In-Service Performance Evaluation of Longitudinal Barrier to Study Occupant Risk

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Submitted July 20, 2018
Resubmitted March 22, 2019

Word count
Number of words in abstract, text, and references = 5,470
Figures & Tables: 7 @ 250 words each = 1,750
Total number of words = 7,220

Paper prepared for consideration of presentation and publication at the 98th Annual Meeting of the Transportation Research Board, January 2019
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ABSTRACT

Roadside safety features generally demonstrate successful performance through crash testing, which provides an assessment of occupant risk, post-impact trajectory, and structural adequacy. It has been long recognized that the performance of safety features cannot be assessed by crash testing alone and should be followed by in-service performance evaluations (ISPEs).

The primary objective of any ISPE is to evaluate occupant risk under real-world field conditions. A secondary objective may be to determine which factors influence performance (e.g., maintenance, installation, hardware design, etc.). This paper assembled available data from both the literature and the states of Ohio, Pennsylvania, and Tennessee to demonstrate the various data sources readily available to answer the primary ISPE question of occupant risk. While much more can be done with the data available from each of these states, this paper is limited to a review of occupant risk. This paper has shown that there is a very large amount of data very easily accessible for an ISPE. While some states maintain an inventory of safety features, some do not, and additional information was needed to identify the feature and proceed with the evaluation.
INTRODUCTION

Roadside safety features such as longitudinal barriers, sign supports, guardrail terminals, and work zone devices generally demonstrate successful performance according to the currently adopted crash test and evaluation criteria to be eligible for federal-aid funding on the National Highway System and/or to be put on many State’s qualified products list. This crash test laboratory performance evaluation of safety features during the development phase provides an assessment of occupant risk, post-impact trajectory, and structural adequacy using carefully monitored crash tests conducted at specific impact speeds and with specific vehicle types. The safety feature is installed carefully in a controlled environment where the installers are not subjected to a work zone with live traffic in the adjacent lanes. The safety feature is checked for conformance to the design specifications; the approach and run-out areas are flat and clear of obstacles and the impact conditions are carefully controlled. These crash tests are designed not only to evaluate performance but also to ensure repeatability among crash testing laboratories.

During crash test evaluations, there is no question that the safety feature is properly constructed and in pristine crash-ready condition. The effect of construction and maintenance practices, environmental effects (e.g., time in service, weather, etc.), or prior crashes are not assessed in a full-scale crash test because the safety feature was in ideal condition. The effects of the possible variety of site conditions are not assessed during crash testing. The hardware designer is asking a single question in a crash test: given that a crash occurs, will the new, properly constructed crash-ready safety feature installed on a controlled site meet the Manual for Assessing Safety Hardware (MASH) performance criteria? While this is an important evaluation step, it clearly may or may not translate into desirable field performance. Conversely, poor crash testing results may not indicate poor field performance.

It has been long recognized that the performance of safety features cannot be assessed by crash testing only. While crash testing is necessary, it does not indicate that a feature will have satisfactory performance under real-world conditions nor does it take the place of satisfactory field performance. While a single poor outcome in a crash test has justified not passing that test and the continued design and development of that safety feature, the same is not true for in-service evaluations (ISPEs). ISPEs are a review of more than a handful of crashes. Poor outcome in one field-observed crash does not unilaterally justify failure.

The objective of an ISPE is to assess the crashworthiness of safety features under field conditions. The primary objective of any ISPE is to determine how well the safety treatment is performing in the field under real-world field conditions. The secondary objective is to determine which factors influence performance (e.g., maintenance, installation, hardware design, etc.). There are a number of possible topics which influence the field performance of safety treatments and could be considered in any ISPE, but an ISPE need not consider each. For example:

- Is the safety feature achieving the desired performance?
- Is the performance of the safety treatment degraded by weather, age, climate, or other environmental conditions?
- Is the safety treatment installed correctly and does improper installation cause any particular performance problems?
- Do the site constraints limit the safety feature beyond those limitations assumed by crash testing and do the additional limitations cause any particular performance problems?
- Does a safety feature meet the field performance standard despite unacceptable crash test performance such that the safety feature should continue to be considered crash worthy?
The first and primary question should be addressed prior to considering any additional
evaluations: “Is the safety feature achieving the desired performance?” If the answer is yes,
there is no need to continue evaluating that safety feature. If the answer is no, then continued
evaluation would provide further insight.

