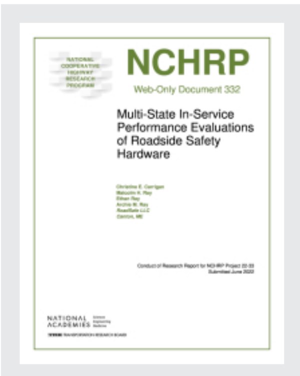



# Multi-State In-Service Performance Evaluations of Roadside Safety Hardware (2022)

## DETAILS

63 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-69495-7 | DOI 10.17226/26749

## CONTRIBUTORS

Christine E. Carrigan, Malcolm H. Ray, Ethan Ray, Archie M. Ray; National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine



## SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine. 2022. *Multi-State In-Service Performance Evaluations of Roadside Safety Hardware*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26749.

# NCHRP

Web-Only Document 332

# Multi-State In-Service Performance Evaluations of Roadside Safety Hardware

**Christine E. Carrigan**
**Malcolm H. Ray**
**Ethan Ray**
**Archie M. Ray**
***RoadSafe LLC***
***Canton, ME***

Conduct of Research Report for NCHRP Project 22-33
Submitted June 2022



**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state departments of transportation (DOTs) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration (FHWA), United States Department of Transportation, under Agreement No. 693JJ31950003.



NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

COOPERATIVE RESEARCH PROGRAMS

## CRP STAFF FOR NCHRP WEB-ONLY DOCUMENT 332

**Christopher J. Hedges,** *Director, Cooperative Research Programs*
**Waseem Dekelbab,** *Deputy Director, Cooperative Research Programs, and Manager, National Cooperative Highway Research Program*
**Sid Mohan,** *Associate Program Manager, Implementation and Technology Transfer, National Cooperative Highway Research Program*
**David Jared,** *Senior Program Officer*
**Traci Caldwell,** *Senior Program Assistant*
**Natalie Barnes,** *Director of Publications*
**Heather DiAngelis,** *Associate Director of Publications*
**Janet McNaughton,** *Senior Editor*
**Jennifer Correro,** *Assistant Editor*

## NCHRP PROJECT 22-33 PANEL
### Field of Design—Area of Vehicle Barrier Systems

**Erik O. Emerson,** Wisconsin Department of Transportation, Madison, WI (Chair)
**D. Lance Bullard, Jr.,** *Texas A&M Transportation Institute, College Station, TX*
**Keith A. Cota,** *Epsom, NH*
**Randy Hiatt,** *California Department of Transportation (Caltrans), Sacramento, CA*
**Chris Lindsey,** *Texas Department of Transportation, Austin, TX*
**Kurt Sielbach,** *Washington State Department of Transportation, Olympia, WA*
**Jason J. Siwula,** *Kentucky Transportation Cabinet, Frankfort, KY*
**Ana Maria Eigen,** *FHWA Liaison*
**Kelly K. Hardy,** *AASHTO Liaison*
**Stephen F. Maher,** *TRB Liaison*

# TABLE OF CONTENTS



*NCHRP Web-Only Document 332: Multi-State In-Service Performance Evaluations of Roadside Safety Hardware* is associated with *NCHRP Research Report 1010: In-Service Performance Evaluation: Guidelines for the Assembly and Analysis of Data*. Readers can read or purchase *NCHRP Research Report 1010* on the National Academies Press website (www.nap.edu).

# INTRODUCTION

The evolution of roadside hardware in the past has been largely dictated by changes to crash testing guidance rather than observed field performance. For example, there has been a national effort to update state roadside design guidance to provide 31-inch-tall guardrail rather than the previously used 27.75-inch tall guardrail based on the results of a failed Report 350 crash test and observations made through crash testing of splices. For some Highway Agencies, it is unclear how the funds spent updating their construction standards to include 31-inch-tall guardrail will impact their road users' risk. "While there may be no question that the updated hardware preforms better under the crash testing specifications, it is unclear how many fewer fatal or serious injuries might result from deploying the improved hardware" [C. E. Carrigan, research for the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highways, Task 360: "Development of a Strategic Plan for the Technical Committee on Roadside Safety (TCRS)," 2015].

The AASHTO Manual for Assessing Safety Hardware (MASH) establishes the criteria for the design and development of new roadside hardware (AASHTO 2016). Hardware developed using MASH demonstrates performance, through crash testing, within the bounds of the criteria used in the crash tests. The variability of vehicles, occupants, and impact conditions are controlled in crash tests but cannot be controlled in-service. Field conditions, common installation and repair obstacles, or maintenance issues are not evaluated by crash tests. The range of vehicle sizes, impact speeds, impact angles and other conditions are thought to be addressed by specified crash test conditions but testing for all possible combinations is not practical. Instead, the countless variations in impact conditions are better assessed through the in-service performance evaluation (ISPE) of roadside hardware. An ISPE may be used to confirm hardware is working as expected with the full range of vehicles, impact conditions, and site conditions experienced in an agency's jurisdiction. Furthermore, an ISPE may be used to identify areas where additional design and development efforts should be focused to provide improved performance in the field. An ISPE makes the leap from a handful of specific impact speeds, angles and vehicle types assessed during a limited number of crash tests to the wide array of actual vehicles and impact conditions observed in the field. Since it is the performance of roadside hardware in the field that is important, an ISPE is the definitive measure of roadside hardware effectiveness.

The AASHTO *Roadside Design Guide* (RDG) provides guidelines for the selection and placement of roadside hardware (AASHTO 2011). Transportation Agencies individually choose to adopt the AASTHO RDG or develop their own agency-specific design guidelines for the selection and placement of roadside hardware. An ISPE may suggest where changes are needed to the AASHTO RDG and/or Transportation Agency design manuals.

The objective of this research was to develop a unified format and nationally compatible ISPE methodology employing various individual state database parameters. The ISPE methodology developed under this research capitalizes on data that is often already available in a typical Transportation Agency and minimizes new data collection to situations where it is beneficial.

This report summarizes the research effort. Phase I consist of eleven research tasks, including an alpha test of the research products—*NCHRP Research Report 1010: In-Service Performance Evaluation: Guidelines for the Assembly and Analysis of Data* (Carrigan and Ray

2022) (hereafter referred to as the "ISPE Guidelines Document"), the ISPE Resource Hub, and the ISPE Data Set and Analysis Template. The research team and panel members participated in an alpha test of these products, which led to the verification and validation of the Phase I research products. These early research products evolved into beta versions. Training materials for the conduct of ISPEs using this methodology were developed and presented in a two-day workshop to ten Transportation Agencies. Following the workshop, these Transportation Agencies conducted a pilot test of the research products. The comments received during the pilot test have been incorporated into the research products. The results presented in this report is the culmination of all the research tasks rather than a rendition of each of the steps taken in pursuit of the research objectives.

The pilot test resulted in nine ISPEs being successfully executed and documented. An example of an ISPE report developed during the pilot test is available in Appendix A. Additionally, a standalone technical memorandum titled "Implementation of Research Findings and Products" and a PowerPoint file summarizing the research have been developed and submitted along with this Final Report.

## BEST PRACTICES AND INSTITUTIONAL BARRIERS

One reoccurring theme in each re-writing of crash test and evaluation procedures over the last 40 years is the recommendation to conduct ISPEs of roadside safety features. Michie (1981) recommended ISPEs in *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. The importance and need for ISPEs was reiterated by Ross et al. (1993) in *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* as well as by AASHTO in the MASH (AASHTO 2009, 2016).

The Federal Highway Administration (FHWA) likewise says, "ideally all highway agencies should know precisely what has been incorporated into its roadway/roadside infrastructure and be able to monitor the performance of individual components of its highway system. Asset management has become a primary means of accomplishing this goal in many states. However, there remains one area where in-service evaluation or performance monitoring seems to be minimal at best, and that is the area of roadside safety features" (Baxter 2005).

Capitalizing on best practices and removing barriers to conducting ISPE may prove helpful toward implementation of these research products and future ISPE programs. Four workshops were organized, prior to the initiation of this research project, to identify the institutional barriers to performing ISPEs and to share best practices. These workshops were conducted at the Transportation Research Board (TRB) AKD20 (formally AFB20) committee meetings. The obstacles and best practices identified at these workshops were summarized at the onset of this research. The best practices were capitalized upon when developing the research products while solutions were identified for the obstacles and incorporated into the research products.

The workshop participants acknowledged that some state agencies lack dedicated funds for ISPEs and/or lack dedicated personnel. Participants pointed out that there is confusion about what is included in an ISPE and little understanding of what constitutes a "real" ISPE. The potential for inconsistency between states was also concerning to workshop participants. The definition of and data needs for an ISPE are addressed in the ISPE Guidelines Document. Consistency between states is also addressed in the ISPE Guidelines Document.

There were concerns about the level of training and/or experience needed to be an evaluator of roadside safety features and if there should be some level of accreditation or certification. Training of personnel to conduct ISPEs is specifically addressed by this effort. Furthermore, the FHWA National Highway Institute has funded an ongoing effort to develop training for the conduct of an ISPE ("In-Service Performance Evaluation of Roadside Hardware").

Finally, participants voiced concerns about what to do with the results of an ISPE and how to best use those results in highway agency decision making and policy development. Participants suggested that a clear path for using the ISPE results would be very helpful when communicating the need for ISPEs. Clarity about what to do with the results and their importance could lead to more initial investments and funding approvals from management. The AASHTO TCRS recently advanced research needs statement to fund research addressing this obstacle.

Identifying the data which could be collected in the field to supplement the available data and the development of consistent field data collection methodologies were also considered an obstacle. The ongoing NCHRP Project 22-44, "A Transportation Agency Data Collection Practice for Use with In-Service Performance Evaluations (ISPEs)," is developing a transportation agency data collection methodology and associated data collection guidelines to support ISPEs, which will address this concern.

The lack of resources to conduct ISPEs, including dedicated personnel and funding, were noted as obstacles to conducting ISPEs. Transportation Pooled Fund Study TPF-5(481), "In-Service Performance Evaluation (ISPE) of Roadway Safety Features" has been established: "The primary objective of this pooled fund study is to evaluate the performance of roadside safety hardware in the field through inter-state collaboration by using standardized data collection and data analysis with a uniform interpretation of results. The second objective is to provide a forum for states to share ISPE data, experiences, practices, information, and resources." This pooled fund will give Transportation Agencies the opportunity to collaborate not only through sharing data but also through pooling available resources and minimizing the duplication of efforts.

Many of the obstacles to performing and using ISPEs were addressed by this effort and other recently initiated efforts which will lead to wider spread observation of the benefits of ISPE and consequently wider spread implementation of these research products (i.e., the ISPE Guidelines Document, the ISPE Data Set and Analysis Template, and the ISPE Resource Hub).

## ISPE GUIDELINES DOCUMENT

The primary objective of this research was to develop an ISPE guidelines document. An alpha version of that document was tested, verified, and validated by the research team and panel. A beta version was developed and distributed at a two-day training workshop to pilot state participants for use during the pilot test. The comments received during the pilot test were incorporated into the beta version, culminating in the ISPE Guidelines Document.

It is anticipated that the ISPE Guidelines Document will become to ISPEs what MASH is to crash testing: a step-by-step procedure for how to plan, perform and document the results of ISPEs. Just as crash testing procedures and evaluation criteria have evolved over the past decades, the ISPE Guidelines Document is the first step in what is hoped to be an evolution of ISPE evaluation criteria that will continue into the future.

Chapter 1 of the ISPE Guidelines Document outlines the purpose of the guidelines, the objectives of an ISPE, and the underlying philosophy of roadside safety feature design. Chapter 2 provides the ISPE methodology. Chapter 2 discusses the safety features addressed and presents the two-tiered approach for conducting ISPEs. Specifically, the first tier is designed to exploit data which is already available (i.e., Routine ISPE). The second tier is guided based on the findings of the Routine ISPE. This second tier is investigative in nature (i.e., Investigative ISPE) and generally involves supplementing already available data with new specially collected data from the field. Chapter 4 outlines a standardized ISPE data set which includes the data suggested for consideration when conducting an ISPE. The standardized data set is used for both Routine and Investigative ISPEs. Chapter 4 presents the Evaluation Measures used when conducting an ISPE, and Chapter 5 discusses the assessment and interpretation of the results of an ISPE. Chapter 6 summarizes a methodology for conducting multi-state ISPEs, and Chapter 7 presents standardized documentation practices for ISPEs.

Standardizing the ISPE data set, the evaluation measures considered, and the documentation of an ISPE establishes the foundation necessary for multi-state ISPEs. By extension, using the ISPE Guidelines Document provides the foundation for the conduct of multi-state ISPEs. The ISPE Guidelines Document is largely procedural in nature. The approach taken and the reasoning applied when developing the ISPE Evaluation Measures, therefore, is not discussed within the ISPE Guidelines Document because it is extraneous to the procedure. The reasoning has been documented here for posterity.

## EVALUATION MEASURES

Evaluation Measures assess these performance outcomes: (1) the structural adequacy of the safety feature under evaluation; (2) occupant risk through consideration of the crash severity; and (3) post-impact vehicle trajectory and vehicle orientation at impact through consideration of the crash sequence of events. Evaluation Measures A, B, and C consider structural adequacy. Evaluation Measures D, F, and H consider occupant risk. Evaluation Measures J, K, L, and M consider vehicle trajectories and orientation. The ongoing NCHRP Project 22-44 is developing Transportation Agency data collection guidelines to support ISPEs which will support ISPEs using these Evaluation Measures.

### Evaluation Measures for Structural Adequacy

There are three Evaluation Measures that consider Structural Adequacy: Evaluation A (Safety Feature Breach), Evaluation B (Breakaway), and Evaluation C (Controlled Penetration, Redirection, Stopping). Evaluation A is applicable to longitudinal barrier. Evaluation B is applicable to Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles. Evaluation C is applicable to terminals, crash cushions, truck- and trailer-mounted attenuators, variable message signs, and arrow board trailers

The evaluation measures for Structural Adequacy consider both single and multiple vehicle crashes where the impact with the safety feature occurred anywhere in the sequence of events. The influence of an impact with a vehicle prior to the second impact with the safety feature may influence redirective or breakaway mechanisms of the safety features. These measures evaluate the outcome (i.e., breach, breakaway, etc.), therefore, all crashes with the safety feature are considered. The interaction with the safety feature may have occurred anywhere in the sequence of events. Using both single and multiple vehicle crashes was favored to ensure any events which lead to the studied outcomes are captured in an ISPE. The influence of events prior to the impact with the safety features are captured, which complicates the interpretation of severity data. Occupant risk is evaluated separately.

**Evaluation Measures for Occupant Risk**

There are three Evaluation Measures which consider Occupant Risk: Evaluation D (Occupant Compartment Penetration), Evaluation F (Rollover), and Evaluation H (Vehicle Mix). These three Evaluation Measures are applicable to all safety features. These evaluation measures use the proportion of fatal and serious injuries as a direct measure of occupant risk, therefore, are limited to single vehicle crashes to remove the influence of interacting with other vehicles. Evaluation D considered the influence of penetrating the occupant compartment on occupant risk. Evaluation F considers the influence of rolling over after interacting with the safety feature on occupant risk. Evaluation H more broadly considers the influence of multiple events both proceeding and following the interaction with the safety feature on occupant risk. Evaluation H also considers crashes where the interaction with the safety feature is the first and only harmful event (FOHE) in the sequence. FOHE crashes are most closely associated with crash testing criteria.

**Evaluation Measures to Assess Vehicle Trajectory and Orientation**

There are two Evaluation Measures which consider post-impact secondary collisions: Evaluation J (Secondary Impact on Roadside) and Evaluation K (Secondary Impact on Road). These Evaluation Measures are applicable to all safety features and consider crashes where the interaction with the safety feature was the first harmful event in the crash sequence of events. Evaluation J is limited to single vehicle crashes and Evaluation K considers multi-unit crashes. Applying a single-unit limitation to Evaluation K would exclude vehicle to vehicle and vehicle to pedestrian crashes following the impact with the safety feature and those are exactly the types of secondary events this evaluation measure examines.

Evaluation Measures L and M consider the vehicle impact orientation. Evaluation L is applicable to terminals, crash cushions, truck- and trailer-mounted attenuators, variable message signs, arrow board trailers, support structures, work zone traffic control devices, and breakaway utility poles. Evaluation M is applicable to longitudinal barriers. Each are limited to single vehicle crashes where the interaction with the safety feature was the first harmful event in the crash sequence.

The need to update future crash testing guidelines is one possible outcome of an ISPE. Report 350 included criteria related to vehicle trajectory. These criteria were eliminated from MASH because they “were found to be non-discriminating and served little purpose.” (AASHTO 2009) While these outcomes are no longer assessed in a crash test, each can be assessed in an ISPE. These evaluation measures may find that safety features are achieving the desired performance goals and there is no need to assess post-impact trajectories during crash testing. Conversely, it may be found that there is a need to consider post-impact trajectories to limit the redirection back into a roadway. If there is a demonstrated increased risk when vehicles re-enter the traffic lanes it will be apparent in the ISPE results.

Impact orientation is not varied during a crash test. During a crash test, the impacting vehicle is tracking and either impacts the safety feature head on or at a specified angle, but always with the front of the vehicle. The exception was the optional side-impact testing in

Appendix G of Report 350, which was removed from MASH (Ross et al. 1993, AASHTO 2009). While crash data does not typically provide impact angles, the initial contact point (ICP) of the vehicle is recorded on many crash reports as recommended by the *Model Minimum Uniform Crash* Criteria (MMUCC) guidelines (NHTSA 2017). Using the ICP allows for the consideration of the untested vehicle orientation and allows for quantifying the influence of not testing various orientation on crash severity.

# ISPE DATA SET AND ANALYSIS TEMPLATE

The ISPE Data Set and Analysis Template is a Microsoft Excel–based workbook containing a worksheet for the ISPE data set and separate worksheets which automatically calculate each Evaluation Measure outlined in the ISPE Guidelines Document. The ISPE Data Set and Analysis Template implements the computations outlined in the ISPE Guidelines Document and automatically summarizes the results using the standardized documentation format recommended within the ISPE Guidelines Document. The workbook has been selectively protected so that users can input information and edit user input fields but cannot change the equations or logic in the automatically calculating tables.

When using the ISPE Data Set and Analysis Template a user will first compile their raw data such that the fields agree with the data dictionary outlined in the ISPE Guidelines Document. Once the raw data has been compiled, the user can simply copy and paste all of the appropriate rows for the safety feature under evaluation into the "ISPEdata" worksheet of the ISPE Data Set and Analysis Template. If the pasted data has formulas in the copied cells, make sure to paste values into the ISPE Data Set and Analysis Template.

The ISPE Guidelines Document address both permanent and temporary highway safety features. The safety feature under evaluation (SFUE) is entered in the first column of the standard ISPE data set (i.e., column A). The value entered in Column A are used to apply the appropriate Evaluations Measures. The SFUEs considered include these broad groups:

1. Longitudinal Barriers
2. Terminals and Crash Cushions
3. Truck- and Trailer-Mounted Attenuators and Variable Message Signs and Arrow Board Trailers
4. Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles
5. Other features

By extension, the ISPE Data Set and Analysis Template accepts data for these groups. The pasted data should be limited to a single SFUE group. Separate workbooks should be used for different SFUE groups.

