In-Service Performance Evaluation (ISPE) of New England Transportation Consortium (NETC) Steel Bridge Railings

FINAL REPORT

Project 20211012000000000359

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Author Acknowledgements

The success of any ISPE hinges on cooperation with and from the state partners. The NETC state partners were instrumental in identifying and providing the data used for this project. The authors wish to thank Jeff Folsom, Dale Peabody, and Sean McDonald from the MaineDOT; David Kilpatrick from ConnDOT; Chelsea Noyes, Amanda Joe Paulino, Sally Gunn, David Gaylord, and Aaron Janssen from NHDOT; Chris Gagnon, Craig Nazareth, and Sean Raymond from RIDOT; Chris Mooney, Laura Stone, Mandy White, Ben Howe from VTrans; and Nicholas Zavolas from MassDOT. The authors are grateful to each of these member states for their invaluable efforts to identify available data and the insight when interpreting the results of these ISPEs.

1 Introduction

The predominate bridge railing used in the New England States are two-, three-, and four-bar steel post-and-beam designs developed and crash tested under the auspices of the New England Transportation Consortium (NETC). These bridge railing designs are commonly referred to as NETC bridge railings. The crash tests were performed in compliance with the AASHTO Guide Specification for Bridge Railings Performance Level 2 (GSBR PL2) and/or NCHRP Report 350 (R350) test procedures. (AASHTO 1989, Ross, Sicking et al. 1993) These bridge rail systems have been used in the New England states for more than 20 years. According to the Joint Agreement between AASHTO and FHWA, each state is required to specify MASH compliant bridge rails for new and full replacements on the National Highway System (NHS) with contract letting dates after December 31, 2019. In accordance with those requirements, a project was recently completed to evaluate the crash performance of the NETC bridge rail systems under the MASH criteria using finite element analysis. (Plaxico and Ray 2020) The study concluded that the existing NETC bridge railing designs would meet the new crash testing standards, but also recommended minor design modifications to further improve performance.

Establishing that these long-standing bridge railing designs are performing well in the field would provide further confidence that the current, as well as the improved, NETC bridge railing designs adequately meet the performance criteria of MASH without the need to perform additional full-scale testing. While the in-service performance of the NETC bridge railings is believed to be good, an in-service performance evaluation (ISPE) has never been conducted to confirm that impression. The objective of this project was to determine the in-service performance of the NETC steel post-and-beam bridge railings and transition systems using evaluation procedures provided in the recently completed NCHRP Project 22-33, "Multi-State In-Service Performance Evaluations of Roadside Safety Hardware". (Carrigan and Ray 2022 [expected])

2 Background

One reoccurring theme in each re-writing of crash test and evaluation procedures over the last 40 years is the recommendation to conduct in-service performance evaluations (ISPEs) of roadside hardware. NCHRP Report 153 was published in 1974. Report 153 notes the purpose of "… crash tests are to screen out those candidate systems with functional deficiencies…. The final evaluation of an appurtenance must be based on carefully documented in-service use." (Bronstad and Michie 1974) Michie *et al*. recommended ISPEs in the National Cooperative Highway Research Project (NCHRP) Report 230 crash test and evaluation procedures published in 1981. The importance and need for ISPEs was reiterated by Ross *et al*. in NCHRP Report 350 as well as by AASHTO in both editions of the *Manual for Assessing Safety Hardware* (MASH). (Michie 1981, Ross, Sicking et al. 1993, AASHTO 2009, AASHTO 2016)

In a recent study funded by NETC, the crash performance of several NETC steel bridge railing and transition designs were evaluated under *MASH* impact conditions and performance criteria using finite element analysis (FEA). The high cost of full-scale crash testing and, to a lesser degree FEA computer simulations, limits crash testing and FEA to a small number of impact cases (e.g., two or three tests for longitudinal barriers) which are generally performed under ideal conditions (e.g., flat approach, dry surface, good weather). While these evaluations are an important first step for ensuring that roadside hardware systems meet a basic threshold of safety before being considered for installation, the crash test performance observed may not always be indicative of good performance in the field under actual service conditions. Establishing and documenting the field performance of the NETC steel bridge railing and approach guardrail transition (AGT) systems makes the leap from the handful of specific impact speeds, angles and vehicle types suggested by MASH to the full spectrum of vehicle types, impact conditions, maintenance, weather, and traffic conditions that these systems have been exposed to in New England for the past 20 plus years.