This paper assembled available data from both the literature and the states of Ohio,
Pennsylvania, and Tennessee to demonstrate the variety data available to answer the primary
ISPE question of occupant risk. While much more can be done with the data available from each
of these states, this paper is limited to a review of occupant risk. As discussed at the close of this
paper, this preliminary analysis will inform further analysis regarding the influence of posted
speed limit and vehicle type as well as post-impact vehicle trajectory (i.e., rollover after impact,
secondary crash, etc.) and structural adequacy.

METHOD

Recall, when conducting a crash test, the hardware designer asks: given that a crash
occurs, will the new, properly constructed crash-ready safety feature installed on a controlled site
meet the MASH performance criteria? Similarly, when conducting an ISPE, the engineer asks:
given a crash with a safety feature under evaluation, is the safety feature achieving the desired
performance? Performance is measured through achieving the goal of roadside safety, reducing
occupant risk. A crash database is therefore a minimum requirement for conducting an ISPE.

Accepting the that first and primary question should be addressed prior to considering
any additional evaluations focuses attention on available data to address that question: “Is the
safety feature achieving the desired performance?” With the understanding that crash data is
needed and the ISPE is intent on occupant risk during a crash with a particular safety feature,
identification of the safety features at some level is necessary. The more precise the form of
identification, the more informative the study. There are many means by which to achieve this
identification. This paper demonstrates several below. After the crash data is obtained and the
hardware identified, the assessment of occupant risk takes place. Therefore, to address this
fundamental first (and possible only) question of and ISPE, these steps were taken:

1. Obtain available crash databases and isolate the crashes with the safety feature under
   evaluation (e.g., longitudinal barriers)
2. Determine if the jurisdiction has an inventory or other means (e.g., construction
   records, insurance records, etc.) to identify the safety features involved in crashes. If
   not, identify through photo logs or google earth. Alternatively, the safety feature may
   be identified using the crash data.
3. Assess occupant risk.
4. If performance does not meet the desirable performance outcome adopted by the
   agency, conduct a more detailed evaluation.

These steps are discussed below. Please note that desirable performance outcomes are currently
being researched under NCHRP 22-33. (2) Adopting such a performance outcome is a policy
decision made by the adopting agency.

CRASH DATA (STEP 1)

Crash databases were made available by the states of Ohio, Pennsylvania, and Tennessee.
Crashes which penetrate, rollover, or vault the feature or crashes that either rollover after
redirection or experience a second crash after redirection were excluded from this study such that
the result will represent the severity of a single event in the overall crash sequence. This ensures
that the occupant risk can be confidently associated to the collision with the feature under
evaluation. The crashes coded as a single vehicle (SV) first and only harmful event (FOHE)
longitudinal barrier (LB) crash were isolated from each data set.

The Ohio HSIS data for 2003 through 2013 were used. SV FOHE LB crashes were
identified using harmful events 1-4, First Harmful Event (FHE), and the “numvehs” fields in the
crash data. Crashes were considered to be SV FOHE LB if the “numvehs” field equaled 1, the
FHE was identified as either code 30 (guardrail face) or 32 (median barrier), and the other events
were either blank or having codes 8 (ran off road right), 9 (ran off road left), or 10 (cross
median/centerline).

The Pennsylvania DOT crash database for 2010 through 2015 was used. SV FOHE LB
crashes were identified using harmful events 1-4, First Harmful Event, and the
“TOTAL_UNITS” fields. Crashes were considered SV FOHE LB crashes if: “TOTAL_UNITS”
= 1, First Harmful Event =25 (hit guard or guide rail), 28 (hit concrete or longitudinal barrier),
and no harmful event (blank entry) in the harmful event immediately succeeding the first harmful
event.