After pasting the data to be analyzed, the user should input the following values on the "Eval A" worksheet of the ISPE Data Set and Analysis Template: the ISPE project ID, test level of SFUE and the confidence interval z value. The project ID field can be populated with any combination of letters numbers and symbols, the test level field is chosen from a drop-down list, and the confidence interval z value field is numeric. Each of these fields are discussed in the ISPE Guidelines Document.

# ISPE RESOURCE HUB

Sharing ISPE results and collaborating between Transportation Agencies is made easier by using the standardized procedures described in the ISPE Guidelines Document. ISPEs conducted using these procedures can be combined in a meta-analysis approach such that more reliable information is available to not only the participants of the component ISPEs but to the roadside safety design community in general. This type of sharing and collaboration is facilitated using the ISPE Resource Hub. The Hub was developed for NCHRP Project 22-33 and is not currently available to the public; however, the host site is to be determined after the conclusion of the research.

The ISPE Resource Hub is structured such that the completed ISPE can be submitted by Transportation Agencies. The results are then available for review by other Transportation Agencies who may want to replicate the ISPE in their own jurisdiction to compare the performance in their jurisdiction to that in other locations or to combine the results though meta-analysis to provide more robust conclusions. The ISPE Resource Hub has several functions:

1. Provide a single location where all completed ISPEs can be uploaded, stored, and reviewed.
2. Provide a location where Transportation Agencies can determine what ISPEs have already been conducted and what the results of those ISPEs were.
3. Provide a platform which supports combining ISPE results through meta-analyses such that more robust estimates of safety performance can be calculated.

The participants of the multiple “Best Practices and Obstacles” workshops discussed above have acknowledged numerous times that one obstacle to ISPEs is the lack of a clearing house or single location to find information on previously conducted ISPEs. ISPE results would often be published within an internal department of transportation (DOT) report that did not receive wide circulation. Sometimes results were published as journal articles or conference papers but finding these results requires a diligent literature search of many different conference proceedings and journals. The ISPE Resource Hub solves this problem by creating a single location where ISPE results can be stored, searched, and reviewed. Information about how to conduct an ISPE and other tools and resources can also be shared on the ISPE Resource Hub.

Transportation Agencies can take advantage of the ISPE Resource Hub in several ways. First, they can easily determine what ISPEs have already been performed by other agencies and what the results of those ISPE were. This will help agencies in other jurisdictions make inferences from other ISPEs about how the same safety feature might perform in their jurisdiction. Second, knowing what ISPEs have already been done will let other agencies plan new ISPEs that either fill gaps in the knowledge by performing ISPEs of unevaluated safety features or increase the confidence of the results from existing ISPE by performing complimentary ISPEs of safety features and combining the results through a meta-analysis. As new ISPEs are added that address the same safety feature, the reliability of the performance estimates will improve in turn providing more confidence in the results. Knowing what other agencies have studied provides opportunities for agencies to collaborate and thereby maximize available resources to determine the performance of safety features.

The ISPE Resource Hub has been developed using the widely used Microsoft Office 365 platform. The Microsoft Office 365 suite is comprised of many cloud-based software products including SharePoint, Forms, and Flow to mention just a few. SharePoint is the primary product used by the ISPE Resource Hub, but Forms and Flow are used in conjunction with SharePoint to achieve the functions desired for the site. Transportation Agencies need not have a license for Microsoft Office 365 to use the ISPE Resource Hub.

SharePoint is a tool for creating and maintaining web sites. SharePoint features a secure platform for storing and sharing data and is accessible using many internet browsers (e.g., Internet Explorer, Firefox, Chrome, etc.). Each SharePoint site is secured by unique permissions which can be modified to fit the needs of each site. As the functionality, utility, and popularity of the ISPE Resource Hub grows, it may naturally evolve into a type of clearinghouse for ISPE results and data collection tools (e.g., forms, templates, tablet apps for collecting field data).

# PILOT TEST

The pilot test implementing the research products developed under this project was initially a one-year study. The pilot test commenced following a two-day in-person training workshop, which took place on February 25th and 26th, 2020, in Portland, Maine. Almost immediately, in March 2020, the Covid-19 pandemic necessitated many changes to what would have been considered normal workplace protocols. Workplaces were shut down and employees began working from home in March 2020. The one-year pilot test was extended by six months to conclude in August 2021. Nevertheless, the pilot states made tremendous strides in testing the research products.

The two-day in-person workshop provided training for conducting an ISPE and demonstrated the ISPE Guidelines Document, ISPE Data Set and Analysis Template, and ISPE Resource Hub. The workshop initiated the pilot test. The objectives of the pilot test were many, including ensuring research product readiness. The workshop included participation from nine states and representation from all four AASHTO regions. Following the conduct of the training workshop, a request from the Arizona Department of Transportation (ADOT) was made to join the pilot test. Subsequently, a two-day online training workshop was conducted for ADOT and ADOT elected to join the pilot test. The pilot study participants included representatives from the following state transportation agencies:

1. Arizona,
2. Connecticut,
3. Maine,
4. New Hampshire,
5. Georgia,
6. South Carolina,
7. Tennessee,
8. Iowa,
9. Utah, and
10. Washington.

After the training workshop, the pilot states were encouraged to begin using the beta research products to conduct their own ISPEs. During the beta test, the research team provided support to the pilot States through help with assembling their data, electronic mail communications, and phone support as appropriate. In some instances, the research team also helped assemble the ISPE Reports documenting a pilot states' ISPEs. It was initially envisioned that support would include travel to the pilot states, however, that was not permitted due to the travel restrictions in place as a result of the Covid-19 pandemic.

Common issues and challenges to conducting ISPEs were identified and addressed through updating of the research products. One suggestion was to increase the number of data fields suggested for conducting an ISPE. The pilot states recommended extending the suggested data fields. The pilot states were confident the suggested additions could be accommodated by a variety of states. There were also common challenges observed when the Pilot States were interpreting the ISPE Guidelines Document. As a result, changes were made to clarify the ISPE Guidelines Document. The challenges presented by the Covid-19 related restrictions were widespread and did not spare this pilot test. Multiple Pilot States found the challenges related to COVID impeded their full participation in the pilot test. One Pilot State was in the process of a database migration and infrastructure rebuild for most of the pilot test; this State plans to complete their pilot test after the submittal of this report.

Five Pilot States completed at least one ISPE Report following the documentation procedures provided in the ISPE Guidelines Document. Two Pilot States completed multiple ISPE Reports during the Pilot Test. Two States continue to work on the development of there ISPE Reports and one State was not able to complete an ISPE Report. An example of the report completed by the Utah DOT is included here as Appendix B.

It has been observed in the past that Transportation Agencies often lack dedicated personnel to conduct ISPEs, however, Maine and Washington dedicated staff to completing this Pilot Test and Connecticut hired an Intern to assemble the available data. Iowa explained that they leveraged their maintenance staff to document crash damage in their system, but do not have a dedicated person for reviewing how the features performed. New Hampshire plans to hire an intern in the future to review the reports and dedicate engineering personnel to evaluating the assembled data. Utah attributed their success to excellent teamwork and collaboration between two staff members with different expertise (i.e., crash data and asset management data) which facilitated programmatically assembling the ISPE data set using their available databases.

When the Pilot States were asked if the ISPEs they conducted provided information that will be useful in making decisions about roadside hardware, there were many yeses. Utah explained the results were very interesting and spurred some good internal discussion. Maine used the results of their ISPE to provide confirmation and support for their current policy and standards. Washington assessed the performance differences for two similar systems and described their findings as helpful. New Hampshire and Connecticut both studied systems with very low inventories and are looking for ways to further extend their findings. Nevertheless, Connecticut observed that the data reviewed offered a general sense of how the system was preforming and New Hampshire is looking to extend their study using the multi-state approach provided within the ISPE Guidelines Document.

At the onset of the Pilot Test, many participants were unsure of the data available within their states for conducting ISPEs, however, a tremendous amount of available data sources were identified and new data collection undertaken. New Hampshire planned to use their available insurance recovery data, however, found processing that data to be tedious. New Hampshire used google earth to confirm the hardware involved but found that to be similarly tedious. New Hampshire is currently starting an inventory of hardware that will be updated by their construction section as changes are made. Connecticut is currently creating a statewide GIS inventory of roadside hardware and developing a web portal crash repository. Maine manually reviewed their crash reports and tied each report to their available maintenance asset database to identify the hardware involved. Utah, Washington, and Iowa linked their crash databases with their asset inventories. Utah developed an innovative means for linking their crash data set and asset inventory. While crashes are generally represented by a point, Utah assigned a length to each point within their GIS software to facilitate linking with the appropriate hardware. South Carolina and Arizona successfully benchmarked the field performance of most of their roadside hardware through using crash data alone.

Each of the Pilot States agreed that they plan to do more ISPE. New Hampshire had to receive special approval to view the crash reports, noting that future ISPEs will be easier because there is now a process in place to review crash report. Maine plans to continually add data to their ISPE data set to provide further support for decision making. Connecticut plans to explore additional crash database characteristics to determine what additional data can be harvested. Iowa is excited to conduct future ISPEs using their new dashboards and reporting tools. Washington is currently undertaking two additional ISPEs.

### SUMMARY

This successful pilot test has demonstrated that ISPEs can be conducted using available staff and resources and, more importantly, yield useful information about the field performance of roadside safety features. Based on the success experienced by the Pilot States, it is recommended that ISPEs can and should be integrated explicitly into the hardware design and roadside design life cycles (i.e., design, test, and evaluate). The results of such ISPEs will allow Transportation Agencies to develop design and maintenance policies based on observable performance rather than one-off crash tests. Furthermore, crash testing guidelines can evolve based on observed field performance rather than changing vehicle fleets.

## CONCLUSIONS

Crash test evaluations of roadside safety features have long been recognized as an initial assessment of hardware performance. Generally, roadside safety features perform as designed and evaluated when impacted within the performance limits established by crash test guidelines. An ISPE demonstrates how roadside safety features perform within a broader range of real-world conditions such as environmental and operational situations. Similarly, an ISPE captures the full range of vehicle types, impact angles and vehicle orientations. It is recognized that these conditions can vary widely from the conditions under which roadside safety features are crash tested. The ISPE Guidelines Document developed under this research clarifies “the objective of an in-service performance evaluation is to assess the crashworthiness of safety features under field conditions. A secondary objective is to determine which factors are influencing performance (e.g., maintenance, installation, hardware design, etc.). Consistent with the crash test evaluation criteria in MASH, safety feature performance is assessed through consideration of (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory and orientation with the greatest consideration being given to occupant risk.”

An ISPE has several major phases: planning, data collection, data assembly, data analysis, and making recommendations and decisions based on the observed performance. The planning, data assembly, data analysis, and recommendations were addressed under this research project. NCHRP Project 22-44 is currently underway and will address the second (i.e., data collection) for situations where it would be beneficial to collect additional data.

The data available within already collected crash databases are paramount for the successful conduct of an ISPE. An asset inventory is not necessary to conduct an ISPE. Transportation agencies, however, may find it beneficial to maintain an inventory of roadside hardware to monitor the field performance of roadside hardware and to address more complex questions. Creating an inventory of roadside hardware provides data that supplements the already available crash data.

Transportation agencies can effectively improve their understanding of the field performance of roadside safety features through the conduct of individual ISPEs, the institutionalization of ISPE programs, or as part of their agency asset management program:

- Routine ISPEs can be initiated using available data, already collected by the agency. Based on the outcome of the review of the available data, Transportation Agencies may choose to conduct an Investigative ISPE which may involve reviewing field crashes as they occur to further refine the data available for review field performance.
- ISPE programs may involve continuous monitoring and documenting of in-service crashes accompanied by the scheduled analysis and documentation of ISPE reports.
- Asset management is “a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis ….” (Title 23, United State Code, https://www.fhwa.dot.gov/map21/docs/title23usc.pdf.) Expanding the data collected under an asset management program could be used to support Routine ISPEs and ISPE programs. These data may range from asset identification to the history of the asset at each particular location.

As more ISPEs are conducted and the field performance of roadside safety features is better understood, research should be initiated to compile the results to determine what, if any, changes should be made to the crash testing criteria. For example, if it is found that post-impact trajectories are concerning, crash testing criteria could be expanded to apply limits to post-impact trajectories during the design and development of roadside safety features. Similarly, if it is found that post-impact rollovers on the field side of the roadside safety features are concerning, roadside design criteria could be developed to further refine recommended installation and grading guidelines.

# REFERENCES

AASHTO. 2009. *Manual for Assessing Safety Hardware*. Washington, DC. https://trid.trb.org/view/914505.

AASHTO. 2011. *Roadside Design Guide*, 4th ed. Washington, DC.

AASHTO. 2016. *Manual for Assessing Safety Hardware*, 2nd ed. Washington, DC. https://trid.trb.org/view/914505.

Baxter, J. R. 2005. Memorandum: In-Service Performance Evaluation and Continuous Monitoring of Roadside Safety Features. Washington, DC, Federal Highway Administration.

Carrigan, C. E., and M. H. Ray. 2022. *NCHRP Research Report 1010: In-Service Performance Evaluation: Guidelines for the Assembly and Analysis of Data*. Transportation Research Board, Washington, DC.

Michie, J. D. 1981. *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. TRB, National Research Council, Washington, DC. https://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_230.pdf.

NHTSA. 2017. *MMUCC Guideline: Model Minimum Uniform Crash Criteria*, 5th ed. Washington, DC. https://www.nhtsa.gov/mmucc-1.

Ross, H. E., Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie. 1993. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* TRB, National Research Council, Washington, DC.

# APPENDIX: UTAH DEPARTMENT OF TRANSPORTATION ISPE EVALUATION OF LONGITUDINAL BARRIER

## TABLE OF CONTENTS



## LIST OF FIGURES

## LIST OF TABLES

# CHAPTER 1: INTRODUCTION

A routine In-Service Performance Evaluation (ISPE) was undertaken using the uniform criteria presented in the ISPE Guidelines Document [*NCHRP Research Report 1010: In-Service Performance Evaluation: Guidelines for the Assembly and Analysis of Data* (Carrigan and Ray 2022)]. The present report documents a routine ISPE of longitudinal barrier in the State of Utah. The Utah Transportation and Public Safety – Crash Data Initiative (UTAPS-CDI) crash database for 2016 through 2020 was used in conjunction with the Utah Department of Transportation (UDOT) collected longitudinal barrier inventory. Both the crash data and barrier data were limited to UDOT state routes.

The primary objective of this ISPE was to evaluate occupant risk, structural adequacy, and post impact vehicle trajectory of longitudinal barrier in the State of Utah under real-world field conditions. Since longitudinal barriers are being evaluated, Evaluation Measures F, H, J, K, and M were considered as shown below.

| | |
|---|---|
| Crash Data Collection Area: | UDOT State Routes |
| Inventory Collection Area: | UDOT State Routes |
| Data Collection Period: | 1/1/2016 to 12/31/2020 |
| Safety Features Under Evaluation: | Longitudinal Barrier (i.e., SFUE=1) |
| Evaluation Measures: | F (Rollover) |
| | H (Vehicle Mix) |
| | J (Secondary Impact on Roadside) |
| | K (Secondary Impact on Roadway) |
| | M (Impact Orientation) |

This report documents the collection, assembly, and analysis of in-service performance data for this ISPE.

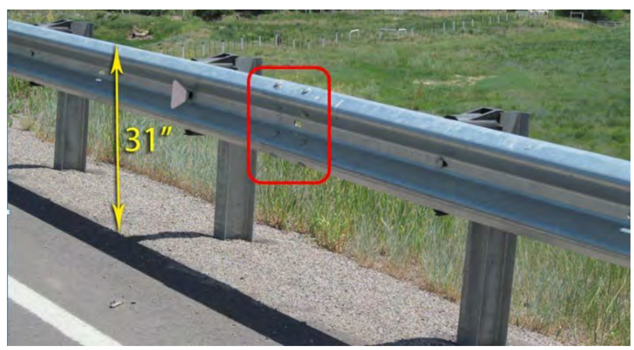
# CHAPTER 2: SYSTEM DETAILS

A wide variety of longitudinal barrier types are used in the State of Utah. UDOT maintains an inventory of barrier assets on state routes using a biennial LiDAR collection by Mandli Communications, Inc. This report focuses on the in-service performance of longitudinal barrier used within Utah by analyzing the crash database for all vehicles coded with ‘40’, ‘41’, or ‘42’ (hit guardrail, concrete barrier, or cable barrier, respectively) in the four sequence of events fields and the most harmful event field. A run of barrier is considered to be an extent of a length of barrier that is all the same type (ie, all cable barrier).

The type of longitudinal barrier involved was identified for 13,019 events (number of vehicles that hit barrier). The methodology for narrowing down the crash data set and linking each vehicle to the corresponding barrier is discussed further in Chapter 4.

**Table 1. Longitudinal Barrier Types used in Utah.**

| | |
|---|---|
| **New Jersey Shape with Wire Loop/ Jersey Barrier 230 / Precast Jersey 230 / Jersey Barrier 12.5**<br><br>This system was retired in roughly 1993, and uses the standard Jersey shape connected with wire loops and pins, and without stabilization pin slots for anchoring the barrier to the ground. |  |
| **New Jersey Shape NCHRP-350 Barrier / Jersey Barrier 350 / Precast Jersey 350 / Jersey Barrier 20**<br><br>This system uses the standard New Jersey shape connected with solid loops and pins and includes stabilization pin slots for anchoring the barrier to the ground. |  |
| **Cast-in-place Constant Slope TL-3 and TL-5 / Constant Slope Concrete Barrier / 42" Single Slope Parapet / CIP Constant Slope**<br><br>These barriers have smooth (single) slope from bottom to top and are cast together with expansion joints in the concrete. Heights range from 42" and up. |  |

| | |
|---|---|
| **W-Beam with steel blocks (NCHRP 230 W-Beam)**<br><br>W-beam barrier with steel blocks. This is also originally installed at mounting heights of up to 26”, and rail splice joints are located at posts. |  |
| **G-4 W-Beam Guardrail System and Rigid Barrier Transition**<br><br>NCHRP-350 tested system; rail splices located at posts, posts may be steel or wood, splice blocks could be wood or composite, mounting height 29” +/- 1”. Uses a 25’ W-beam standard transition from rigid barrier to W-beam; system constructed with steel or wood posts, 12.5’ nested rail elements, 11 steel or wood posts. |  |
| **MGS (Midwest Guardrail System) W-Beam Guardrail and Transition**<br><br>MASH tested W-Beam guardrail system; rail splices are located between posts, posts may be steel or wood, splice blocks could be wood or composite, mounting height 31” +/- 1”. Uses a 18’ thrie-beam transition from rigid barrier to W-beam; thriebeam nested rail, asymmetrical rail element, 6-7’ long steel posts, 3-6’ long steel posts. |  |
| **Motorcycle W-Beam Guardrail**<br><br>Motorcycle W-beam guardrail consists of G-4 or Midwest Guardrail System with a bottom rail element attached with no blocks. Bottom rail consists of either the DR-46 motorcycle barrier attenuator or the standard W-beam rail element that is galvanized or yellow powder coated. |  |

# CHAPTER 3: STUDY PERIOD AND REGION

This study was a routine ISPE of longitudinal barrier. Crash data collected for this ISPE included all reported crashes occurring on the roughly 6,000 centerline miles of state-maintained roads within the State of Utah. The crash data collection period began on January 1, 2016 and ended on December 31, 2020 encompassing five full years of data collection. The longitudinal barrier asset inventory includes only barriers installed on UDOT maintained roadways.

