Calibration factors effectively scale (or factor) the SPFs to better align the HSM models with the local jurisdiction; however, in some cases, this adjustment may be significant, perhaps indicating that the adjusted model does not correctly predict crashes in the local jurisdiction. Often this is due to significant differences in crash performance or overall crash distribution patterns, for which the HSM models make generalized assumptions. However, the HSM does encourage the replacement of default crash distributions with local data, where available.

Plots of the cumulative residuals of the calibrated models (CURE plots) were used to estimate the appropriateness and accuracy of the calibration factors. These plots provide a
confidence interval that can help to statistically identify the effectiveness of the calibration
factors. The CURE plots were then used to evaluate the calibration factors and determine if any
of the models were not sufficiently adjusted with the calibration factors. There were 6 facility
types of the 18 that were identified as less reliable adjustments and were recommended for SPF
development in lieu of calibration factors: rural multilane four-leg signalized and unsignalized
intersections, urban three-lane arterials, urban four-lane divided and undivided arterials, and five-
lane arterials. Figure 2 shows an example of one of the CURE plots for one of the sites
recommended for SPF development.

FIGURE 2  Example CURE plot for rural multilane 4-leg signalized intersections by major
road AADT.

Case Study 4: Missouri Interstate 270 North Environmental Assessment

Project Description
The Missouri Department of Transportation (MoDOT), in cooperation with the Federal Highway
Administration (FHWA), conducted an Environmental Assessment (EA) for the northern portion
of Interstate 270 between the I-70 system interchange and the Chain of Rocks Bridge over the
Mississippi River. The intent of the effort was to identify proposed improvements that address
the safety, mobility, congestion, accessibility, and aging infrastructure issues associated with the
corridor.

MoDOT chose to assess the safety impacts of the proposed alternatives using the
Enhanced Interchange Safety Analysis Tool (ISATe). ISATe was developed to implement the
predictive methodologies presented in the HSM for freeways and interchanges. The study area
corridor was divided into 11 subareas, each bounded by an interchange crossroad, and each
subarea divided into several analysis segments. Use of ISATe provided the ability to obtain an
assessment of baseline conditions, model future traffic volumes with the existing geometry, and
to model future traffic volumes with the reasonable and preferred alternatives geometries.

The first phase of the safety analysis for this 15-mile corridor focused on predictive
safety analyses of reasonable alternatives. Once the first phase was completed and the preferred
alternative selected, a predictive safety analysis was performed for the no build and preferred
alternative conditions to estimate the expected number of crashes associated with each roadway
configuration. Comparing these results was useful to assess the relative safety between the
various designs proposed for the freeway and interchange configurations, and did not require
calibration. Comparing relative safety in this manner provided input as to which geometric configurations can maximize the potential to reduce the severity of or prevent crashes.

Challenges and Strategies

Model Limitations  ISATe has known limitations, primarily related to specific site types or geometric conditions that are not able to be modeled with the available SPFs. For example:

- There are maximum numbers of lanes that can be modeled for freeway segments, collector-distributor roads, and ramp segments which are further defined by area type.
- The minimum inside shoulder width is two feet.
- Certain site types, such as single point urban and diverging diamond interchanges, do not have SPFs yet developed.

The data sets from which the models were developed could not include every potential condition and therefore those conditions cannot yet be analyzed. Some of these limitations, or gaps, were encountered in the application of ISATe to this study corridor. Table 1 summarizes these gaps and the strategies developed to address them.

### TABLE 1  Summary of I-270 ISATe Challenges and Strategies

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description of Challenge</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumptions</td>
<td>Limitations of ISATe/the HSM required assumptions to fairly compare the predictive safety output for the alternatives and no build conditions.</td>
<td>Extensive documentation of the assumptions – important for future readers to be aware of the ISATe limitations at the time of the study.</td>
</tr>
<tr>
<td>Slip Ramps</td>
<td>ISATe/the HSM does not provide option to model the slip ramps from I-270 to two-way frontage roads.</td>
<td>Modeled the mainline only and compare ramp connections and frontage road systems in a qualitative comparison.</td>
</tr>
<tr>
<td>Interchange Configuration</td>
<td>Single point urban interchanges (SPUI) and diverging diamond interchanges in build alternatives cannot currently be modeled with ISATe/the HSM. These could not be quantitatively compared for ramp and terminal operations.</td>
<td>Modeled mainline, ramp merge/diverge points, and the associated weaving sections only.</td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>Maximum number of lanes in ISATe is 10 lanes for an urban interstate (including applicable auxiliary lanes). Existing condition has an 11-lane section near an exit.</td>
<td>Represented section as a 10-lane section with a 1600 foot speed-change lane. Future conditions with 11- and 12-lane sections also used 10-lane cross-sections for analysis.</td>
</tr>
<tr>
<td>Calibration Factors</td>
<td>One set of calibration factors is input into ISATe for 4-lane sections, which is then applied to all of the roadway sections regardless of the number of lanes. I-270 is primarily a 6-lane cross-section.</td>
<td>The calibration factor for 6-lane freeways was input to be applied to all cross-sections (16).</td>
</tr>
</tbody>
</table>
MoDOT chose to apply a hybridized quantitative and qualitative approach to evaluating the proposed alternatives. Where the associated models fit the conditions or where reasonable assumptions could be made as to the geometric input, the ISATe tool was used to evaluate the existing and proposed alternatives. Where the models didn’t fit, a high level qualitative approach was used to evaluate the proposed conditions and differences between existing and proposed. The client considered this information during the determination of reasonable alternatives and preferred alternative selection.