The Tennessee DOT crash database for 2012 through 2016 was used. SV FOHE LB
-crashes were identified using event sequence 1-10, First Harmful Event, and “Total Veh” fields.
Crashes were considered SV FOHE LB crashes if: ”Total Veh” = 1, First Harmful Event =
"Concrete Traffic Barrier", "Guardrail Face", or "Cable Barrier", and the event immediately
succeeding the first harmful event is either blank or is "Cross Center Line", "Cross Median",
"Ran Off Road-Left", "Ran Off Road-Right", immediately followed by a blank entry in the next
event sequence. Unlike some states, Tennessee has a First Harmful Event field separate from the
event sequences. The police report has an entry for this and is listed as “First Harmful Event for
the Crash”. (3) It is implied that this field represents the first harmful event in the crash, not
simply the first event. There were zero crashes that had "Cross Center Line", "Cross Median",
"Ran Off Road-Left", or "Ran Off Road-Right" listed as the First Harmful Event, and some
instances where one of these entries were in the Event Sequence 1, followed by "Concrete
Traffic Barrier", "Guardrail Face", or "Cable Barrier" in Event Sequence 2, with one of the
barrier types being listed as the First Harmful Event.

IDENTIFYING THE SAFETY FEATURES (STEP 2)

Ohio

The ODOT hardware inventory was merged with the SV FOHE LB crashes using Route,
Milepost, and roadside location of hardware. The event codes 8 (ran off road right), 9 (ran off
road left), and 10 (cross median/centerline) were used in conjunction with the “veh_n_from”
(direction vehicle was traveling from) and “veh_n_to” (direction vehicle was traveling to) fields
to determine the location and type of hardware involved.

A total of 31,540 SV FOHE LB crashes were found during the study period in Ohio.
These crashes were then linked to the roadside hardware inventory for each identified
longitudinal barrier. Ohio identifies the following longitudinal barriers within the inventory:

- Guardrail
- 32” Jersey Barrier
- 42”+ Jersey Barrier
- Single Slope (i.e., either 42” or 57”)

(3) It is implied that this field represents the first harmful event in the crash, not simply the first event. There were zero crashes that had "Cross Center Line", "Cross Median", "Ran Off Road-Left", or "Ran Off Road-Right" listed as the First Harmful Event, and some instances where one of these entries were in the Event Sequence 1, followed by "Concrete Traffic Barrier", "Guardrail Face", or "Cable Barrier" in Event Sequence 2, with one of the barrier types being listed as the First Harmful Event.
• Propriety cable barriers (i.e., Brifen’s wire rope safety fence (WRSF), Trinity’s Cable Safety System (CASS), Gibraltar’s Cable Barrier System, and Nucor Steel Marion’s Nu-Cable Barrier)

• Other

A review of the Ohio DOT guardrail standard drawings shows that guardrail is a generic reference for w-beam barriers and that w-beam is the standard guardrail used in Ohio. When guardrail is referenced within the Ohio DOT inventory, w-beam is assumed to be in that location. Single slope barriers may be 42” or 57”.

There were zero reported SV FOHE LB crashes with the inventoried propriety barriers. There were two property damage only (“O”) severity SV FOHE crashes with the barrier inventoried as “other.” There were 28,141 SV FOHE LB crashes where the type of barrier involved could not be positively identified using the Ohio inventory. The full severity distribution for SV FOHE LB crashes by barrier type is summarized in Table 1, including those crashes which could not be associated with a barrier type. Due to the high rate of unassociated barrier types, the Ohio data will not be used in further discussions. A reasonable resolution option would be to manually review each crash location using the state maintained photologs to determine the barrier involved, however, that step was not taken as part of this study.