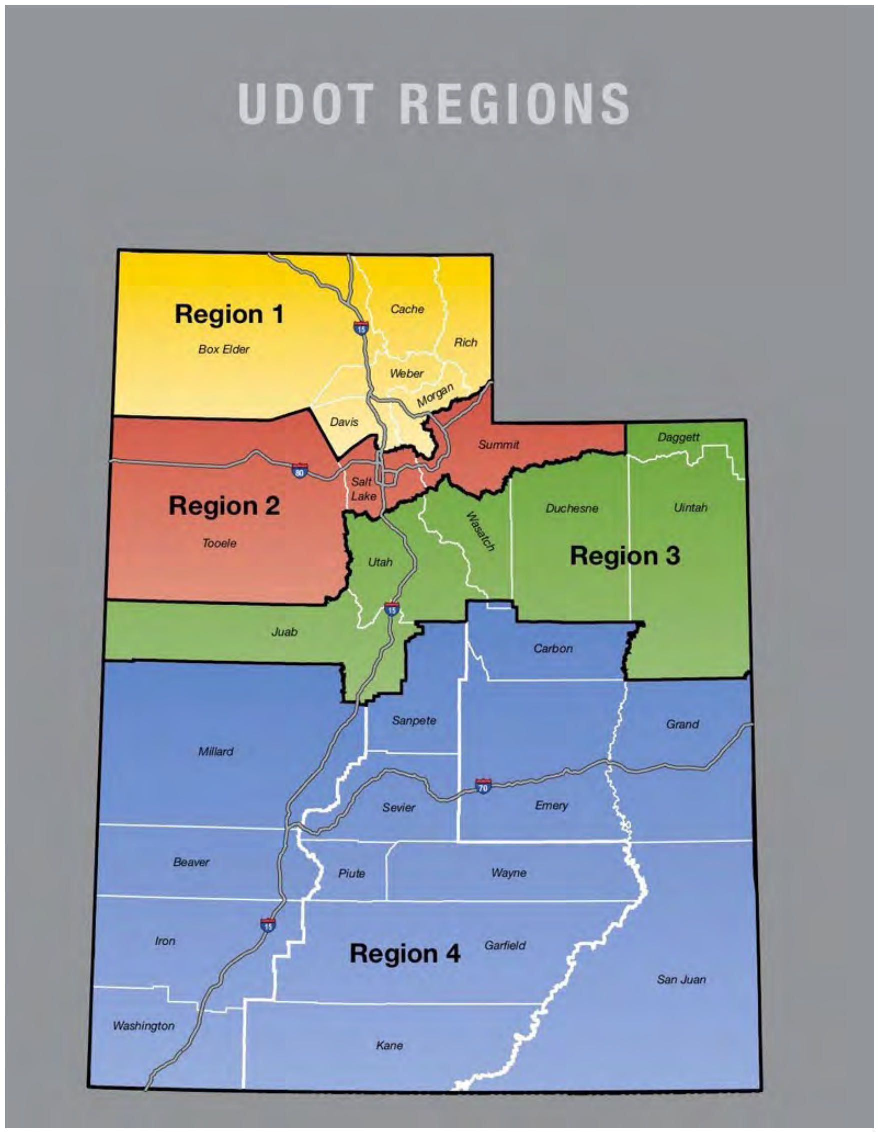



**Figure 1. Map of Study Area.**

# CHAPTER 4: AVAILABLE DATA

The UTAPS-CDI crash database for 2016 through 2020 was used in conjunction with the 2019 statewide roadside safety hardware asset inventory. This ISPE analysis was performed by staff from the UDOT Traffic & Safety Division, and the original data used in the analysis is available upon request.

The Department of Public Safety (DPS) data dictionary[1] was used in the assembling of UTAPS-CDI crash database. Figure 2 provides the steps taken during the ISPE dataset assemblage and case reduction.

As indicated by flag 1 and the corresponding explanation on the right side of Figure 3, the data reduction started by identifying all events that occurred on a state route and had a barrier hit identified as one of the sequence of events and/or the most harmful event. The codes used to identify longitudinal barrier hit include: '40' (hit guardrail), '41' (hit concrete barrier), and '42' (hit cable barrier). The events remaining for each year of the data collection, after this first data reduction step, are shown in Figure 3. After this first data reduction step, AADT values were assigned to each crash using route and milepost. AADT values are not calculated for ramps, and AADT values are only assigned to positive route directions, but are in reality cumulative values for both positive and negative route directions. AADT was not used in the final analysis.

It is important to note that due to the limited staffing resources on this project, a manual review of each crash report was not possible. Manual review of each crash diagram and narrative could likely provide additional insights into each event, thus allowing more accurate and more detailed coding of some ISPE fields. This is further discussed in Next Steps, Section 6.4 of this report. For the purposes of this analysis, it was assumed that the responding officer recorded the crash data correctly, and that the barrier that was proximate to the crash location was the barrier that was involved in the crash. It should be noted that all crashes in UTAPS-CDI crash database went through quality control process for route, milepost, and other most commonly used fields (such as manner of collision).

The source material and fields used to develop the ISPE Dataset are outlined in Table 2 with reference to the corresponding equivalencies tables (i.e., Table 3 through Table 5). The crash codes for vehicle severity (MAX_SEV), vehicle type (VEH_TYPE) and post impact harmful events (POSTHE) are mapped to the NCHRP 22-33 Guidelines Document definitions in Table 3 through Table 5.

The longitudinal barrier types were identified by matching the state collected asset inventory to the location of the crash. The route and milepost attributes for both datasets were used, and to avoid having an event drop out of the analysis because the single milepost value of the point did not overlap with the linear milepost description of the barrier, the analysts made each crash a short polyline by bracketing the milepost value by 0.05 miles on each end. This increased the likelihood that related barriers and crashes would be captured by the LRS-based route overlay analysis, and is shown in Figure 2. In the event that an event was spatially associated with more than one barrier, the barrier type was examined. If all of the barriers were of the same type, then the duplicate runs were eliminated (for example, I-80 in the west desert has cable barrier in both a median installation and shoulder installation, so a crash in that area

[1] Utah Motor Vehicle Crash Report Data Dictionary (March 2021), https://highwaysafety.utah.gov/wpcontent/uploads/sites/22/2021/03/Utah-Crash-Report-Data-Dictionary-2021-v8-030121.pdf

may have been associated with two different runs of barrier, but they are the same type). If the crash was associated with more than one barrier and they were different types, then the crash codes were used to differentiate between the types and identify the correct run of barrier. For example, if a crash was associated with a run of Jersey 230 and a run of W-beam, and the crash was coded with ‘41’ (hit concrete barrier), then the Jersey 230 was logged as the associated barrier and the W-beam run was dropped. Events in which the correct barrier could not be identified were removed from the analysis.

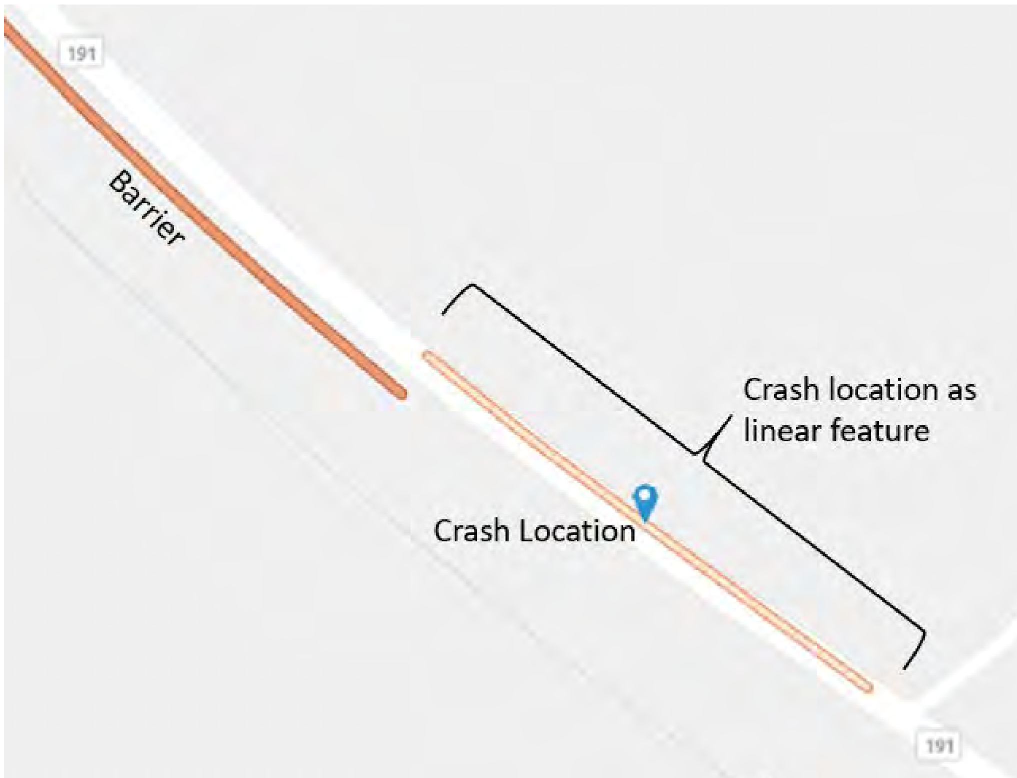



**Figure 2. Example of GIS analysis.**

| Year | Events | Reduction #1 | Events | Reduction #2 | Events |
|---|---|---|---|---|---|
| 2016 | 32,889 | Crash codes for harmful vehicle events 40, 41, 42 → | 3,613 | GIS overlay to identify crashes with correct barrier type → | 2,500 |
| 2017 | 33,343 | | 4,017 | | 2,768 |
| 2018 | 35,003 | | 3,688 | | 2,552 |
| 2019 | 35,235 | | 4,244 | | 3,027 |
| 2020 | 35,245 | | 3,118 | | 2,172 |

**Figure 3. Dataset Assemblage and Reduction Sheet.**

**Table 2. Compiled ISPE Dataset and Source Material.**

| Column | Field Name | Definitions | Source |
|---|---|---|---|
| A | SFUE | Safety Feature Under Evaluation | Crash data (vehicle level) most harmful event and sequence of events 1-4, fields coded 40, 41, 42. |
| B | CRN | Crash number | Crash data, field code crash_id. |
| C | CRASH_DATE | Date of crash | Crash data, field code crash _datetime. |
| D | TOTAL_UNITS | Number of units involve in the crash | Crash data, field code number of vehicles involved plus added number of nonmotorist involved (counted number of pedestrian and bicyclist). |
| E | MAX_SEV | Maximum severity of the vehicle | See Table 3. Calculated from maximum person level injury for each vehicle that interacted with the barrier. |
| F | VEH_TYPE | Body type of vehicle | See Table 4. |
| G | SPEED_LIMIT | Speed limit | Crash Data, vehicle level, field code posted speed |
| H | PostHE | Post harmful event after safety feature interaction | See Table 5. |
| I | MHE | Safety feature was most harmful event | Crash data vehicle level data field code most_harmful_event_id. |
| J | FHE | Safety feature was first harmful event | Crash data field code first_harmful_event_id. |
| K | AHE | Safety feature was any harmful event | Crash data field code for all harmful events within the sequence. |
| L | FOHE | Safety feature was first and only harmful event | As documents in section 3.3.12 of ISPE Guidelines Document. |
| M | BREACH | Vehicle breached safety feature | Assumed 99, not evaluated. *Future ISPEs which are concerned with BREACH should perform a review of crash diagrams and review of crash narrative.* |
| N | BREAK | Predictable breakaway | Not applicable |
| O | PRS | Controlled penetration, redirection, or stop | Not applicable |
| P | PEN | Safety Feature Intrusion | This information was not available. An Investigative ISPE was not undertaken at this time. Assumed 99. |
| Q | ICP | Initial contact point | Crash data vehicle level data field code area_init_impact_id |
| R | NAME | Subgroupings of safety feature | Equivalence shown in Table 6. |
| S | AADT | Average Annual Daily Traffic in vehicles per day | Highway inventory, field code AADT. |
| T | INSTALL | Construction inspection | UDOT inspects hardware as it is installed on UDOT roadways. Installation inspections are not performed on local jurisdictions. |
| U | MAINT | Maintenance Inspection | Maintenance is done as needed and noticed by station personnel, not on a regularly scheduled interval. |

**Table 3. ISPE Dataset MAX_SEV Equivalence Table.**

| MAX_SEV | Crash data field code MAX_SEVERITY_LEVEL |
|---|---|
| K | 5 - Fatal |
| A | 4 - Suspected serious injury |
| B | 3 - Suspected minor injury |
| C | 2 - Possible injury |
| O | 1 - No injury / Property damage only (PDO) |
| U | 89 - Unknown |

**Table 4. Equivalency of the State Motor Vehicle Body Type to Dataset Variables.**

| VEH_TYPE | Crash data field code VEH_CONFIG_CD | |
|---|---|---|
| MC | 12 | (retired) Motorcycle |
| | 22 | Motorcycle (2 wheels) |
| | 23 | Motorcycle (3 wheels) |
| PC | 1 | Passenger Car |
| | 2 | (retired) Passenger Car (4 door) |
| | 3 | (retired) Station Wagon |
| | 25 | Passenger Van (<9 seats) |
| PU | 4 | Pickup |
| | 5 | Sport Utility Vehicle |
| | 6 | (retired) Van or Mini Van |
| | 24 | Cargo Van |
| | 26 | Passenger Van (9-12 seats) |
| | 28 | Limousine |
| SUT | 7 | Single Unit Truck |
| | 8 | (retired) Single Unit Truck (3 or more axles) |
| | 18 | RV/Motor Home |
| | 27 | Passenger Van (15 seats) |
| BUS | 13 | School Bus |
| | 14 | (retired) Bus/Motorcoach (not school) |
| | 29 | Transit Bus |
| | 30 | Motorcoach |
| | 31 | Other Bus Type* |
| TT | 9 | Truck Tractor |
| | 10 | (retired) Truck/Trailer |
| | 11 | Heavy Truck Other |
| Other | 15 | Farm Equipment (tractor, combine, etc.) |
| | 16 | Motorized Scooter/Moped/Motorized Bicycle, etc. |
| | 17 | (retired) Off Road Vehicle (snowmobile, ATV, etc.) |
| | 20 | ATV - Street Legal |
| | 21 | ATV/OHV - Off Road |
| | 32 | Construction Equipment (backhoe, bulldozer, etc.) |
| | 33 | Snowmobile |
| | 34 | Golf Cart |
| | 97 | Other* |
| | 99 | Unknown |
| | 89 | Unknown |
| | 19 | error |

**Table 5. ISPE Dataset PostHE Equivalence Table.**

| PostHE | Crash data field codes for harmful events, fields 1-4. |
|---|---|
| 00 | No harmful event following impact with the safety feature listed in crash sequence. And (96) - Not Applicable (used only to fill unused box(es)) and (89) – BLANK. |
| 99 | (99) – Unknown what was hit |
| RFS | Not used |
| RSS | Not used |
| ROLL | (7) – Overturn/ Rollover |
| VEH. | When any of these codes appear after code 40, 41, or 42 in Harmful events: (20) - Collision With Other Motor Vehicle in Transport, (21) - Collision With Parked Motor Vehicle, (27) - Work Zone/Maintenance Equipment, (28) - Freight Rail, (29) - Light Rail, (30) - Passenger Heavy Rail |
| PED | When any of these codes appear after code 40, 41, or 42 in Harmful events: (22) – Pedestrian, (24) - Other Non-Motorist |
| FO | When any of these codes appear after code 40, 41, or 42 in Harmful events: (49) - Bridge Pier or Support, (50) - Bridge Overhead Structure, (54) - Utility Pole/Light Support, (55) - Traffic Signal Support, (60) - Tree/Shrubbery, (61) - (retired) Mailbox/Fire Hydrant, (62) – Fence, (64) - Fire Hydrant, (66) – Building, (67) - Utility Box, (69) - Other Fixed Object |
| BA | When any of these codes appear after code 40, 41, or 42 in Harmful events: (51) - Traffic Sign Support, (53) - Other Post, Pole or Support, (65) - Mailbox |
| BAR | (40) – Guardrail, (41) - Concrete Barrier, (42) - Cable Barrier, (43) - Crash Cushion, (44) - Guardrail End Section, (45) - Concrete Sloped End Section, (46) - Cable Barrier End Section, (47) - (retired) Access Control Cable, (48) - Bridge Rail |

**Table 6. NAME Equivalence Table to Particular Hardware**

| NAME | Jurisdiction's Description | Test Level |
|---|---|---|
| a | Box Beam | NCHRP-350 TL 3 |
| b | Brifen 4 Rope O-Post Cable | MASH 4 |
| c | Cable Brifen | NCHRP-350 TL 3 |
| d | Cable Trinity | NCHRP-350 TL 3 |
| e | Constant Slope Concrete Barrier | MASH TL 3 |
| f | Crescent Rail | Pre-requirements |
| g | Double Sided | NCHRP-350 TL 3 |
| h | Jersey Barrier 12.5 / 230 / Precast Jersey 230 | NCHRP-230 TL 3 |
| i | Jersey Barrier 20 / 350 / Precast Jersey 350 | NCHRP-350 TL 3 |
| j | MGS W-Beam | MASH TL 3 |
| k | Other | - |
| l | Jersey Parapet | NCHRP-350 TL 3 |
| m | Point Hazard | - |
| n | W-Beam | NCHRP-350 TL 3 |
| p | W-Beam w/ Motorcycle Barrier | NCHRP-350 TL 3 |
| q | CIP Jersey | NCHRP-350 TL 3 |
| r | Parapet | NCHRP-350 TL 3 |
| s | Precast Half Barrier | NCHRP-350 TL 3 |
| t | Not used | - |
| u | 42" Single Slope Parapet | MASH TL 4 |
| v | CIP Constant Slope | MASH TL 3 |
| w | Not used | - |
| x | Precast 42" Constant Slope | NCHRP-350 TL 3 |
| y | Not used | - |
| z | Not used | - |
| 99 | Unknown | - |

# CHAPTER 5: PERFORMANCE OUTCOMES, EVALUATION MEASURES, AND CONDITIONS

## 5.1 FULL DATASET

An ISPE first considers the availably of known data through Condition 1. Condition 1 is met when the sampled data are not biased and the statistical power of the study is maximized. Unknown or missing values in the dataset are indicated with the number 99 entered in a row for the crash corresponding to the field for which the value is unknown. Some amount of unknown data is expected. As shown here, there are few instances of unknown values and these unknown values do not interfere with the power of the study.