**Stakeholder Acceptance** While the ISATe was an important element analysis performed to assess the impacts of the various alternatives and no build conditions, a lesson learned from this effort was the importance of educating project stakeholders about the capabilities and limitations of ISATe at the beginning of a project so they will not be surprised by the analysis gaps created by ISATe’s limitations. Although the stakeholders of this EA ultimately accepted the limitations and the strategies developed to work around them, the mixture of quantitative and qualitative results led to some mild skepticism about the accuracy of the safety impacts associated with the various interchange configurations. However, both stakeholders and the public accepted the hybrid analysis process that incorporated the data-driven analysis results with qualitative assessments.

The use of ISATe to assess the safety impacts of proposed improvements to the I-270 North corridor led to a few recommendations for its use with future safety assessments. The strategies employed to overcome gaps created between the geometric conditions and the tool input requirements were thoroughly documented with text and diagrams depicting the segmentation. Also, a set of metrics for both quantitative and qualitative analyses was developed to assess potential safety impacts of the alternatives.

**DISCUSSION**

**Data Needs**

The integration of substantive safety into project development is a data-driven process that requires a substantial amount of different types of data. However, agencies appear to be learning to apply these methods with lesser resources and fewer data points. Roadway design, traffic volume, crash, and traffic control (asset) inventory databases to support substantive safety are being tailored to support the level of analysis the agency desires to achieve.

Data requirements for calculating SPFs, CMFs, and calibration factors vary by facility type and are directly related to the base conditions for a facility. Additionally, the specific data needs for analysis will differ depending on the stage of project development. For example, assessments at the planning level will require less data than alternatives assessment at the detailed design stage. While the ease of access to data sources can affect the range of analysis approaches that can be used in the assessment and level of detail, the amount and level of detail in data collection can still be scaled to fit. It is therefore necessary to understand the base conditions and associated CMFs. The form and format of all data fall under the guidance provided in the Model Minimum Uniform Crash Criteria (MMUCC) and the Model Minimum Inventory of Roadway Elements (MMIRE). Agencies can use this information to develop a data management plan to fit their agencies’ available resources. Engineering judgment and default data values can be applied where data are not readily available and still provide meaningful insight into safety performance.
The data needs for using the advanced methods in the HSM depend on the data needs associated with the SPFs and CMFs. The data elements needed for this level of quantitative analysis are those that describe the base conditions of the particular SPF and the input necessary to calculate the applicable CMFs. Inevitably, the availability of more detailed data will support identification and evaluation of more reliable performance measures for a project alternative and increased potential for crash reduction.

**Predictive Model Limitations**

While the development of the SPFs contained in the HSM used a broad range of crash and geometric data that was related to geographic location, the availability and level of detail for both crash and geometric elements varies. This variance had an effect on the range of design and traffic control elements that could be effectively modeled at the time. As a result, the models do not always perfectly fit the conditions to be analyzed.

While it might be assumed that given the lack of exact applicability for the situation being analyzed that practitioners are shying away from using the methods, the opposite is the case. They are still using the HSM as a tool to evaluate safety performance in some capacity, opting for some level of quantitative safety analysis as opposed to none. One approach is through the use of assumptions or default values, developed by critically evaluating the context of the study site or project area to determine the most appropriate model for calculating safety performance. For example, as with WYDOT, even if a roadway is in what would be classified as a rural area, the cross-section of the road may be more similar to what is defined as an urban or suburban cross-section, or vice versa, and therefore may be appropriate to be analyzed as such.

When data elements used by the SPFs are not readily available, the HSM often provides reasonable assumptions for typical geometric, volume, or land use conditions that can yield viable results for the purpose of scenario/alternative comparison during the planning and programming phase. The methodology is scalable and analysis can be completed using default or assumed values when available data are limited. Quantitative analysis, even if estimated, provides valuable insight into potential design decisions and is still better suited to a data-driven process than traditional approaches using only qualitative safety information. As a supplement to quantitative analysis, the qualitative assessment of performance measures that cannot be addressed by the HSM models can potentially provide a means to bridge the gap while still allowing for a quantitative assessment of the known variables.

Any strategies employed to overcome gaps created between the geometric conditions and the tool input requirements should be thoroughly documented. Also, a set of metrics for both quantitative and qualitative analyses should be developed to assess the potential safety impacts of alternatives.

**CONCLUSIONS AND RECOMMENDATIONS**

Despite the limitations of the current edition of the HSM, there are still a number of ways to implement the concepts and methodologies into many stages of the project development process, even if this is done for only certain components. Future editions of the HSM and associated supporting research will likely address many of the gaps in knowledge regarding site types and conditions that are not addressed by the current edition. However, there are recommendations and guidance that could be provided to aid practitioners in addressing some of the gaps that are currently being encountered and/or may not be addressed through new models; specifically the
development and/or revision to models so that they are applicable to a wider range of variables, and the development of crash type and severity distributions sensitive to changes in CMFs.

At this point in time, there is no quantitative approach to assessing the effectiveness and impact of the assumptions made for these analyses. This is largely due to the recent nature of these projects, and the lack of “after data”. However, revisiting these projects once data is available to assess the actual performance of the sites would provide a means of determining whether the assumptions made were reasonable. This would validate the approach used in the analysis and perhaps provide a level of guidance for future efforts, where applicable.

The HSM is still a work in progress and does not have all of the answers, but that should not preclude practitioners from incorporating aspects of the manual into planning, design, and analysis efforts. While every site may not be able to be ideally analyzed, the HSM provides a data-driven approach to safety analysis that has been lacking until now. Using pieces of the HSM methodologies encourages more research and further development of quantitative analysis processes and improves the quality of current analyses. As these analyses improve, the ability to better address safety and maximize the impact of funding dollars in roadway planning and design will also improve and begin to fill in the gaps currently being experienced while implementing the HSM.

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REFERENCES