Pennsylvania

The PennDOT barrier inventory was merged with the SV FOHE LB crashes using the County Number, State Route Number, Segment Number, Beginning Offset, Ending Offset, and Guide Rail Side fields. The Travel Direction field was used in conjunction with the Harmful Event Side 1-4 fields to determine the location and type of hardware involved in each SV FOHE LB crash. Pennsylvania differentiates between single-sided and double-sided guardrail systems, allowing median barrier crashes on divided highways to be used. All identified crashes were associated with the roadside inventory. This success was attributed to the inventory including fields locating the hardware both longitudinally and by edge with respect to the roadway as well as the crash data consistently providing the edge the vehicle exited.

A total of 5,903 SV FOHE LB crashes were found during the study period in Pennsylvania. These LB crashes were then linked to the roadside hardware inventory for each identified longitudinal barrier. Pennsylvania identifies the following longitudinal barriers within the inventory:

• Strong Post Cable
• Weak Post Cable
• Strong Post W-Beam W/ Rub Rail & Offset Bracket
• Strong Post W-Beam W/ Offset Bracket
• Strong Post W-Beam
• Weak Post W-Beam
• Strong Post W-Beam, Double Faced
• Weak Post W-Beam, Double Faced
• Weak Post Box Beam
• Concrete Safety Shape
• IBC Barrier
• Propriety cable barriers (i.e., Brifen’s wire rope safety fence (WRSF), Trinity’s Cable Safety System (CASS), Blue Systems AB’s Safence, Gibraltar’s Cable Barrier System, and Nucor Steel Marion’s Nu-Cable Barrier)

• Other

Each of these systems is further explained in the Pennsylvania Department of Transportation (PennDOT) Shoulder and Guide Rail Condition Survey Field Manual, Publication 33.

Concrete safety shape barrier was found, through review of the PennDOT standards to be a 32” New Jersey Barrier.

The linked results are shown in Table 1. There were two reported SV FOHE LB crashes with the CASS (i.e., one PDO and one Unk). There were three reported SV FOHE LB crashes with the WRSF (i.e., three PDO). There were thirteen reported crashes with the Safence (i.e., one “A”, one “B”, three “C”, six PDO and one unknow). There were sixty-two reported crashes with the Gibraltar cable barrier (i.e., one “B”, ten “C”, forty-eight PDO, and three unknown).

There were two reported crashes with the Nu-cable (i.e., one “C” and one PDO). These proprietary cable systems have been summarized as one in Table 1. SV FOHE LB crashes which were associated with the inventory code “Other” barrier are also shown in Table 1.

Tennessee

The Tennessee DOT hardware inventory was merged with the SV FOHE LB crashes using the County, Route Number, BEG_LOG, END_LOG, and Log Mile fields. The Vehicle Going Direction field along with "Cross Center Line", "Cross Median", "Ran Off Road-Left", "Ran Off Road-Right" in the events sequence 1-10 to determine which barrier was involved in each SV FOHE LB crash. Tennessee also differentiates between “Median Right”, “Median Left”, and “Centerline”, allowing median barrier crashes to be used.

A total of 2,881 SV FOHE LB crashes were found during the study period (2012-2016) in Tennessee. These crashes were then linked to the roadside hardware inventory for each identified longitudinal barrier. Tennessee identifies the following longitudinal barriers within the inventory:

• Jersey Barrier
• W-Beam
• Cable Barrier – Gibraltar NCHRP350
• Cable Barrier - NuCable

The severity distributions for each barrier type are shown in Table 1. There were 124 reported SV FOHE LB crashes with the Jersey Barrier. There were 72 reported SV FOHE LB crashes with the W-Beam.

There were 18 reported SV FOHE LB crashes with the Gibraltar cable barrier including zero fatal and one serious injury crash. There were 37 reported crashes with the NuCable system including zero fatalities and two serious injuries. The severity distribution of these proprietary cable systems are shown combined in Table 1. There were 2,630 reported crashes that were not associated with the hardware inventory. This considerable number of unassociated crashes is due to the police crash reports often excluding the run-off-road direction, which prevented positive identification of the barrier involved using this retrospective approach. Due to the high rate of unassociated barrier types, the Tennessee data will not be used in further discussions.