This ISPE of longitudinal barriers considered the following Evaluation Measures for the identified performance outcomes:

- • Performance Outcome: Occupant Risk o Evaluation Measure F (Rollover) o Evaluation Measure H (Vehicle Mix)
- • Performance Outcome: Vehicle Trajectory o Evaluation Measure J (Secondary Impact on Roadside) o Evaluation Measure K (Secondary Impact on Road) o Evaluation Measure M (Impact Orientation)

Structural Adequacy Evaluation Measures B and C and Vehicle Trajectory Evaluation Measure L are not applicable to SFUE 1 devices.

The findings for Condition 1 (i.e., availability of data) for each considered Evaluation Measure are summarized in Table 7. The ISPE *Summary of Data and Results Sheets* are provided in the Appendix A of this report for further details. Evaluation Measures F, H, J, K, and M meet Condition 1 and are applicable to SFUE 1 devices, therefore will be assessed further. Evaluation Measures A and D did not meet Condition 1 so were not evaluated further.

UDOT inspects longitudinal barriers on state-maintained routes when they are installed. There is not a formally documented maintenance inspection program, however, maintenance station personnel drive their routes on a daily basis and perform a visual inspection on all roadside safety hardware. The results of this analysis for Condition 2 and 3 are also summarized in Table 7. Since performance goals for installation inspections and on-going maintenance inspections have not been established by UDOT, the evaluation of Conditions 2 and 3 were not applicable to this dataset.

**Table 7. Evaluation of Conditions 1, 2, and 3 for each Evaluation Measure.**

| Condition | Performance Outcome | Evaluation Measures | Condition Threshold (%) | ISPE dataset measurement (%) | Evaluation |
|---|---|---|---|---|---|
| *1 (Unknowns) | Structural Adequacy | A | <30 | 100 | Not Met |
| | Occupant Risk | D | NA | 100 | Not Met |
| | | F | <20 | 2 | Met |
| | | H | NA | 0 | Met |
| | Vehicle Trajectory | J | <25 | 2 | Met |
| | | K | <20 | 2 | Met |
| | | M | <10 | 1 | Met |
| *2 (Installation) | Structural Adequacy | A | NA | -- | NA |
| | Occupant Risk | D | NA | -- | NA |
| | | F | NA | 100 | NA |
| | | H | NA | 100 | NA |
| | Vehicle Trajectory | J | NA | 100 | NA |
| | | K | NA | 100 | NA |
| | | M | NA | 100 | NA |
| *3 (Maintenance) | Structural Adequacy | A | NA | -- | NA |
| | Occupant Risk | D | NA | -- | NA |
| | | F | NA | 0 | NA |
| | | H | NA | 0 | NA |
| | Vehicle Trajectory | J | NA | 0 | NA |
| | | K | NA | 0 | NA |
| | | M | NA | 0 | NA |

The point estimate ($\hat{p}$) value $R^2$ for each Evaluation Measure in Table 8 indicates the proportion of times that the unexpected event occurs (e.g., for Evaluation Measure F: proportion of times a rollover occurs after a crash with a longitudinal barrier). The Effect Size (ES) value for each Evaluation Measure in Table 8 indicates the effect size of a fatal or serious injury crash outcome when the unexpected outcome occurs (e.g., for Evaluation Measure J: effect size of a crash with a fatal or serious crash outcome when there is a secondary crash on the roadside after a crash with a longitudinal barrier).

Performance Assessment Levels 1, 2, 3, and 4 (i.e., PAL1, PAL2, PAL3, PAL4) for the dataset are summarized in Table 8. The Evaluation Measures use the ISPE dataset to make inferences for the entire population of longitudinal barriers represented by the dataset through consideration of the 85$^{th}$ percentile confidence interval as suggested by the NCHRP Project 2233 ISPE Guidelines Document.

PAL1 evaluates the performance of the longitudinal barriers across the full dataset. This means that the full vehicle mix and posted speed limits are included in the assessment at this performance level. This first assessment progresses with the calculation of $\hat{p}$ and ES for each appropriate Evaluation Measure. Corresponding confidence intervals are also determined for both the point estimates and ES values.

PAL2 evaluates the performance of the longitudinal barriers limited by the vehicle types it was designed and evaluated for in crash tests. Most of the longitudinal barriers installed in the state of Utah and particularly those studied in this ISPE (i.e., the systems listed in Table 9) were designed and tested to either Report 350 or MASH Test Level 3 requirements. TL3 barriers are tested with passenger cars and pickup trucks (VEH_TYPE = PC or PU). The PAL2 data are a subset of the assembled ISPE dataset, where VEH_TYPE is equal to PC or PU.

PAL3 (Performance by Posted Speed Limit) evaluates the performance of the longitudinal barriers limited by the posted speed limit corresponding to the crash test impact speed for longitudinal barriers. Most of the longitudinal barriers installed in the state of Utah and particularly those studied in this ISPE (i.e., the systems listed in Table 9) were designed and tested for Report 350 or MASH Test Level 3 which uses an impact speed of 62.4 mph. The PAL3 data are a subset of the assembled ISPE dataset, where SPEED_LIMT≤65 mph.

PAL4 (Performance by Vehicle Type and Posted Speed Limit) evaluates the performance of the longitudinal barriers through limiting the dataset by both the vehicle type (VEH_TYPE = PC or PU) and posted speed limit (i.e., SPEED_LIMT≤65 mph) for TL3 systems.

UDOT has not previously conducted an ISPE of longitudinal barriers using the uniform criteria presented in the ISPE Guidelines Document, developed under NCHRP Project 22-33, therefore, all performance goal (PG) values are established by the values at PAL1 for each Evaluation Measure of this IPSE.

**Table 8. Performance Assessment by Level.**

| | Evaluation Measures | | PAL1 *Full Vehicle Mix* | PAL2 *Design Vehicles* | PAL3 *Design Speed* | PAL4 *Design Vehicles and Speed* | PG[2] *Performance Goal* | Eval |
|---|---|---|---|---|---|---|---|---|
| Occupant Risk | **F** *Post-Crash Rollover* | R2 | 0.0378 (0.0347,0.0411) | 0.0339 (0.0310,0.0371) | 0.0518 (0.0449,0.0596) | 0.0447 (0.0382,0.0523) | 0.0378 | Met |
| | | ES | 11.4833 (8.5601,15.4048) | | | | NA | NA |
| | **H_AHE** *Any Harmful Event Crash Severity* | R2 | 0.0152 (0.0135,0.0172) | 0.0119 (0.0103,0.0136) | 0.0209 (0.0170,0.0256) | 0.0153 (0.0119,0.0195) | 0.0152 | Met |
| | **H_FHE** *First Harmful Event Crash Severity* | R2 | 0.0153 (0.0136,0.0173) | 0.0119 (0.0103,0.0136) | 0.0213 (0.0174,0.0260) | 0.0153 (0.0119,0.0195) | 0.0153 | Met |
| | **H_MHE** *Most Harmful Event Crash Severity* | R2 | 0.0122 (0.0106,0.0139) | 0.0093 (0.0079,0.0109) | 0.0163 (0.0129,0.0205) | 0.0104 (0.0077,0.0140) | 0.0122 | Met |
| | **H_FOHE** *First & Only Event Crash Severity* | R2 | 0.0093 (0.0077,0.0111) | 0.0074 (0.0060,0.0091) | 0.0117 (0.0084,0.0162) | 0.0084 (0.0057,0.0125) | 0.0093 | Met |
| Vehicle Trajectory | **J** *Secondary Crash on the Roadside* | R2 | 0.0061 (0.0049,0.0076) | 0.0060 (0.0048,0.0075) | 0.0105 (0.0075,0.0145) | 0.0104 (0.0074,0.0146) | 0.0061 | Met |
| | | ES | 9.1344 (4.5033,18.5282) | | | | NA | NA |
| | **K** *Secondary Crash on the Roadway* | R2 | 0.1776 (0.1718,0.1834) | 0.1786 (0.1728,0.1846) | 0.1834 (0.1720,0.1953) | 0.1869 (0.1752,0.1992) | 0.1776 | Met |
| | | ES | 1.9300 (1.4486,2.5716) | | | | NA | NA |
| | **M** *Impact Orientation* | R2 | 0.5544 (0.5457,0.5630) | 0.5572 (0.5484,0.5660) | 0.5307 (0.5137,0.5477) | 0.5355 (0.5181,0.5528) | 0.5544 | Met |
| | | ES | 0.6451 (0.4873,0.8541) | | | | NA | NA |

[2] Performance Goals are being established using PAL1 of this ISPE.

## 5.2 DATASET STRATIFIED BY VALUES OF NAME

The hardware involved in each reported crash was identified as discussed in Chapter 4. There are 21 possible values of NAME based on the hardware inventory. NAME equivalencies and sample size (i.e., number or crashes in the dataset) are shown in Table 9. The results for the ISPE by values of NAME for each of the applicable Evaluation Measures and Performance Assessment Levels are shown in Appendix A.

**Table 9. Sample size (number of crashes) for each value of NAME in the full dataset.**

| NAME | Longitudinal Barrier System Description | Crash Test Standard and Test Level | Number of Crashes in Dataset |
|---|---|---|---|
| a | Box Beam | NCHRP-350 TL-3 | 39 |
| b | Brifen 4 Rope O-Post Cable | MASH TL-4 | 0 |
| c | Cable Brifen | NCHRP 350 TL-3 | 265 |
| d | Cable Trinity | NCHRP 350 TL-3 | 1,481 |
| e | Constant Slope Concrete Barrier | MASH TL-3[3] | 7,656 |
| f | Crescent Rail | Prior to crash test requirements | 0 |
| g | Double Sided | NCHRP 350 TL-3 | 16 |
| h | Jersey Barrier 12.5<br>Jersey Barrier 230<br>PRECAST JERSEY 230 | NCHRP 230 TL-3 | 547 |
| i | Jersey Barrier 20<br>Jersey Barrier 350<br>PRECAST JERSEY 350 | NCHRP 350 TL-3 | 1,080 |
| j | MGS W-Beam | MASH TL-3 | 22 |
| k | Other | Unknown | 38 |
| l | Jersey parapet | NCHRP-350 TL-3 | 0 |
| m | Point Hazard | Unknown | 12 |
| n | W-Beam | NCHRP 350 TL-3 | 1,276 |
| p | W-Beam w/ Motorcycle Barrier | NCHRP 350 TL-3 | 2 |
| q | CIP JERSEY | NCHRP 350 TL-3 | 17 |
| r | PARAPET | NCHRP 350 TL-3 | 546 |
| s | PRECAST HALF BARRIER | NCHRP 350 TL-3 | 9 |
| t | *Not used* | | |
| u | 42" Single Slope Parapet | MASH TL-4 | 0 |
| v | CIP CONSTANT SLOPE | MASH TL-3[2] | 3 |
| w | *Not used* | | |
| x | PRECAST 42" CONSTANT SLOPE | NCHRP 350 TL-3 | 10 |

[3] Listed as TL3 because foundations are only tested to TL-3, the rest of the barrier is designed as TL-4.

# CHAPTER 6: SUMMARY AND CONCLUSIONS

This chapter includes interpretation of results, conclusions, and recommendations for future ISPEs in Utah.

## 6.1 INTERPRETING RESULTS OF FULL DATASET

Comparison of post impact harmful events for the full dataset (i.e., PAL1) is provided in Figure 4. The probability that a crash involves a post-impact rollover event (Evaluation Measure F), secondary collision on the roadside (Evaluation Measure J), or secondary collision on the roadway (Evaluation Measure K) after interaction with the longitudinal barrier are shown. There is a 3.8% risk of a vehicle rolling over after interacting with a longitudinal barrier. There is a 0.6% risk of a vehicle having a secondary collision on the roadside after it interacts with a longitudinal barrier. There is a 17.8% risk of a vehicle having a secondary collision on the roadway after it interacts with a longitudinal barrier. It is important to remember that the values presented in Figure 4 do not indicate crash severity, but probability of occurrence given an impact with the hardware.

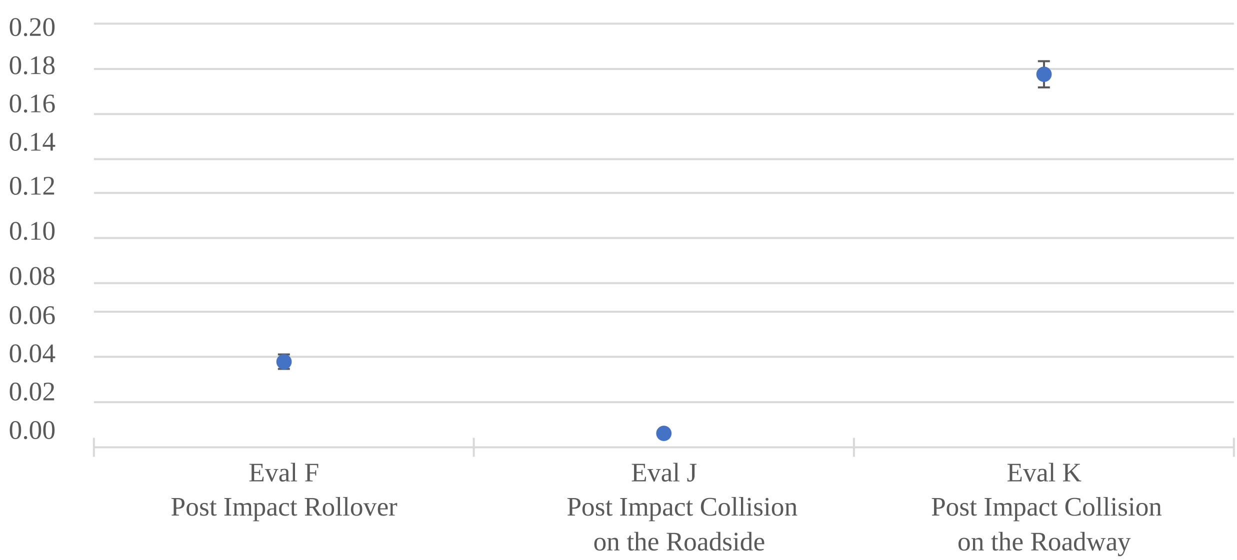



**Figure 4. Proportion of crashes resulting in a harmful event following the interaction with a longitudinal barrier – full dataset (PAL1).**

Figure 5 shows the effect size (i.e., relative risk) for crashes that involve post-impact harmful events for the full dataset (i.e., PAL1). If a vehicle interacts with a longitudinal barrier and subsequently rolls over, a KA outcome is almost 12 times more likely than if no post impact harmful event occurred. If a longitudinal barrier crash is followed by a secondary collision on the roadside, with a fixed object, the risk of a KA outcome is nine times more likely than if no post impact harmful event occurred. Similarly, if a longitudinal barrier crash is followed by a secondary collision on the roadway the risk of a KA outcome is two times more likely than if no post impact harmful event occurred. There were relatively few crashes which resulted in post impact rollover (Evaluation F) and post-impact secondary collisions on the roadside (Evaluations J), therefore, the confidence intervals are wide and these values lack precision. In summary, although rolling over and secondary collisions on the roadside after impacting longitudinal barriers is rare, as seen in Figure 4, the crash outcomes are more severe. Secondary collisions on the roadway are relatively more common and increase the risk of a fatal or serious injury by between 1.4 and 2.6 times.

Since the ES and the lower confidence interval for all three Evaluation Measures is greater than 1.0, there is a statistically significantly higher risk of KA crash when a post impact rollover, secondary collision on the roadside, or secondary collision on the roadway occurs than when no post impact harmful event occurs.

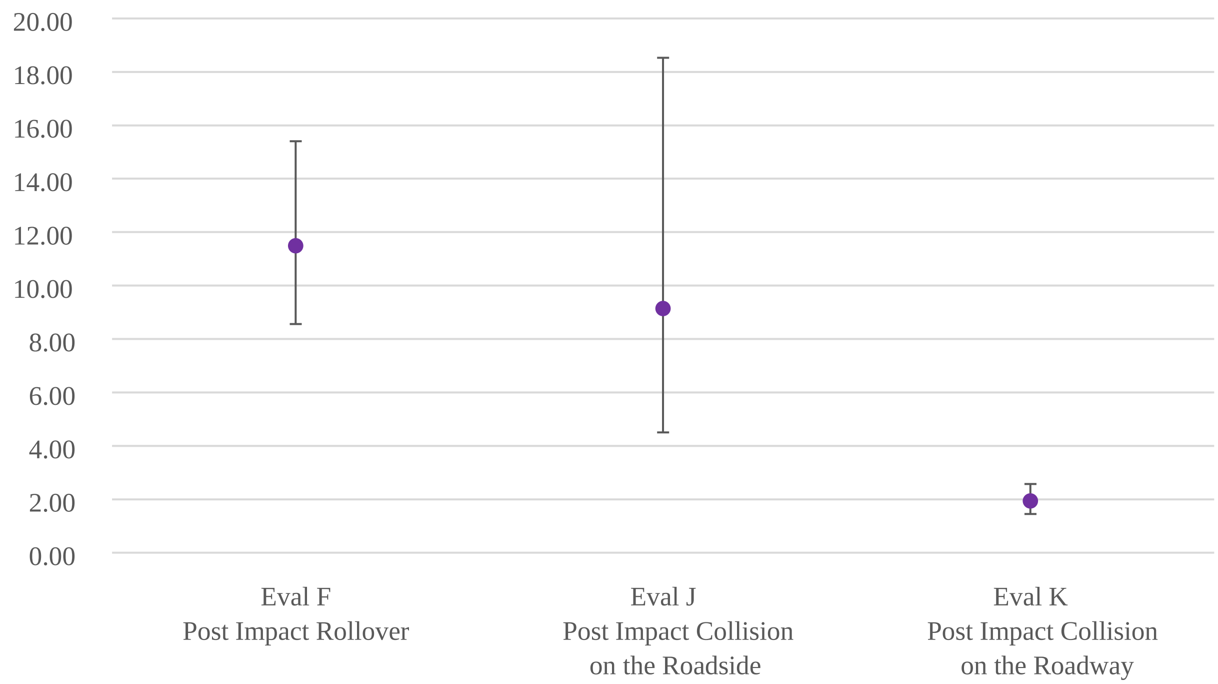



**Figure 5. Effect size (i.e., relative risk) of KA crash for crashes with harmful events following interaction with a longitudinal barrier – full dataset.**

Evaluation Measure H considers occupant risk for events where the impact with the longitudinal barrier occurs in various phases of the sequence of events. For the full vehicle mix on the roadway (i.e., PAL1), there is a 1.5% risk that a crash will result in a KA outcome when a longitudinal barrier is listed anywhere in the sequence of events. There is a 1.5% risk that a crash will result in a KA outcome when a longitudinal barrier is listed as the first harmful event in the sequence of events. There is a 1.2% risk that a crash will result in a KA outcome when a longitudinal barrier is listed as the most harmful event in the sequence of events. There is a 0.9% risk that a crash will result in a KA outcome when a longitudinal barrier is listed as the first and only harmful event in the sequence of events.