One resolution option would be to manually review each crash to determine the barrier involved, however, that step was not taken as part of this study.
### Table 1. SV FOHE LB Crash Counts.

<table>
<thead>
<tr>
<th>State</th>
<th>Barrier Type</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>PDO/UNK</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>Jersey Barrier</td>
<td>0</td>
<td>3</td>
<td>15</td>
<td>22</td>
<td>84</td>
</tr>
<tr>
<td>TN</td>
<td>W-beam</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>12</td>
<td>53</td>
</tr>
<tr>
<td>TN</td>
<td>Proprietary Cable Barrier</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>47</td>
</tr>
<tr>
<td>TN</td>
<td>Not associated with barrier</td>
<td>5</td>
<td>51</td>
<td>182</td>
<td>339</td>
<td>2053</td>
</tr>
<tr>
<td>PA</td>
<td>Strong Post Cable</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>39</td>
</tr>
<tr>
<td>PA</td>
<td>Weak Post Cable</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>PA</td>
<td>Strong Post W-beam with rub rail and offset bracket</td>
<td>0</td>
<td>5</td>
<td>12</td>
<td>49</td>
<td>182</td>
</tr>
<tr>
<td>PA</td>
<td>Strong Post W-beam with offset bracket</td>
<td>12</td>
<td>63</td>
<td>163</td>
<td>506</td>
<td>1788</td>
</tr>
<tr>
<td>PA</td>
<td>Strong Post W-beam</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td>PA</td>
<td>Weak Post W-beam</td>
<td>1</td>
<td>14</td>
<td>38</td>
<td>137</td>
<td>857</td>
</tr>
<tr>
<td>PA</td>
<td>Strong Post W-beam, Double Faced</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>16</td>
<td>42</td>
</tr>
<tr>
<td>PA</td>
<td>Weak Post W-beam, Double Faced</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>53</td>
</tr>
<tr>
<td>PA</td>
<td>Weak Post Box Beam</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>PA</td>
<td>Concrete Safety Shape (i.e., 32” New Jersey Barrier)</td>
<td>1</td>
<td>10</td>
<td>74</td>
<td>288</td>
<td>842</td>
</tr>
<tr>
<td>PA</td>
<td>IBC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>PA</td>
<td>Proprietary Cable Systems</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>PA</td>
<td>Other</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>OH</td>
<td>W-Beam</td>
<td>9</td>
<td>46</td>
<td>306</td>
<td>242</td>
<td>2449</td>
</tr>
<tr>
<td>OH</td>
<td>32” Jersey</td>
<td>0</td>
<td>6</td>
<td>27</td>
<td>22</td>
<td>140</td>
</tr>
<tr>
<td>OH</td>
<td>42”+ Jersey</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>42</td>
</tr>
<tr>
<td>OH</td>
<td>Single Slope</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>OH</td>
<td>Not Associated with Barrier</td>
<td>35</td>
<td>541</td>
<td>3234</td>
<td>3123</td>
<td>21208</td>
</tr>
</tbody>
</table>

### Other Means of Identifying Hardware

A literature review shows that there are many successful means of identifying safety features beyond an inventory. One research objective of NCHRP 22-12(03), “Recommended Guidelines for the Selection of Test Level 2 through 5 Bridge Railings,” was the field evaluation of the hardware. NCHRP 22-12(03) included the gathering of crash data for the concrete median barrier family and the verification of the hardware involved in the crash. As outlined in the contractor’s final report, several techniques were used to identify the hardware involved. These techniques varied by State, with the intent of maximizing the use of available data in those states. (7) The data gathered is shown in Table 2. The barrier type was identified in New Jersey (NJ) using construction records. The barrier type was identified in Massachusetts (MA) through field visits. The barrier type in Washington (WA) was identified using the state photo logs. The barrier types in Nebraska (NE) were identified using Google Earth.
Table 2. New Jersey, Massachusetts, Washington, and Pennsylvania Concrete Safety Shape
Barrier Crash Severity Distribution. [after (7)]

<table>
<thead>
<tr>
<th>State</th>
<th>Barrier Type</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>PDO/UNK</th>
</tr>
</thead>
<tbody>
<tr>
<td>NJ</td>
<td>TL5 Concrete</td>
<td>0</td>
<td>12</td>
<td>115</td>
<td>342</td>
<td>1588</td>
</tr>
<tr>
<td>MA</td>
<td>32” F-Shape</td>
<td>3</td>
<td>4</td>
<td>40</td>
<td>21</td>
<td>86</td>
</tr>
<tr>
<td>MA</td>
<td>42” F-Shape</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>WA</td>
<td>32” Safety Shape (i.e., NJ Shape)</td>
<td>2</td>
<td>4</td>
<td>62</td>
<td>112</td>
<td>369</td>
</tr>
<tr>
<td>WA</td>
<td>34” Single Slope</td>
<td>0</td>
<td>3</td>
<td>20</td>
<td>28</td>
<td>127</td>
</tr>
<tr>
<td>NE</td>
<td>29” Vertical Wall</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>NE</td>
<td>34” Vertical Wall</td>
<td>7</td>
<td>20</td>
<td>43</td>
<td>54</td>
<td>347</td>
</tr>
<tr>
<td>NE</td>
<td>42” Vertical Wall</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>NE</td>
<td>32” NJ Shape</td>
<td>1</td>
<td>6</td>
<td>14</td>
<td>14</td>
<td>134</td>
</tr>
<tr>
<td>NE</td>
<td>42” NJ Shape</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>18</td>
<td>39</td>
</tr>
</tbody>
</table>

NOTE: The Original source distinguishes between posted speed limit and vehicle type. These variables have been omitted due to limitations on space.

An extensive literature search of available ISPE data was previously conducted during the development of the RSAPv3 program in order to develop a severity measure for use in the updated software.(8) The findings for a variety of barriers across the full severity distribution is shown in Table 3. Each of these studies primarily identified the hardware through construction records.

Table 3. Barrier Crash Data Assembled Under NCHRP 22-27 (9)

<table>
<thead>
<tr>
<th>State</th>
<th>Barrier Type</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>PDO/UNK</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA</td>
<td>TL3 LT Cable MB</td>
<td>0</td>
<td>1</td>
<td>15</td>
<td>29</td>
<td>549</td>
</tr>
<tr>
<td>WA</td>
<td>TL3 HT Cable MB</td>
<td>2</td>
<td>1</td>
<td>25</td>
<td>34</td>
<td>479</td>
</tr>
<tr>
<td>AZ</td>
<td>TL3 LT Cable MB</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>IA</td>
<td>TL3 HT Cable MB</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>NC</td>
<td>TL3 LT Cable MB</td>
<td>0</td>
<td>2</td>
<td>9</td>
<td>28</td>
<td>88</td>
</tr>
<tr>
<td>OR</td>
<td>TL3 LT Cable MB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>TX</td>
<td>TL4 32” NJ MB</td>
<td>8</td>
<td>115</td>
<td>456</td>
<td>209</td>
<td>890</td>
</tr>
</tbody>
</table>

ASSESS PERFORMANCE (STEP 3)

Carrigan and Ray defined the absolute risk of A+K crashes can be found by summing the total number of A+K crashes in the data for a hardware category and dividing by the total number of all crashes of all severities for that same category, as shown here:(10)

\[
\text{Absolute Risk} = \frac{A+K}{KABCOU}
\]

where:
- A+K Severe and fatal injury crashes
- KABCOU Crashes of all reported severities including U for unknown severities.
The keen observer will note that absolute risk is simply a proportion. When multiplied by 100, it is also a percentage. When absolute risk is defined this way, it is also the probability of observing an A+K crash given all crashes, P(KA|C). This measure is used to assess occupant risk.