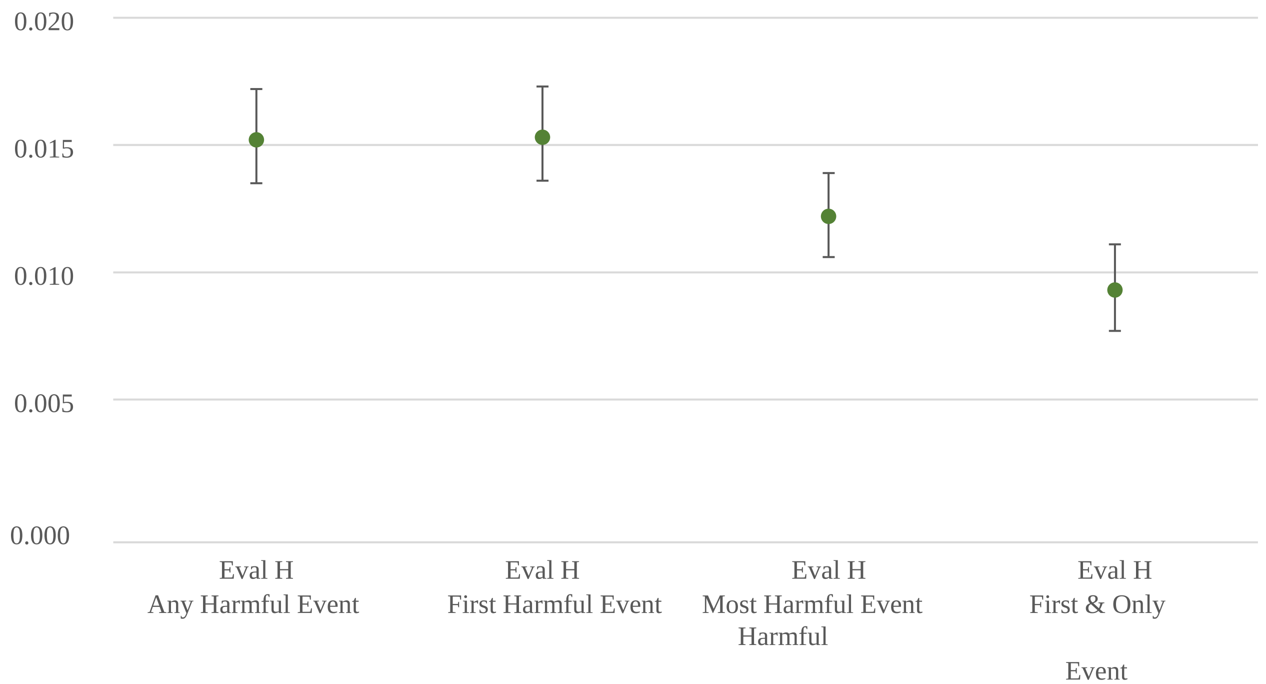



**Figure 6. Proportion of KA crashes for Evaluation Measure H (vehicle mix) at PAL1 for the AHE, FHE, MHE and FOHE datasets.**

Longitudinal barriers are designed for tracking impacts, generally with the front corner panels. Evaluation Measure M evaluates the probability that the initial contact point of a longitudinal barrier crash is not on the driver side or passenger side front quarter panels. It was found that the risk the initial contact point was not in the expected region (areas indicated by red boxes in Figure 7) is 55%, as shown on the left side of Figure 8. Interestingly, when a longitudinal barrier crash with an unexpected initial contact point occurs, the risk of a KA outcome is lower (i.e., 0.6 times) than if the crash had an expected impact orientation, as seen on the right side of Figure 8. Unexpected orientations of the impacting vehicles do not appear to be a concern within these data, which provides helpful additional information about the functionality of longitudinal barrier that is not provided by a standard crash test.

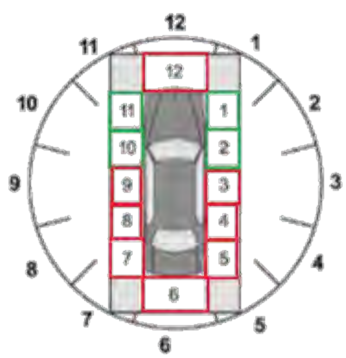



**Figure 7. Initial contact points, expected indicated by green, unexpected indicated by red.**

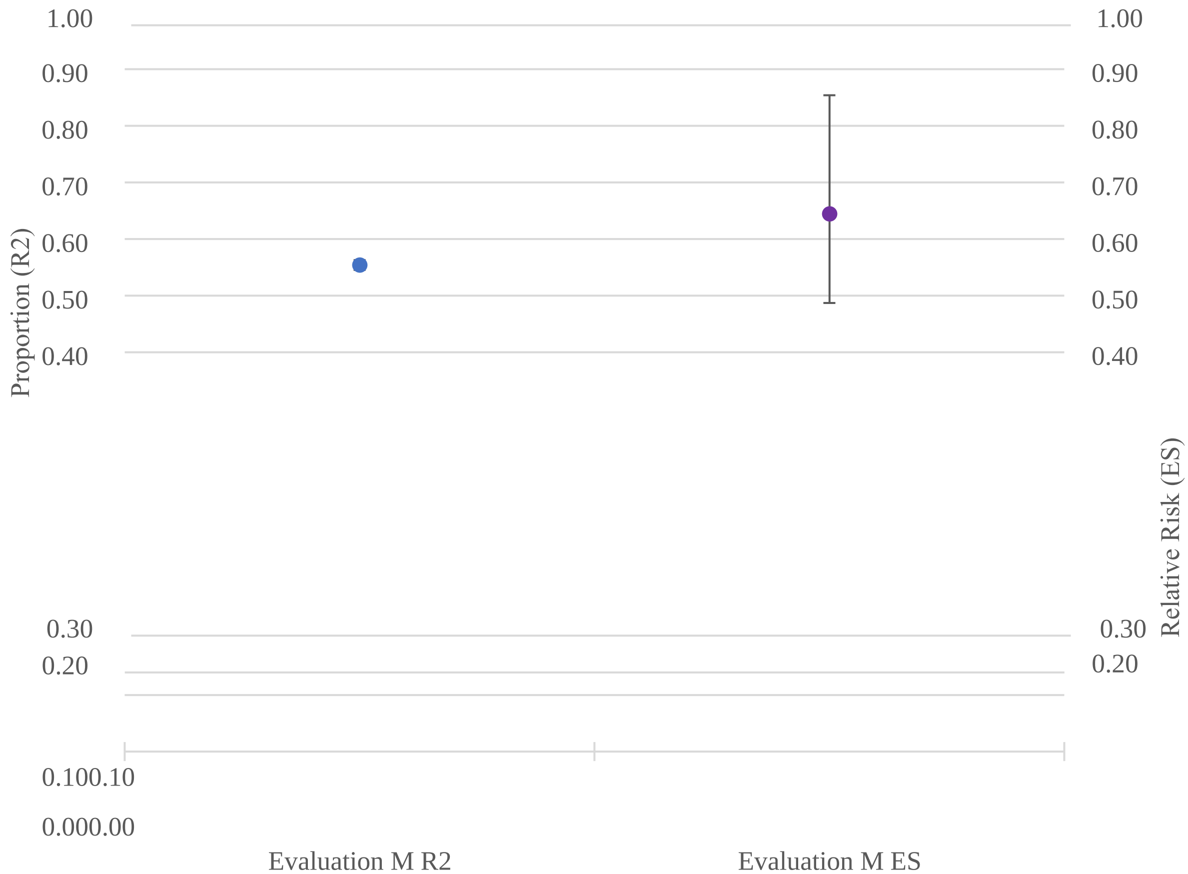



**Figure 8. Proportion of longitudinal barrier crashes with an unexpected impact orientation (left), effect size for longitudinal barrier crashes with an unexpected impact orientation (right) – full dataset (PAL1).**

## 6.2 INTERPRETING RESULTS OF DATASET STRATIFIED BY VALUES OF NAME

Figure 9 shows the proportion of longitudinal barrier crashes that result in a rollover versus no post impact harmful event by the specific longitudinal barrier type impacted (i.e., Evaluation Measure F stratified by NAME). As an example, if a "W-Beam" barrier is impacted there is a 7.1% chance that a rollover after interaction will occur. When looking at the point estimates in the values for some barrier types are 0.0 (e.g., "MGS W-Beam" and "Other"), this indicates that there were impacts with these systems but there were no rollover events after longitudinal barrier interaction. The "W-Beam w/ Motorcycle Barrier" system has a value of 1.0, this indicates that all the impacts with that barrier type resulted in a post impact rollover event. Values of either zero or unity do not indicate absolute conclusions, but rather indicate that additional crash data is needed to form conclusions.

When looking at the point estimates for barrier types that have tight confidence intervals, some conclusions can be made. For example, the lowest proportion of rollovers in the dataset comes after interacting with "Constant Slope Concrete Barriers", 2.8%. Since the confidence intervals don't overlap there is a statistically significant lower proportion of vehicles rolling over after interaction with the "Constant Slope Concrete Barrier" than when impacting either "Jersey Barriers" crash tested to Report 230 TL3 conditions or "W-Beam" barriers.

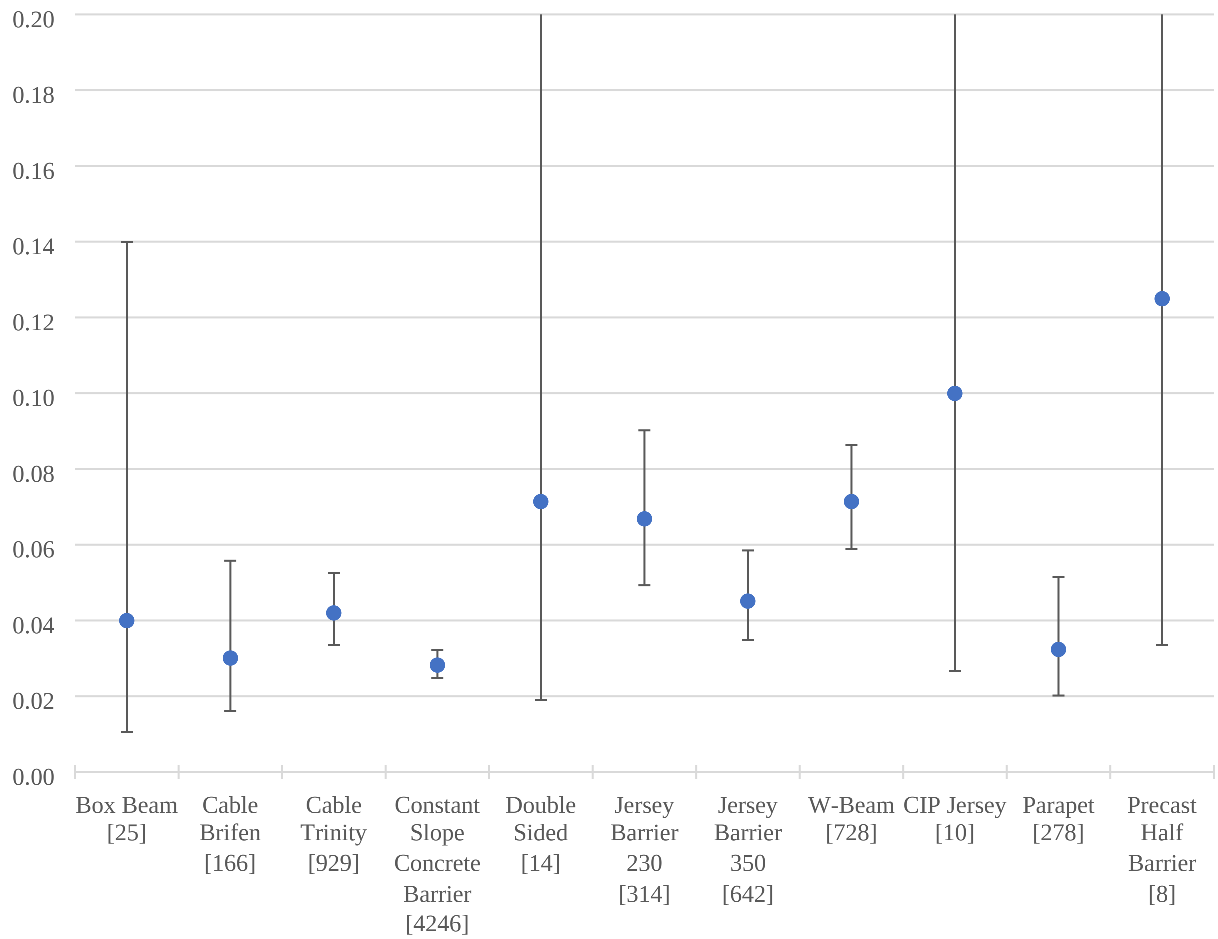



**Figure 9. Proportion of crashes with a rollover event following the interaction with a longitudinal barrier, subdivided by barrier type – full dataset (PAL1).**

Figure 10 shows the proportion of longitudinal barrier crashes that result in a fatal or serious injury outcome by the specific longitudinal barrier type impacted as any harmful event (i.e., Evaluation Measure H). As an example, if a Jersey Barrier crash tested to Report 230 TL3 conditions is impacted there is a 3.0% chance that the crash will result in a fatal or serious injury severity outcome. As discussed previously, conclusions should not be formed for values of zero or unity. Evaluation Measure H results have been calculated for the first harmful event, most harmful event and first and only harmful event datasets as well and the results are similar, with point estimates trending somewhat downward and the confidence intervals getting wider as can be seen in Figure 11 through 13.

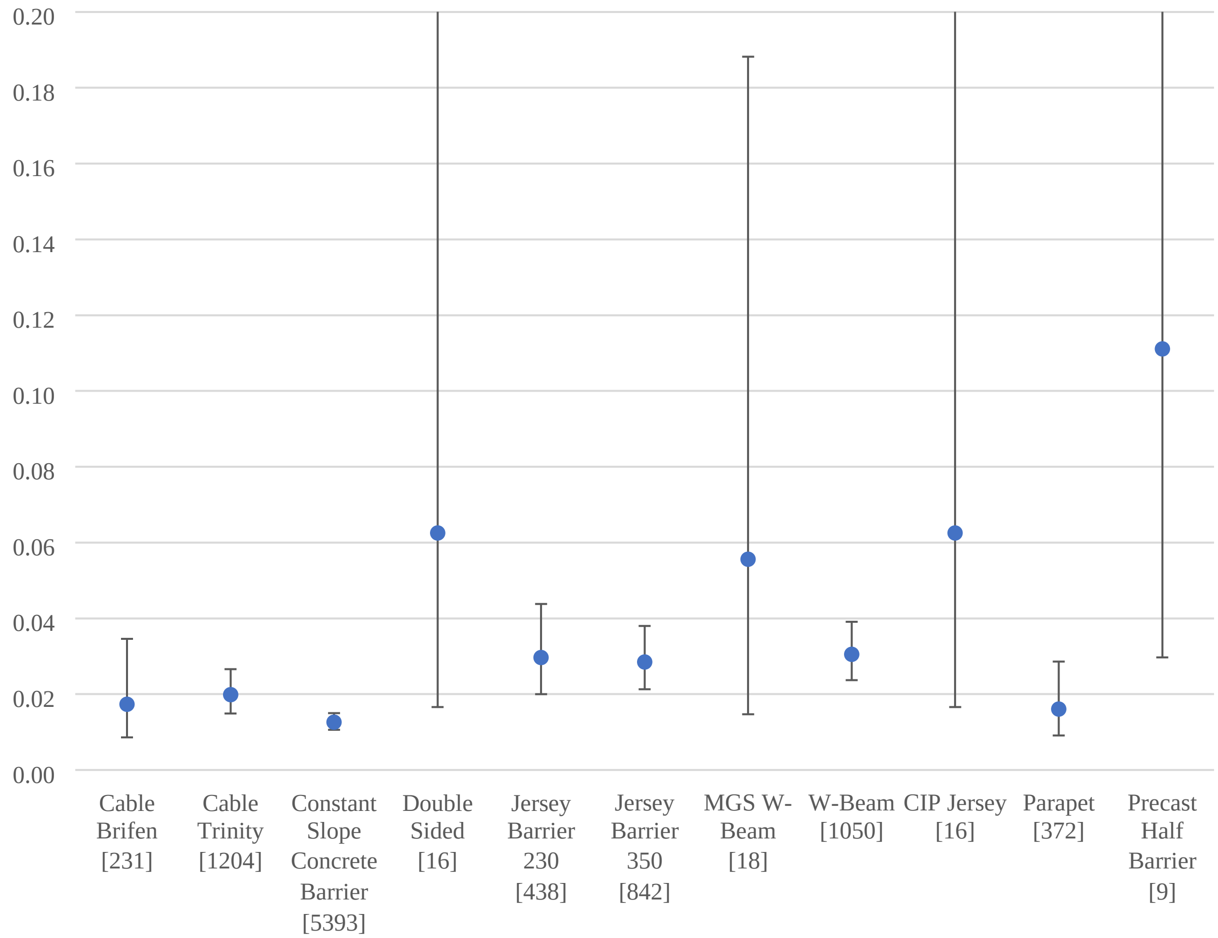



**Figure 10. Proportion of KA crashes for crashes where the longitudinal barrier is listed as any harmful event, subdivided by barrier type – full dataset (PAL1).**

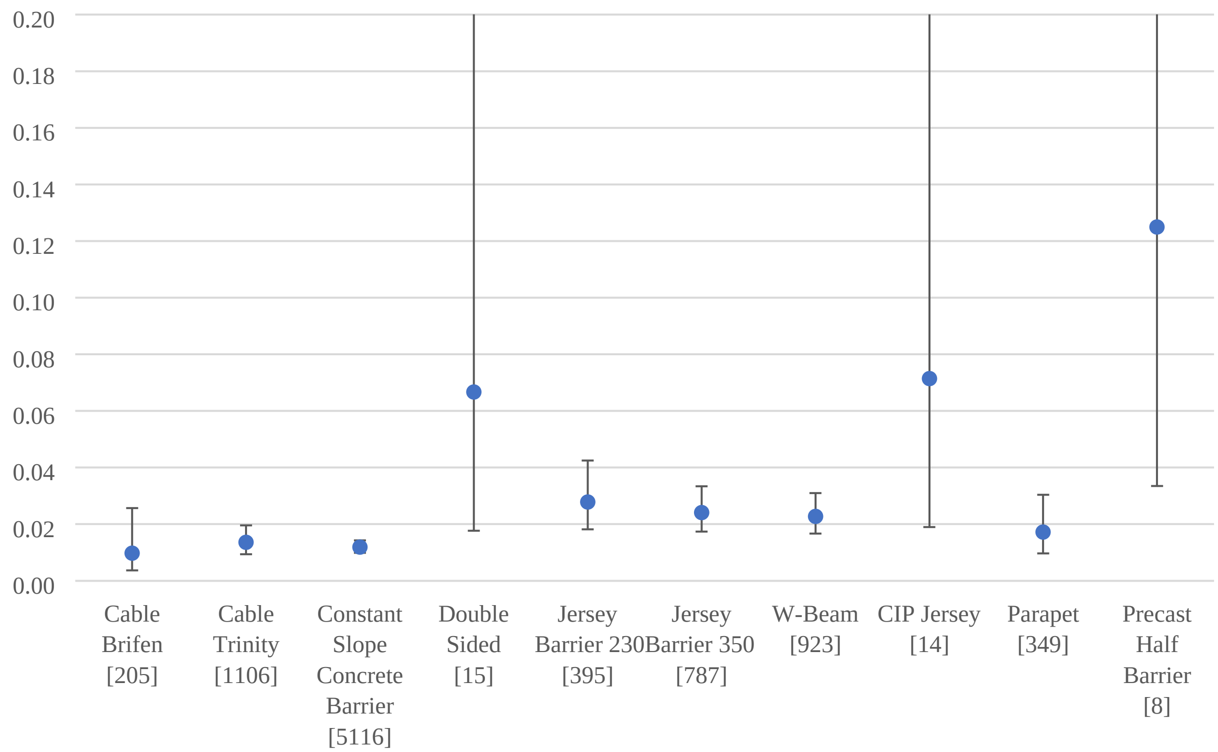



**Figure 11. Proportion of KA crashes for crashes where the longitudinal barrier is listed as the first harmful event, subdivided by barrier type – full dataset (PAL1).**