The risk calculation is a point estimate calculated from a sample of the population of interest. Since the risk of the entire population (\( p \)) is unknown, the estimated risk (\( \hat{p} \)) from the sample is used and expressed with a confidence interval to allow inferences to be made on the larger population. (11; 12) A confidence interval is much more useful than a p-value, as it provides a range of values that the entire population is likely between. For example, if the 90% confidence bounds are provided for a risk estimate, this can be interpreted as: “based on the sample data, we are 90% confident that the ‘true’ risk of an A+K crash with the hardware studied is between x% and y%.” The probability of observing a value outside of the area is less than 0.10 (i.e., 1-0.90=0.10). (10) The confidence interval can be calculated using the Wilson score interval as follows: (13)

\[
p' = \left( \frac{\hat{p} + \frac{z^2}{2n}}{1 + \frac{z^2}{n}} \right)
\]

\[
s' = \sqrt{\frac{\hat{p}(1-\hat{p})}{n} + \frac{z^2}{4n^2}}
\]

\[
w^- = p' - (z \cdot s') \quad \text{and} \quad w^+ = p' + (z \cdot s')
\]

Where:
- \( \hat{p} \) Risk calculated from the sample.
- \( z \) Number of standard deviations away from the mean. The \( z \)-value for a confidence level of 0.90 is 1.645.
- \( n \) Sample size.
- \( p' \) Wilson relocated center estimate of risk of sample.
- \( s' \) Wilson correction of standard deviation of sample.
- \( w \) Wilson + and − score interval.

The ability to obtain significant results should be interpreted in much the same way a jury verdict is interpreted in the United States. “Just because a person has been declared “not guilty”, it does not mean that he is innocent.” (14) Statistically non-significant results can be used to determine a trend in the data. Even when an effect is found to be not statistically significant, one should have more confidence than before the research was conducted. However, the support may be weak and the data may be inconclusive.

**Concrete Barrier Family**

The occupant risk, using P(KA|C) and the 90% confidence interval, are shown for each barrier within the concrete barrier family in Figure 1. P(KA|C) for each concrete barrier is
shown on the y-axis. The blue dots represent the point estimate of $P(KA|C)$ with a concrete barrier. The bars extending above and below the blue diamonds are the 90% confidence intervals. Based on the sampled data, we are 90% confident that the ‘true’ $P(KA|C)$ for concrete barriers is within the range shown by the bars for each diamond.

![Figure 1. Occupant Risk for the Concrete Barrier Family.](image)

Notice how the range represented by the bars overlap each other. This indicates that there is not a statically observed difference in these data between, for example, the Vertical Wall shape. A review of the combined estimates for the Jersey shape was also performed and shown in Figure 1 to the far right with the “PA, WA, NE” label. When there were not multiple states, but were multiple heights of the same shape within a single state, that data was combined, shown here with the label “All.”
Cable Barrier Family

Occupant risk using $P(KA|C)$ and the 90% confidence interval are shown for each barrier within the cable barrier family in Figure 2. As before, the blue dots represent the point estimate of $P(KA|C)$ with cable barriers and the bars represent the 90% confidence interval. Based on the sampled data, we are 90% confident that the ‘true’ $P(KA|C)$ for cable barrier is within the range shown by the bars for each cable system.

There were no fatal crashes observed in the low tension (LT) cable data. Recall the high tension (HT) cable systems were combined, which explains the statistical confidence, but does not allow for distinguishing between systems. Figure 2 also provides a combined analysis of HT and LT cable. While the probability of a severe or fatal injury given a crash, $P(KA|C)$ with a LT system does appear to be marginally less than with a HT system, the evidence is inconclusive because the confidence bars overlap.

Metal Beam Barrier Family

Occupant Risk using $P(KA|C)$ and the 90% confidence interval are shown for each barrier within the metal beam barrier family in Figure 3. The point estimate of $P(KA|C)$ is shown using blue dots with corresponding numeric values on the y-axis. Based on the sample
data, we are 90% confident that the ‘true’ \( P(KA|C) \) for each dot is within the range shown by the bars for each metal beam barrier studied.

The Pennsylvania data provides a wide spectrum of the many types of w-beam installed within Pennsylvania. Notably, the Pennsylvania inventory captures each of these different beam systems. The data represent the performance of NCHRP Report 350 systems. Notice, in Figure 3 that the Pennsylvania strong post data has been combined into a single category. Also shown is the combined analysis of all of the weak post w-beam.

As MASH systems penetrate the market, the same analysis can be conducted to determine if there has been any improvement to performance as measured by occupant risk. The study of MASH w-beam systems would likely also include post-impact trajectory and structural adequacy given the changes to height and the underlying motivations.

Figure 3. Occupant Risk for the Metal Beam Barrier Family.
RESULTS AND DISCUSSION

The laboratory crash test assessments are conducted under a series of assumptions, based on field collected data, about the likely field impact conditions (e.g., impact speed, impact angle, vehicle type). Laboratory performance evaluations include an assessment of: occupant risk, post-impact trajectory, and structural adequacy. It is understood that even the most carefully researched and evaluated safety treatment has performance limitations. An ISPE will help to better understand those limitations and to assess how the safety treatment is preforming under real world conditions.

This paper summarized occupant risk using the very large amount of data currently available without additional data collection for an ISPE. While some states maintain an inventory of safety features, some do not, and additional information was needed to identify the feature and proceed with the evaluation. A summary of the occupant risk findings from this example are shown in Figure 4 by barrier family.

Keeping in mind these are systems developed under Report 350 and occupant risk was the study objective, some conclusions can be made. This study of occupant risk has shown that Jersey shape and vertical wall shape barriers have a higher occupant risk than strong post w-beam and the cable barrier systems. The results of the single slope and f-shape are inconclusive.

![Figure 4. Summary for Longitudinal Barrier Occupant Risk.](image-url)

Any interpretation of these results should include consideration that this study was limited to Report 350 hardware and to the study of occupant risk. Post-impact trajectory and structural adequacy have not been documented herein. These additional considerations would necessitate filtering the crash data differently such that the sequence of events is maintained or conducting a field review of the crashes.
The objective of the safety feature owner (e.g., State, County, or Municipal Transportation Agency) during an ISPE may be to document that the desired field performance has been achieved. When desired performance is achieved, the safety feature is considered crashworthy regardless of which crash testing standard the safety feature was developed under. When the desired field performance has not been achieved, the owner may choose to conduct a more detailed ISPE to identify the underlying cause.

Through a more detailed review, the owner may find that changes are needed to the owner’s practice or to the safety feature to improve performance. When desired performance cannot be achieved through improvements, the owner may choose to discontinue new installations of the safety feature. On the other hand, the owner may find that satisfactory performance has been achieved and there is no cause to make changes to the system simply because, for example, vehicle fleets are changing.

Each of these more detailed questions can and should start with a dataset similar to the dataset discussed herein. These data have available the posted speed limit, vehicle type, and crash sequence of events which can inform a great deal many more ISPE questions prior to any additional data collection.

**AUTHOR CONTRIBUTION STATEMENT**

The authors confirm contribution to the paper as follows: study conception and design: Christine E. Carrigan and Malcolm H. Ray; draft manuscript preparation: Christine E. Carrigan and Malcolm H. Ray. Data collection: Christine E. Carrigan. All authors reviewed the results and approved the final version of the manuscript.

**ACKNOWLEDGEMENTS**

The data assembled and presented in this paper was assembled under NCHRP 22-31, “Recommended Guidelines for the Selection and Placement of Test Levels 2 through 5 Median Barriers.” The data used was graciously shared by the Tennessee DOT, Pennsylvania DOT, and Ohio DOT. The authors wish to thank the NCHRP 22-31 project panel and program officer, Mr. Mark Bush, for their thoughtful comments. The authors also wish to thank the Tennessee, Pennsylvania, and Ohio DOTs for provided the data used in this research.

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