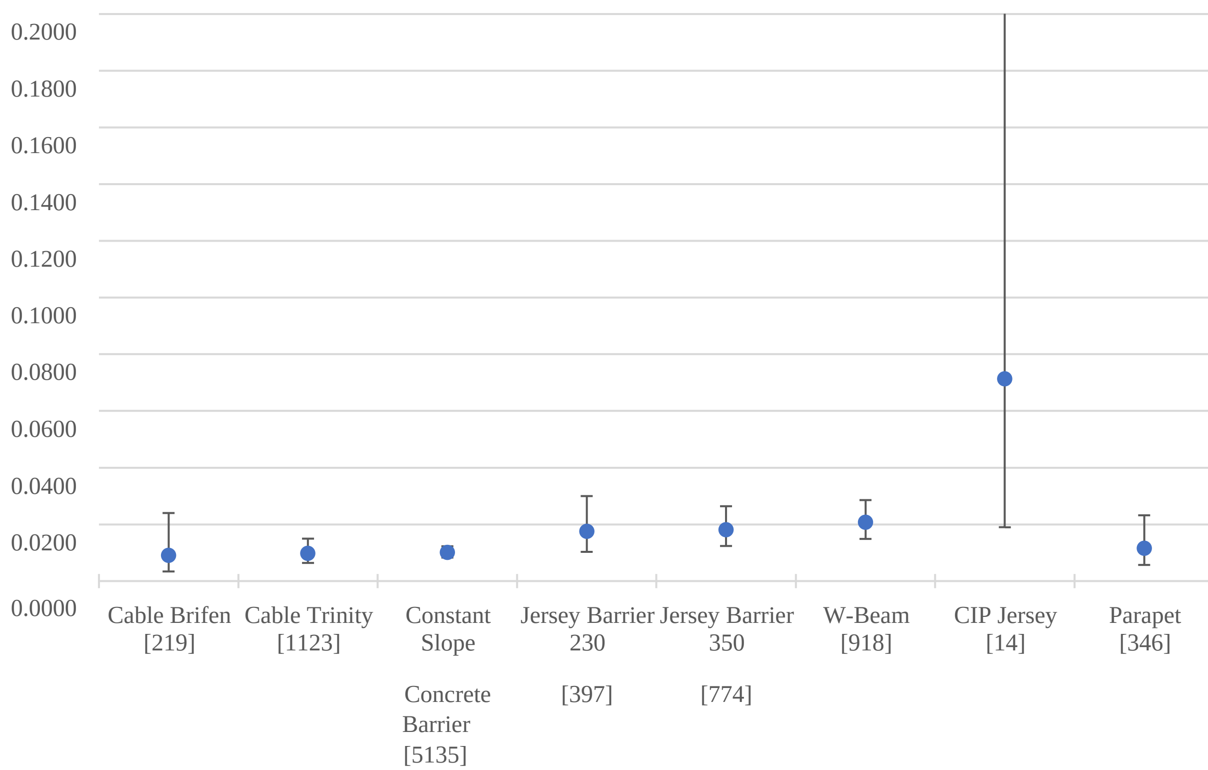



**Figure 12. Proportion of KA crashes for crashes where the longitudinal barrier is listed as the most harmful event, subdivided by barrier type – full dataset (PAL1).**

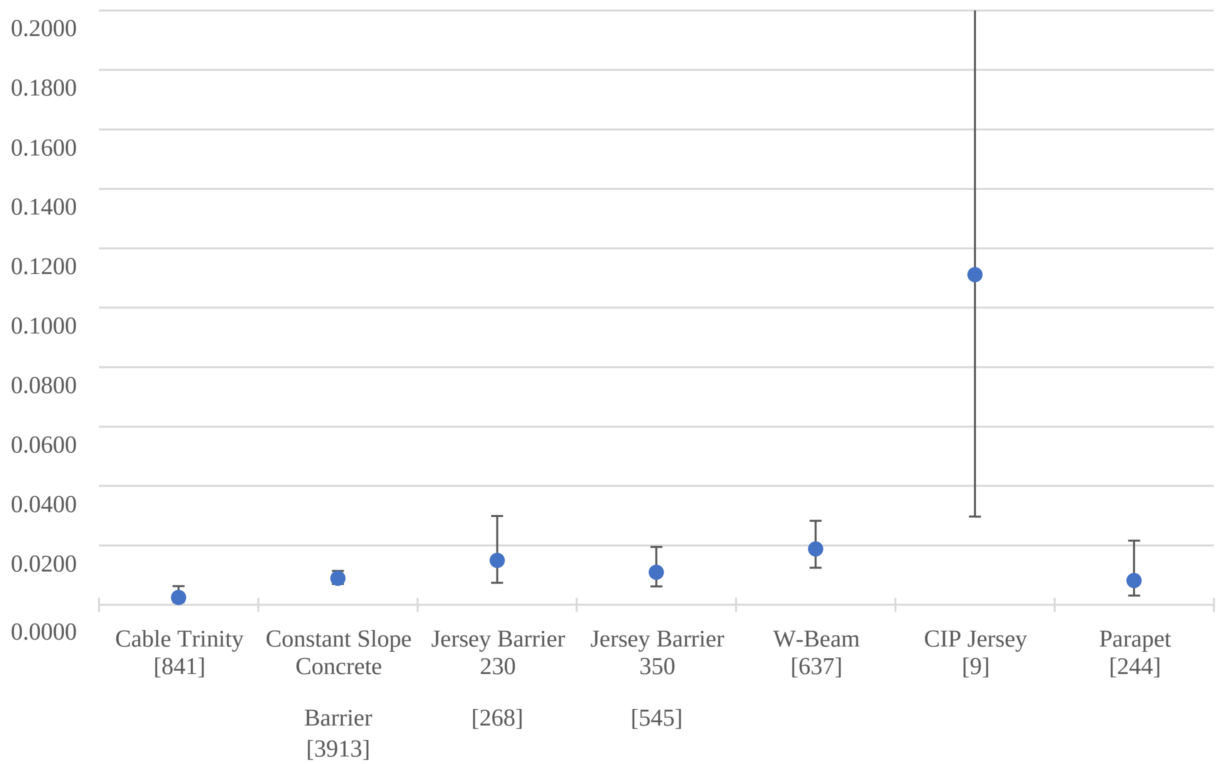



**Figure 13. Proportion of KA crashes for crashes where the longitudinal barrier is listed as the first and only harmful event, subdivided by barrier type – full dataset (PAL1).**

Figure 14 shows the proportion of longitudinal barrier crashes that result in a crash on the roadside versus no post impact harmful event by the specific longitudinal barrier type impacted (i.e., Evaluation Measure J). As an example, if a "Parapet" is impacted there is a 1.1% chance that a secondary crash on the roadside will occur after interaction. When looking at the point estimates in Appendix A the values for some barrier types are 0.0 (e.g., "Box Beam" and "CIP Jersey"), this indicates that there were impacts with these systems but there were no secondary crashes on the roadside after the longitudinal barrier interaction.

When looking at the point estimates for barrier types that have sufficient sample size to have tight confidence intervals, some conclusions can be made. The lowest proportion of secondary crashes on the roadside in the dataset comes after interacting with "Jersey Barriers" crash tested to Report 350 TL3 conditions, 0.16%. There is a statistically significant lower proportion of vehicles having secondary crashes on the roadside after interaction with the Report 350 "Jersey Barriers" than either "Jersey Barriers" crash tested to Report 230 TL3 conditions or "W-Beam" barriers.

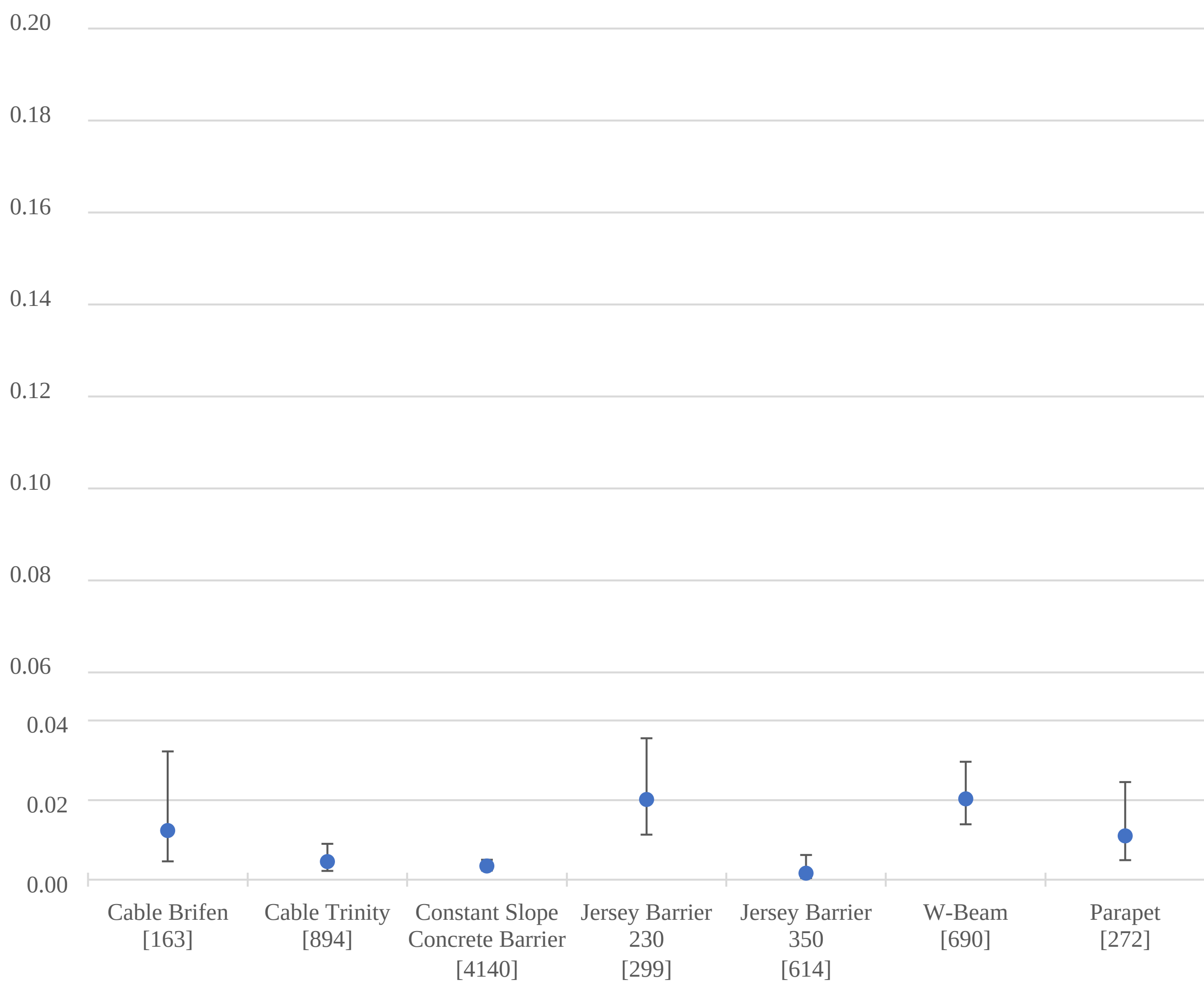



**Figure 14. Proportion of crashes with a secondary crash on the roadside following the interaction with a longitudinal barrier, subdivided by barrier type – full dataset (PAL1).**

Figure 15 shows the proportion of longitudinal barrier crashes that result in a crash on the roadway versus no post impact harmful event by the specific longitudinal barrier type impacted (i.e., Evaluation Measure K). As an example, if a Box Beam is impacted there is a 13.3% chance that a secondary crash on the roadway will occur after interaction rather than no post impact harmful event.

One of the lowest proportion of secondary crashes on the roadway in the dataset comes after interacting with “Cable Trinity” barriers, 12.3%. There is a statistically significant lower proportion of vehicles having secondary crashes on the roadway after interaction with the “Cable Trinity” barriers than when impacting either “Jersey Barriers” crash tested to Report 230 or Report 350 TL3 conditions. Cable barriers are statistically less likely than more rigid concrete barriers to have secondary crashes associated with them. There are two possible explanations for this. First, cable barrier is placed differently. Cable barrier is placed predominately in the median vs. cast-in-place and precast barrier, which is often placed on the right shoulder. This could result in different crash dynamics based on both the geometric considerations as well as driver behaviors. Second, cable barrier is a much less abrupt impact and as such vehicles may not "bounce" as much when they are hit, and the crashed vehicle is not redirected back into the roadway as often.

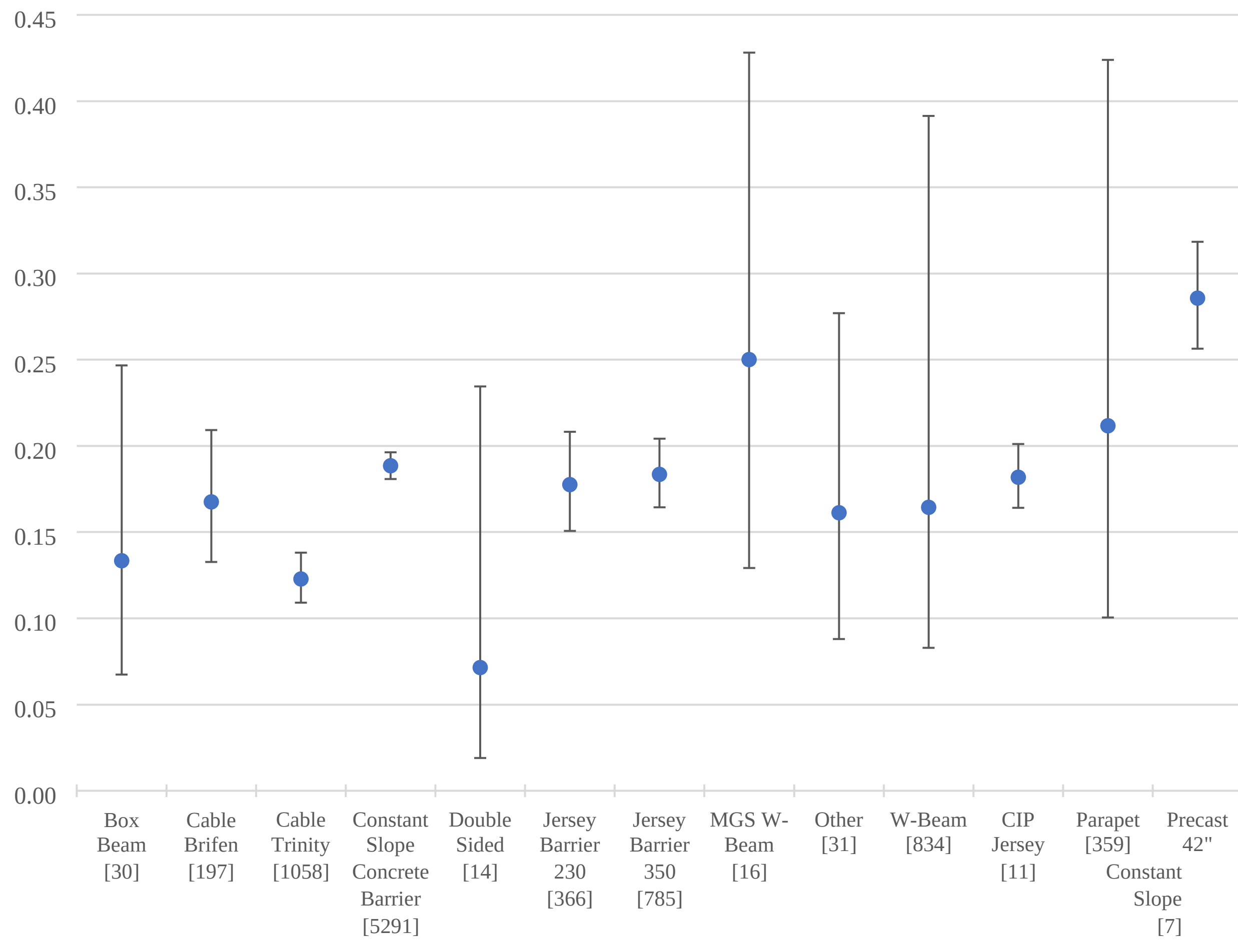



**Figure 15. Proportion of crashes with a secondary crash on the roadway following the interaction with a longitudinal barrier, subdivided by barrier type – full dataset (PAL1).**

## 6.3 CONCLUSIONS

The risk of a crash resulting in a KA outcome when the interaction with the longitudinal barrier is listed as the any harmful event or first and only harmful event (i.e., Evaluation Measure H) is consistent with the values found in other ISPEs of longitudinal barriers. While there is not a national benchmark for occupant risk, a recent meta-analysis of Longitudinal Barrier ISPEs which studied the occupant risk of interaction with various longitudinal barriers found the risk of a serious or fatal crash when the interaction with the longitudinal barrier is the first and only harmful event (FOHE) in the sequence of event is 0.0078 (0.0040, 0.0082) for high tension cable barriers (Carrigan 2019). The same meta-analysis found for FOHEs, there is a risk of a fatal or serious injury of 0.0409 (0.0050, 0.0057) for Jersey Barriers and 0.0284 (0.0047, 0.0055) for strong-post W-beam. This study of longitudinal barriers found lower risks of fatal and serious injuries with longitudinal barriers in Utah.

These results provide added benefit during the updating of current UDOT roadside design and hardware placement/selection procedures.

## 6.4 Next Steps

This ISPE documents the occupant risk of crashes with longitudinal barriers for all state routes in Utah. The next steps to consider in the evaluation of field performance could include:

1. Consider adding fields which capture longitudinal barrier breach and occupant compartment penetration to a future update of the crash report. We expect that this would be a 3-6 year effort to approve changes to the form, update software, and train law enforcement personnel, and would be close to 10 years before there would be useful crash data with which to perform additional analysis.
2. Perform an investigative ISPE with this same dataset where the field BREACH is populated. This may require reviewing individual crash reports and/or crash photos. An ISPE which looks at BREACH will be highly informative with regards to structural adequacy of the barriers used in Utah and could provide support to confirm the suspicion that the MASH Constant Slope barrier performs in the field as a TL4. Estimated time to complete this effort with the existing dataset is one year of full time work (approximately 1,900 hours).
3. Consider continually updating the ISPE dataset assembled under this study by adding crash data as it becomes available. Analysis of this continually collected data could take place on an annual or several year basis to verify similar or better field performance is being achieved. This maintenance-level effort could likely be done with 80-100 hours biennially.
4. Review a sample of in-place longitudinal barriers, focusing on Report 230 and 350 Jersey Barriers and W-Beams to determine if the current installations are typically in crash-ready condition. This effort would be very useful for our development of an asset life cycle estimate as well as liability purposes. This would ideally be integrated with our asset management software to include an electronic field inspection app, and cost/time estimates are entirely dependent on sample size.
5. Consider developing a UDOT routine inspection program for longitudinal barriers to confirm that roadside hardware is and remains in crash-ready condition. This is an expansion of the previous bullet point, and would represent a significant statewide effort. The purpose of such an effort would not be for ISPE analysis, but to enhance UDOT's barrier maintenance efforts.

## REFERENCES

Carrigan, C. E., and M. H. Ray. 2022. *NCHRP Research Report 1010: In-Service Performance Evaluation: Guidelines for the Assembly and Analysis of Data*. Transportation Research Board,Washington, DC.

Carrigan, C. E., and M. H. Ray.

# ISPE SUMMARY OF DATA AND RESULTS SHEETS

**Evaluation F (Rollover)**

ISPE Project ID: BARRIER20210826
Test Level: TL3
CI z Value: 1.44

| | Condition 1 Totals | Condition 1 Dist |
|---|---|---|
| Rollover Field Side | **0** | **0%** |
| Rollover Same Side | **0** | **0%** |
| Rollover - Other | **280** | **4%** |
| None | **7134** | **94%** |
| Unknown | **160** | **2%** |

| | Condition 2 Totals | Condition 2 Dist | Condition 3 Totals | Condition 3 Dist |
|---|---|---|---|---|
| Not Inspected | **0** | **0%** | **7574** | **100%** |
| Inspected | **7574** | **100%** | **0** | **0%** |
| Unknown | **0** | **0%** | **0** | **0%** |

**Performance Assessment Level 1 (PAL1) Distribution and Results of PostHE not limited**

| | K | A | B | C | O | U | Totals | Dist | | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rollover Field Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R1** | **0.1143** | *0.0897* | *0.1445* |
| Rollover Same Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R0** | **0.0100** | *0.0084* | *0.0118* |
| Rollover - Other | 3 | 29 | 73 | 83 | 92 | 0 | **280** | **4%** | **R2** | **0.0378** | *0.0347* | *0.0411* |
| None | 8 | 63 | 456 | 958 | 5647 | 2 | **7134** | **96%** | **ES** | **11.4833** | *8.5601* | *15.4048* |

**of PostHE** ... **PE**

| | K | A | B | C | O | U | Totals | Dist | | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rollover Field Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R1** | **0.1029** | *0.0781* | *0.1344* |
| Rollover Same Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R0** | **0.0078** | *0.0064* | *0.0095* |
| Rollover - Other | 3 | 22 | 61 | 78 | 79 | 0 | **243** | **3%** | **R2** | **0.0339** | *0.0310* | *0.0371* |
| None | 5 | 49 | 435 | 938 | 5494 | 2 | **6923** | **97%** | | | | |

**of PostHE** ... **IIT**

| | K | A | B | C | O | U | Totals | Dist | | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rollover Field Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R1** | **0.1429** | *0.0993* | *0.2012* |
| Rollover Same Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R0** | **0.0123** | *0.0090* | *0.0166* |

| | K | A | B | C | O | U | Totals | Dist | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rollover - Other | 3 | 11 | 27 | 27 | 30 | 0 | **98** | **5%** | **R2 0.0518** | *0.0449* | *0.0596* |
| None | 2 | 20 | 116 | 236 | 1420 | 1 | **1795** | **95%** | | | |

**PAL 4 Distribution and Results of PostHE for TOTAL limited by VEH_TYPE & SPEED_LIMIT**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rollover Field Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R1 0.1250** | *0.0811* | *0.1879* |
| Rollover Same Side | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | **R0 0.0082** | *0.0056* | *0.0120* |
| Rollover - Other | 3 | 7 | 19 | 25 | 26 | 0 | **80** | **4%** | **R2 0.0447** | *0.0382* | *0.0523* |
| None | 1 | 13 | 105 | 226 | 1364 | 1 | **1710** | **96%** | | | |

**Evaluation H (Vehicle Mix) for AHE**

ISPE Project ID: BARRIER20210826
Test Level: TL3
CI z Value: 1.44

| | **Condition 1** | | | **Condition 2** | | **Condition 3** | |
|---|---|---|---|---|---|---|---|
| | **Totals** | **Dist** | | **Totals** | **Dist** | **Totals** | **Dist** |
| Known Veh Type | **9005** | **100%** | Not Inspected | **0** | **0%** | **9005** | **100%** |
| Unknown Veh Type | **0** | **0%** | Inspected | **9005** | **100%** | **0** | **0%** |
| | | | Unknown | **0** | **0%** | **0** | **0%** |

**Performance Assessment Level 1 (PAL1) Distribution and Results of VEH_TYPE and AHE**

| | K | A | B | C | O | U | **Totals** | **Dist** | | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Passenger Car | 7 | 47 | 395 | 742 | 4313 | 0 | **5504** | **61%** | **R2_AHE** | **0.015** | *0.0135* | *0.0172* |
| Pick-Up Truck | 5 | 44 | 242 | 504 | 2387 | 2 | **3184** | **35%** | | | | |
| Single Unit Truck | 0 | 5 | 5 | 5 | 49 | 0 | **64** | **1%** | | | | |
| Tractor Trailer | 3 | 5 | 16 | 20 | 150 | 0 | **194** | **2%** | | | | |
| Motorcycle | 3 | 18 | 24 | 6 | 5 | 0 | **56** | **1%** | | | | |
| Bus | 0 | 0 | 1 | 0 | 2 | 0 | **3** | **0%** | | | | |
| Other | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | | | | |

**PAL2 Distribution and Result limited by VEH_TYPE for AHE**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Passenger Car | 7 | 47 | 395 | 742 | 4313 | 0 | **5504** | **63%** | **R2_AHE 0.0119** | *0.0103* | *0.0136* |
| Pick-Up Truck | 5 | 44 | 242 | 504 | 2387 | 2 | **3184** | **37%** | | | |
| Single Unit Truck | | | | | | | | | | | |
| Tractor Trailer | | | | | | | | | | | |

**PAL3 Distribution and Results of limited by SPEED_LIMIT for AHE**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Passenger Car | 2 | 11 | 107 | 178 | 1032 | 0 | **1330** | **57%** | **R2_AHE 0.0209** | *0.0170* | *0.0256* |
| Pick-Up Truck | 5 | 16 | 66 | 135 | 675 | 1 | **898** | **38%** | | | |
| Single Unit Truck | 0 | 2 | 2 | 2 | 20 | 0 | **26** | **1%** | | | |
| Tractor Trailer | 1 | 1 | 5 | 4 | 48 | 0 | **59** | **3%** | | | |
| Motorcycle | 0 | 11 | 16 | 6 | 2 | 0 | **35** | **1%** | | | |
| Bus | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | | | |
| Other | 0 | 0 | 0 | 0 | 0 | 0 | **0** | **0%** | | | |

**PAL 4 Distribution and Results limited by VEH_TYPE & SPEED_LIMIT for AHE**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Passenger Car | 2 | 11 | 107 | 178 | 1032 | 0 | **1330** | **60%** | **R2_AHE 0.0153** | *0.0119* | *0.0195* |
| Pick-Up Truck | 5 | 16 | 66 | 135 | 675 | 1 | **898** | **40%** | | | |
| Single Unit Truck | | | | | | | | | | | |
| Tractor Trailer | | | | | | | | | | | |

**Evaluation H (Vehicle Mix) Continued for FHE, MHE and FOHE**

**Performance Assessment Level 1 (PAL1) Evaluation H for FHE, MHE & FOHE**

| | K | A | B | C | O | U | **Totals** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|

| | K | A | B | C | O | U | Totals | | | C.I. | C.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Harmful Event | 18 | 120 | 683 | 1277 | 6914 | 2 | **9014** | **R2_FHE** | **0.0153** | *0.0136* | *0.0173* |
| Most Harmful Event | 9 | 101 | 641 | 1242 | 7051 | 2 | **9046** | **R2_MHE** | **0.0122** | *0.0106* | *0.0139* |
| First and Only Harmful Event | 5 | 57 | 419 | 882 | 5324 | 2 | **6689** | **R2_FOHE** | **0.0093** | *0.0077* | *0.0111* |

**PAL2 Distributi n Limited by VE H_TYPE**

| | K | A | B | C | O | U | Totals | | | C.I. | C.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Harmful Event | 12 | 91 | 637 | 1246 | 6700 | 2 | **8688** | **R2_FHE** | **0.0119** | *0.0103* | *0.0136* |
| Most Harmful Event | 6 | 75 | 598 | 1214 | 6833 | 2 | **8728** | **R2_MHE** | **0.0093** | *0.0079* | *0.0109* |
| First and Only Harmful Event | 4 | 44 | 398 | 863 | 5178 | 2 | **6489** | **R2_FOHE** | **0.0074** | *0.0060* | *0.0091* |

**PAL3 Distributio Limited b y SPE D_LIMIT**

| | K | A | B | C | O | U | Totals | | | C.I. | C.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Harmful Event | 8 | 42 | 196 | 325 | 1779 | 1 | **2351** | **R2_FHE** | **0.0213** | *0.0174* | *0.0260* |
| Most Harmful Event | 3 | 35 | 176 | 304 | 1813 | 1 | **2332** | **R2_MHE** | **0.0163** | *0.0129* | *0.0205* |
| First and Only Harmful Event | 1 | 18 | 103 | 210 | 1288 | 1 | **1621** | **R2_FOHE** | **0.0117** | *0.0084* | *0.0162* |

**PAL 4 Distribution Limited by VEH_TYPE & SPEED_LIMIT**

| | K | A | B | C | O | U | Totals | | | C.I. | C.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Harmful Event | 7 | 27 | 173 | 313 | 1707 | 1 | **2228** | **R2_FHE** | **0.0153** | *0.0119* | *0.0195* |
| Most Harmful Event | 2 | 21 | 157 | 292 | 1741 | 1 | **2214** | **R2_MHE** | **0.0104** | *0.0077* | *0.0140* |
| First and Only Harmful Event | 1 | 12 | 92 | 200 | 1236 | 1 | **1542** | **R2_FOHE** | **0.0084** | *0.0057* | *0.0125* |

**Evaluation J (Secondary Impact on Roadside)**

ISPE Project ID: BARRIER20210826

Test Level: TL3

CI z Value: 1.44

| | Condition 1 | | | Condition 2 | | Condition 3 | |
|---|---|---|---|---|---|---|---|
| | **Totals** | **Dist** | | **Totals** | **Dist** | **Totals** | **Dist** |
| Fixed Object | **44** | **1%** | Not Inspected | **0** | **0%** | **7338** | **100%** |
| None | **7134** | **97%** | Inspected | **7338** | **100%** | **0** | **0%** |
| Unknown | **160** | **2%** | Unknown | **0** | **0%** | **0** | **0%** |

**Performance Assessment Level 1 (PAL1) Distribution and Results of PostHE not limited**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fixed Object | 0 | 4 | 9 | 3 | 28 | 0 | **44** | **1%** | **R1 0.0909** | *0.0456* | *0.1730* |
| None | 8 | 63 | 456 | 958 | 5647 | 2 | **7134** | **99%** | **R0 0.0100** | *0.0084* | *0.0118* |
| | | | | | | | | | **R2 0.0061** | *0.0049* | *0.0076* |
| | | | | | | | | | **ES 9.1344** | *4.5033* | *18.5282* |

**PAL2 Distribution and Result of PostHE for limited by VEH_TYPE**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fixed Object | 0 | 4 | 9 | 3 | 26 | 0 | **42** | **1%** | **R1 0.0952** | *0.0478* | *0.1807* |
| None | 5 | 49 | 435 | 938 | 5494 | 2 | **6923** | **99%** | **R0 0.0078** | *0.0064* | *0.0095* |
| | | | | | | | | | **R2 0.0060** | *0.0048* | *0.0075* |

**PAL3 Distribution and Results of PostHE limited by SPEED_LIMIT**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fixed Object | 0 | 0 | 4 | 1 | 14 | 0 | **19** | **1%** | **R1 0.0000** | *0.0000* | *0.0984* |
| None | 2 | 20 | 116 | 236 | 1420 | 1 | **1795** | **99%** | **R0 0.0123** | *0.0090* | *0.0166* |
| | | | | | | | | | **R2 0.0105** | *0.0075* | *0.0145* |

**PAL4 Distribution and Results of BREAK for PostHE limited by VEH_TYPE & SPEED_LIMIT**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fixed Object | 0 | 0 | 4 | 1 | 13 | 0 | **18** | **1%** | **R1 0.0000** | *0.0000* | *0.1033* |
| None | 1 | 13 | 105 | 226 | 1364 | 1 | **1710** | **99%** | **R0 0.0082** | *0.0056* | *0.0120* |
| | | | | | | | | | **R2 0.0104** | *0.0074* | *0.0146* |

**Evaluation K (Secondary Impact on Road)**

ISPE Project ID: BARRIER20210826
Test Level: TL3
CI z Value: 1.44

| | Conditio[n] Totals | Dist |
|---|---|---|
| Impact with Vehicle | 340 | 4% |
| Impact with Peds | 2 | 0% |
| Secondary Impact with Safety Feature | 1259 | 14% |
| None | 7416 | 81% |
| Unknown | 166 | 2% |

| | Condition 2 Totals | Dist | Condition 3 Totals | Dist |
|---|---|---|---|---|
| Not Inspected | 0 | 0% | 9183 | 100% |
| Inspected | 9183 | 100% | 0 | 0% |
| Unknown | 0 | 0% | 0 | 0% |

**Performance Assessment Level 1 (PAL1) Distribution and Results of PostHE not limited**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact with Vehicle | 2 | 10 | 53 | 69 | 206 | 0 | **340** | **4%** | **R1 0.0219** | *0.0172* | *0.0278* |
| Impact with Peds | 0 | 0 | 0 | 1 | 1 | 0 | **2** | **0%** | **R0 0.0113** | *0.0097* | *0.0132* |
| Secondary Impact with Safety Feature | 7 | 16 | 118 | 197 | 921 | 0 | **1259** | **14%** | **R2 0.1776** | *0.1718* | *0.1834* |
| None | 13 | 71 | 484 | 1012 | 5832 | 4 | **7416** | **82%** | **ES 1.9300** | *1.4486* | *2.5716* |

**›f PostHE f** **PE**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact with Vehicle | 2 | 9 | 53 | 66 | 201 | 0 | **331** | **4%** | **R1 0.0186** | *0.0142* | *0.0241* |
| Impact with Peds | 0 | 0 | 0 | 1 | 1 | 0 | **2** | **0%** | **R0 0.0092** | *0.0077* | *0.0109* |
| Secondary Impact with Safety Feature | 5 | 13 | 113 | 195 | 904 | 0 | **1230** | **14%** | **R2 0.1786** | *0.1728* | *0.1846* |
| None | 9 | 57 | 461 | 990 | 5668 | 3 | **7188** | **82%** | | | |

**of PostHE** **IIT**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact with Vehicle | 1 | 4 | 7 | 12 | 64 | 0 | **88** | **4%** | **R1 0.0310** | *0.0209* | *0.0456* |
| Impact with Peds | 0 | 0 | 0 | 1 | 0 | 0 | **1** | **0%** | **R0 0.0134** | *0.0100* | *0.0178* |
| Secondary Impact with Safety Feature | 3 | 5 | 35 | 45 | 243 | 0 | **331** | **14%** | **R2 0.1834** | *0.1720* | *0.1953* |
| None | 3 | 22 | 126 | 247 | 1470 | 2 | **1870** | **82%** | | | |

**PAL 4 Distribution and Results of PostHE for TOTAL limited by VEH_TYPE & SPEED_LIMIT**

| | K | A | B | C | O | U | **Totals** | **Dist** | | *C.I.* | *C.I.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact with Vehicle | 1 | 3 | 7 | 10 | 63 | 0 | **84** | **4%** | **R1 0.0269** | *0.0175* | *0.0410* |
| Impact with Peds | 0 | 0 | 0 | 1 | 0 | 0 | **1** | **0%** | **R0 0.0096** | *0.0068* | *0.0135* |
| Secondary Impact with Safety Feature | 3 | 4 | 34 | 45 | 238 | 0 | **324** | **15%** | **R2 0.1869** | *0.1752* | *0.1992* |
| None | 2 | 15 | 114 | 237 | 1410 | 1 | **1779** | **81%** | | | |

**NAME**

**Evaluation F (Rollover) for Each Level of NAME**

ISPE Project ID: 826 Test Level: CI z Value:

BARRIER20210

TL3

1.44

| NAME | PAL1$_F$, R2 | PAL2$_F$, R2 | PAL3$_F$, R2 | PAL4$_F$, R2 |
|---|---|---|---|---|
| | 0.0400 (0.0106,0.1399) | 0.0435 (0.0115,0.1510) | 0.0000 (0.0000,0.1717) | 0.0000 (0.0000,0.1717) |
| a | | | | |
| b | | | | |
| c | 0.0301 (0.0161,0.0558) | 0.0325 (0.0173,0.0600) | 0.0270 (0.0071,0.0971) | 0.0278 (0.0073,0.0997) |
| d | 0.0420 (0.0335,0.0525) | 0.0401 (0.0317,0.0506) | 0.0320 (0.0159,0.0634) | 0.0325 (0.0162,0.0644) |
| e | 0.0283 (0.0248,0.0322) | 0.0250 (0.0218,0.0287) | 0.0468 (0.0369,0.0592) | 0.0376 (0.0286,0.0492) |
| f | | | | |
| g | 0.0714 (0.0190,0.2345) | 0.0000 (0.0000,0.1473) | 0.1429 (0.0383,0.4106) | 0.0000 (0.0000,0.2568) |
| h | 0.0669 (0.0493,0.0902) | 0.0658 (0.0481,0.0893) | 0.0724 (0.0475,0.1087) | 0.0694 (0.0447,0.1065) |
| i | 0.0452 (0.0348,0.0585) | 0.0422 (0.0320,0.0555) | 0.0379 (0.0252,0.0565) | 0.0368 (0.0240,0.0559) |
| j | 0.0000 (0.0000,0.1473) | 0.0000 (0.0000,0.1586) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| k | 0.0000 (0.0000,0.0739) | 0.0000 (0.0000,0.0827) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) |
| l | | | | |
| m | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| n | 0.0714 (0.0589,0.0864) | 0.0601 (0.0481,0.0747) | 0.0749 (0.0578,0.0966) | 0.0638 (0.0473,0.0854) |
| p | 1.0000 (0.3254,1.0000) | 1.0000 (0.3254,1.0000) | 1.0000 (0.3254,1.0000) | 1.0000 (0.3254,1.0000) |
| q | 0.1000 (0.0267,0.3107) | 0.1000 (0.0267,0.3107) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| r | 0.0324 (0.0202,0.0515) | 0.0300 (0.0182,0.0490) | 0.0476 (0.0237,0.0933) | 0.0482 (0.0240,0.0944) |
| s | 0.1250 (0.0335,0.3709) | 0.1250 (0.0335,0.3709) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| x | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.4087) |

y z

99

x (0.0000,0.4087) (0.0000,0.4087)

y z

99

**NAME**

**Evaluation H (Vehicle Mix) for AHE and Each Level of NAME**

ISPE Project ID: 826 Test Level: CI z Value:

BARRIER20210

TL3

1.44

| | **PAL1$_H$, R2_AHE** | **PAL2$_H$, R2_AHE** | **PAL3$_H$, R2_AHE** | **PAL4$_H$, R2_AHE** |
|---|---|---|---|---|
| | 0.0000 (0.0000,0.0545) | 0.0000 (0.0000,0.0591) | 0.0000 (0.0000,0.1215) | 0.0000 (0.0000,0.1290) |
| a | | | | |
| b | | | | |
| c | 0.0173 (0.0086,0.0346) | 0.0142 (0.0063,0.0314) | 0.0364 (0.0138,0.0927) | 0.0377 (0.0143,0.0960) |
| d | 0.0199 (0.0149,0.0266) | 0.0191 (0.0141,0.0259) | 0.0368 (0.0207,0.0645) | 0.0373 (0.0210,0.0653) |
| e | 0.0126 (0.0106,0.0150) | 0.0105 (0.0086,0.0127) | 0.0119 (0.0079,0.0180) | 0.0094 (0.0058,0.0150) |
| f | | | | |
| g | 0.0625 (0.0166,0.2088) | 0.0000 (0.0000,0.1376) | 0.1429 (0.0383,0.4106) | 0.0000 (0.0000,0.2568) |
| h | 0.0297 (0.0200,0.0438) | 0.0193 (0.0117,0.0317) | 0.0413 (0.0258,0.0654) | 0.0246 (0.0131,0.0457) |
| i | 0.0285 (0.0213,0.0380) | 0.0201 (0.0141,0.0286) | 0.0267 (0.0174,0.0407) | 0.0181 (0.0106,0.0307) |
| j | 0.0556 (0.0147,0.1882) | 0.0000 (0.0000,0.1147) | 0.1000 (0.0267,0.3107) | 0.0000 (0.0000,0.1873) |
| k | 0.0000 (0.0000,0.0591) | 0.0000 (0.0000,0.0647) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.3414) |
| l | | | | |
| m | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| n | 0.0305 (0.0237,0.0391) | 0.0204 (0.0147,0.0283) | 0.0397 (0.0294,0.0535) | 0.0207 (0.0132,0.0324) |
| p | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) |
| q | 0.0625 (0.0166,0.2088) | 0.0625 (0.0166,0.2088) | 0.1111 (0.0297,0.3382) | 0.1111 (0.0297,0.3382) |
| r | 0.0161 (0.0091,0.0286) | 0.0085 (0.0038,0.0189) | 0.0000 (0.0000,0.0179) | 0.0000 (0.0000,0.0180) |
| s | 0.1111 (0.0297,0.3382) | 0.1111 (0.0297,0.3382) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2058) | 0.0000 | 0.0000 |

**NAME**

**Evaluation H (Vehicle Mix) for FHE and Each Level of NAME**

ISPE Project ID: BARRIER20210

826 Test Level: TL3

CI z Value: 1.44

| | **$PAL1_H$, R2_FHE** | **$PAL2_H$, R2_FHE** | **$PAL3_H$, R2_FHE** | **$PAL4_H$, R2_FHE** |
|---|---|---|---|---|
| a | 0.0000 (0.0000,0.0609) | 0.0000 (0.0000,0.0667) | 0.0000 (0.0000,0.1290) | 0.0000 (0.0000,0.1376) |
| b | | | | |
| c | 0.0098 (0.0037,0.0257) | 0.0053 (0.0014,0.0199) | 0.0222 (0.0059,0.0807) | 0.0227 (0.0060,0.0824) |
| d | 0.0136 (0.0094,0.0196) | 0.0122 (0.0082,0.0181) | 0.0267 (0.0132,0.0530) | 0.0270 (0.0134,0.0537) |
| e | 0.0119 (0.0099,0.0143) | 0.0100 (0.0082,0.0122) | 0.0107 (0.0068,0.0168) | 0.0089 (0.0054,0.0147) |
| f | | | | |
| g | 0.0667 (0.0177,0.2209) | 0.0000 (0.0000,0.1376) | 0.1429 (0.0383,0.4106) | 0.0000 (0.0000,0.2568) |
| h | 0.0278 (0.0182,0.0425) | 0.0184 (0.0108,0.0312) | 0.0412 (0.0251,0.0671) | 0.0272 (0.0145,0.0504) |
| i | 0.0241 (0.0174,0.0334) | 0.0186 (0.0127,0.0271) | 0.0259 (0.0166,0.0403) | 0.0191 (0.0112,0.0325) |
| j | 0.0000 (0.0000,0.1376) | 0.0000 (0.0000,0.1473) | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) |
| k | 0.0000 (0.0000,0.0627) | 0.0000 (0.0000,0.0690) | 0.0000 (0.0000,0.3414) | 0.0000 (0.0000,0.4087) |
| l | | | | |
| m | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| n | 0.0228 (0.0167,0.0310) | 0.0155 (0.0104,0.0229) | 0.0307 (0.0213,0.0441) | 0.0183 (0.0111,0.0300) |
| p | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| q | 0.0714 (0.0190,0.2345) | 0.0714 (0.0190,0.2345) | 0.1250 (0.0335,0.3709) | 0.1250 (0.0335,0.3709) |
| r | 0.0172 (0.0097,0.0304) | 0.0090 (0.0040,0.0200) | 0.0000 (0.0000,0.0199) | 0.0000 (0.0000,0.0201) |
| s | 0.1250 (0.0335,0.3709) | 0.1250 (0.0335,0.3709) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2058) | 0.0000 | 0.0000 |

**NAME**

**Evaluation H (Vehicle Mix) for MHE and Each Level of NAME**

| ISPE Project | BARRIER20210 |
|---|---|
| ID: | 826 |
| Test Level: | TL3 |
| CI z Value: | 1.44 |

| | **$PAL1_H$, R2_MHE** | **$PAL2_H$, R2_MHE** | **$PAL3_H$, R2_MHE** | **$PAL4_H$, R2_MHE** |
|---|---|---|---|---|
| | 0.0000 (0.0000,0.0575) | 0.0000 (0.0000,0.0627) | 0.0000 (0.0000,0.1290) | 0.0000 (0.0000,0.1376) |
| a | | | | |
| b | | | | |
| c | 0.0091 (0.0034,0.0240) | 0.0050 (0.0013,0.0188) | 0.0192 (0.0051,0.0703) | 0.0200 (0.0053,0.0730) |
| d | 0.0098 (0.0064,0.0150) | 0.0101 (0.0066,0.0155) | 0.0255 (0.0126,0.0507) | 0.0258 (0.0128,0.0513) |
| e | 0.0101 (0.0083,0.0123) | 0.0084 (0.0067,0.0104) | 0.0086 (0.0052,0.0142) | 0.0056 (0.0030,0.0105) |
| f | | | | |
| g | 0.0000 (0.0000,0.1290) | 0.0000 (0.0000,0.1376) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| h | 0.0176 (0.0103,0.0300) | 0.0105 (0.0052,0.0210) | 0.0259 (0.0138,0.0481) | 0.0162 (0.0072,0.0359) |
| i | 0.0181 (0.0124,0.0264) | 0.0148 (0.0097,0.0227) | 0.0160 (0.0090,0.0284) | 0.0112 (0.0056,0.0226) |
| j | 0.0000 (0.0000,0.1147) | 0.0000 (0.0000,0.1215) | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2058) |
| k | 0.0000 (0.0000,0.0627) | 0.0000 (0.0000,0.0690) | 0.0000 (0.0000,0.3414) | 0.0000 (0.0000,0.4087) |
| l | | | | |
| m | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| | 0.0207 (0.0149,0.0286) | 0.0120 (0.0076,0.0188) | 0.0274 (0.0185,0.0405) | 0.0118 (0.0063,0.0221) |
| n | | | | |
| p | | | | |
| q | 0.0714 (0.0190,0.2345) | 0.0714 (0.0190,0.2345) | 0.1111 (0.0297,0.3382) | 0.1111 (0.0297,0.3382) |
| r | 0.0116 (0.0057,0.0232) | 0.0030 (0.0008,0.0114) | 0.0000 (0.0000,0.0199) | 0.0000 (0.0000,0.0201) |
| s | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) | 0.0000 | 0.0000 |

**Evaluation H (Vehicle Mix) for FOHE and Each Level of NAME**

ISPE Project ID: BARRIER20210 826 Test Level: TL3 CI z Value: 1.44

| | $PAL1_H$, R2_FOHE | $PAL2_H$, R2_FOHE | $PAL3_H$, R2_FOHE | $PAL4_H$, R2_FOHE |
|---|---|---|---|---|
| | 0.0000 (0.0000,0.0899) | 0.0000 (0.0000,0.0984) | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.1873) |
| a | | | | |
| b | | | | |
| c | 0.0000 (0.0000,0.0141) | 0.0000 (0.0000,0.0154) | 0.0000 (0.0000,0.0575) | 0.0000 (0.0000,0.0591) |
| d | 0.0024 (0.0009,0.0063) | 0.0024 (0.0009,0.0065) | 0.0000 (0.0000,0.0174) | 0.0000 (0.0000,0.0177) |
| e | 0.0089 (0.0070,0.0114) | 0.0078 (0.0060,0.0101) | 0.0078 (0.0041,0.0146) | 0.0080 (0.0043,0.0151) |
| f | | | | |
| g | 0.0000 (0.0000,0.1586) | 0.0000 (0.0000,0.1717) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| h | 0.0149 (0.0074,0.0299) | 0.0077 (0.0029,0.0203) | 0.0317 (0.0158,0.0629) | 0.0167 (0.0063,0.0435) |
| i | 0.0110 (0.0062,0.0195) | 0.0095 (0.0051,0.0179) | 0.0077 (0.0029,0.0203) | 0.0041 (0.0011,0.0154) |
| j | 0.0000 (0.0000,0.1586) | 0.0000 (0.0000,0.1717) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| k | 0.0000 (0.0000,0.0795) | 0.0000 (0.0000,0.0899) | 0.0000 (0.0000,0.6746) | |
| l | | | | |
| m | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| | 0.0188 (0.0125,0.0283) | 0.0136 (0.0082,0.0224) | 0.0208 (0.0122,0.0352) | 0.0132 (0.0065,0.0265) |
| n | | | | |
| p | | | | |
| q | 0.1111 (0.0297,0.3382) | 0.1111 (0.0297,0.3382) | 0.1667 (0.0449,0.4596) | 0.1667 (0.0449,0.4596) |
| r | 0.0082 (0.0031,0.0216) | 0.0000 (0.0000,0.0087) | 0.0000 (0.0000,0.0288) | 0.0000 (0.0000,0.0292) |
| s | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| | 0.0000 (0.0000,0.3414) | 0.0000 (0.0000,0.3414) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |

**Evaluation J (Secondary Impact on Roadside) for Each Level of NAME**

ISPE Project ID: BARRIER20210
Test Level: TL3
CI z Value: 1.44

| NAME | $PAL1_J$, R2 | $PAL2_J$, R2 | $PAL3_J$, R2 | $PAL4_J$, R2 |
|---|---|---|---|---|
| a | 0.0000 (0.0000,0.0795) | 0.0000 (0.0000,0.0861) | 0.0000 (0.0000,0.1717) | 0.0000 (0.0000,0.1717) |
| b | | | | |
| c | 0.0123 (0.0046,0.0322) | 0.0132 (0.0050,0.0347) | 0.0270 (0.0071,0.0971) | 0.0278 (0.0073,0.0997) |
| d | 0.0045 (0.0022,0.0090) | 0.0046 (0.0023,0.0093) | 0.0000 (0.0000,0.0168) | 0.0000 (0.0000,0.0171) |
| e | 0.0034 (0.0023,0.0050) | 0.0034 (0.0023,0.0050) | 0.0014 (0.0004,0.0053) | 0.0014 (0.0004,0.0055) |
| f | | | | |
| g | 0.0000 (0.0000,0.1376) | 0.0000 (0.0000,0.1473) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| h | 0.0201 (0.0113,0.0355) | 0.0139 (0.0069,0.0279) | 0.0342 (0.0183,0.0633) | 0.0290 (0.0144,0.0575) |
| i | 0.0016 (0.0004,0.0062) | 0.0017 (0.0004,0.0064) | 0.0000 (0.0000,0.0068) | 0.0000 (0.0000,0.0071) |
| j | 0.0000 (0.0000,0.1473) | 0.0000 (0.0000,0.1586) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| k | 0.0000 (0.0000,0.0739) | 0.0000 (0.0000,0.0827) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) |
| l | | | | |
| m | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2058) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| n | 0.0203 (0.0139,0.0296) | 0.0219 (0.0150,0.0319) | 0.0272 (0.0174,0.0423) | 0.0300 (0.0192,0.0467) |
| p | | | | |
| q | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.1873) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| r | 0.0110 (0.0049,0.0245) | 0.0115 (0.0051,0.0255) | 0.0244 (0.0092,0.0630) | 0.0247 (0.0093,0.0638) |
| s | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| x | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.4087) |

y z

99

**Evaluation K (Secondary Impact on Road) for Each Level of NAME**

ISPE Project BARRIER20210 ID: 826 Test Level: TL3 CI z Value: 1.44

| NAME | $PAL1_K$, R2 | $PAL2_K$, R2 | $PAL3_K$, R2 | $PAL4_K$, R2 |
|---|---|---|---|---|
| | 0.1333 (0.0674,0.2467) | 0.1429 (0.0724,0.2626) | 0.1429 (0.0551,0.3228) | 0.1429 (0.0551,0.3228) |
| a | | | | |
| b | | | | |
| c | 0.1675 (0.1327,0.2092) | 0.1648 (0.1291,0.2082) | 0.1220 (0.0661,0.2142) | 0.1250 (0.0678,0.2192) |
| d | 0.1229 (0.1091,0.1381) | 0.1222 (0.1082,0.1377) | 0.1284 (0.0939,0.1732) | 0.1241 (0.0899,0.1689) |
| e | 0.1884 (0.1808,0.1963) | 0.1894 (0.1817,0.1973) | 0.2195 (0.2008,0.2395) | 0.2216 (0.2026,0.2419) |
| f | | | | |
| g | 0.0714 (0.0190,0.2345) | 0.0769 (0.0204,0.2498) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| h | 0.1776 (0.1507,0.2082) | 0.1798 (0.1523,0.2109) | 0.1609 (0.1248,0.2050) | 0.1677 (0.1302,0.2133) |
| i | 0.1834 (0.1644,0.2042) | 0.1865 (0.1670,0.2078) | 0.1749 (0.1488,0.2046) | 0.1796 (0.1524,0.2104) |
| j | 0.2500 (0.1292,0.4281) | 0.2667 (0.1383,0.4517) | 0.3333 (0.1582,0.5709) | 0.3333 (0.1582,0.5709) |
| k | 0.1613 (0.0880,0.2770) | 0.1786 (0.0978,0.3037) | 0.3333 (0.0925,0.7104) | 0.5000 (0.1433,0.8567) |
| l | | | | |
| m | 0.1111 (0.0297,0.3382) | 0.1111 (0.0297,0.3382) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| | 0.1643 (0.1466,0.1836) | 0.1623 (0.1441,0.1824) | 0.1519 (0.1289,0.1782) | 0.1575 (0.1330,0.1855) |
| n | | | | |
| p | | | | |
| q | 0.1818 (0.0706,0.3940) | 0.1818 (0.0706,0.3940) | 0.2500 (0.0984,0.5045) | 0.2500 (0.0984,0.5045) |
| r | 0.2117 (0.1824,0.2444) | 0.2155 (0.1855,0.2489) | 0.1700 (0.1227,0.2307) | 0.1717 (0.1240,0.2329) |
| s | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| x | 0.2857 (0.1132,0.5561) | 0.2857 (0.1132,0.5561) | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.4087) |

y z

99

**Evaluation K (Secondary Impact on Road) for Each Level of NAME**

ISPE Project ID: BARRIER20210 826 Test Level: TL3 CI z Value: 1.44

| NAME | $PAL1_K$, R2 | $PAL2_K$, R2 | $PAL3_K$, R2 | $PAL4_K$, R2 |
|---|---|---|---|---|
| | 0.1333 (0.0674,0.2467) | 0.1429 (0.0724,0.2626) | 0.1429 (0.0551,0.3228) | 0.1429 (0.0551,0.3228) |
| a | | | | |
| b | | | | |
| c | 0.1675 (0.1327,0.2092) | 0.1648 (0.1291,0.2082) | 0.1220 (0.0661,0.2142) | 0.1250 (0.0678,0.2192) |
| d | 0.1229 (0.1091,0.1381) | 0.1222 (0.1082,0.1377) | 0.1284 (0.0939,0.1732) | 0.1241 (0.0899,0.1689) |
| e | 0.1884 (0.1808,0.1963) | 0.1894 (0.1817,0.1973) | 0.2195 (0.2008,0.2395) | 0.2216 (0.2026,0.2419) |
| f | | | | |
| g | 0.0714 (0.0190,0.2345) | 0.0769 (0.0204,0.2498) | 0.0000 (0.0000,0.2568) | 0.0000 (0.0000,0.2568) |
| h | 0.1776 (0.1507,0.2082) | 0.1798 (0.1523,0.2109) | 0.1609 (0.1248,0.2050) | 0.1677 (0.1302,0.2133) |
| i | 0.1834 (0.1644,0.2042) | 0.1865 (0.1670,0.2078) | 0.1749 (0.1488,0.2046) | 0.1796 (0.1524,0.2104) |
| j | 0.2500 (0.1292,0.4281) | 0.2667 (0.1383,0.4517) | 0.3333 (0.1582,0.5709) | 0.3333 (0.1582,0.5709) |
| k | 0.1613 (0.0880,0.2770) | 0.1786 (0.0978,0.3037) | 0.3333 (0.0925,0.7104) | 0.5000 (0.1433,0.8567) |
| l | | | | |
| m | 0.1111 (0.0297,0.3382) | 0.1111 (0.0297,0.3382) | 0.0000 (0.0000,0.2931) | 0.0000 (0.0000,0.2931) |
| | 0.1643 (0.1466,0.1836) | 0.1623 (0.1441,0.1824) | 0.1519 (0.1289,0.1782) | 0.1575 (0.1330,0.1855) |
| n | | | | |
| p | | | | |
| q | 0.1818 (0.0706,0.3940) | 0.1818 (0.0706,0.3940) | 0.2500 (0.0984,0.5045) | 0.2500 (0.0984,0.5045) |
| r | 0.2117 (0.1824,0.2444) | 0.2155 (0.1855,0.2489) | 0.1700 (0.1227,0.2307) | 0.1717 (0.1240,0.2329) |
| s | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.2285) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) |
| t | | | | |
| u | | | | |
| v | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.5090) | 0.0000 (0.0000,0.6746) | 0.0000 (0.0000,0.6746) |
| w | | | | |
| x | 0.2857 (0.1132,0.5561) | 0.2857 (0.1132,0.5561) | 0.0000 (0.0000,0.4087) | 0.0000 (0.0000,0.4087) |

y z

99