2.1 NETC Steel Bridge Railings and Transitions Design History

The NETC steel bridge rail and approach guardrail transition (AGT) systems used in New England include details for two, three, and four-bar designs. Figure 1 shows representative installations for each of the three primary bridge rail systems and Figure 2 shows representative installations of the corresponding AGT systems. Each of the NETC bridge rail designs include a W6x25 steel post that is welded to a 10x14x1-inch steel baseplate and mounted onto the top of a concrete curb or sidewalk using four 1-inch diameter 12-inch long threaded rods. The posts are spaced at 8 feet on centers. The longitudinal rails are composed of HSS 8x4x5/16-inch and HSS 4x4x1/4-inch steel tube sections. The rails are fastened to the post flanges using ¾-inch diameter round-head bolts inserted through the face of the tubular rail.

2-bar 3-bar 4-bar

Figure 1. Photographs of NETC Bridge Rail Designs

The two-bar curb-mounted bridge rail design was successfully full-scale crash tested in 1993 under the AASHTO Guide Specifications for Bridge Railings (GSBR) for Performance Level 2 (PL2), and the four-bar sidewalk-mounted design was successfully crash tested in 1997 under National Cooperative Highway Research Program (NCHRP) Report 350 for Test Level 4 (TL4) guidelines. (AASHTO 1989, Ross, Sicking et al. 1993) The three-bar curb-mounted design has not been full-scale crash tested but was classified as a NCHRP Report 350 TL4 bridge railing based on the results of the NETC four-bar test based on the assumption that the reinforced curb serves as a replacement for the lower rail of the system.

The approach guardrail transition designs that are used in conjunction with the NETC bridge rails include a w-beam rail at the guardrail approach, which is then connected to a symmetrical thrie-beam transition rail, which connects to a nested thrie-beam rail, which is then connected to either a tube rail section or a concrete buttress, as shown in Figure 2. The rail elements are supported by W6x8.5 steel posts and blockouts. The posts are typically 7', 8' or 8'-8" long and are mounted at decreasing post spacing as the system starts at the w-beam guardrail (e.g., 6'-3" spacing) and approaches the rigid bridge rail (e.g., 18.75-inch spacing).

(a) 2-Bar AGT

(b) 3-Bar AGT

(c) 4-Bar AGT

(d) 4-Bar to Buttress AGT

Figure 2. Photos of NETC AGT Designs

The NETC two-bar to thrie-beam AGT was successfully full-scale crash tested to NCHRP Report 350 TL3 conditions by the Texas Transportation Institute (TTI) in 2005. (Alberson, Buth et al. 2006) The NETC three-bar AGT and NETC four-bar AGT have not been crash tested but received R350 TL3 approval from the FHWA based on the results of the NETC two-bar crash test.

These basic NETC bridge rails and AGT designs are used by several New England states with slight variations in design details, such as spacing between HSS rails and the curb height.

Recently, Plaxico *et al*., performed a study for NETC to evaluate these bridge rail and AGT systems under MASH impact performance criteria using FEA. Detailed numerical models were developed for the NETC bridge rail and transition designs and validated using the prior crash tests.(Plaxico and Ray 2020) The non-linear dynamic FEA software LS-DYNA was then used to simulate impact conditions corresponding to MASH TL3 or TL4 as appropriate for each hardware system. For each analysis case, the design details corresponded to the least conservative material and dimensional design options specified among the user states (e.g., lowest concrete strength, lowest curb height, lowest bolt strength, etc.). Based on the success of the less conservative designs, it was concluded that the more conservative design details would also meet crash performance criteria.

The results of the Plaxico *et al.* study showed that each of the NETC designs safely contained and redirected the impacting vehicle and met all MASH performance requirements. While the simulation was judged to be acceptable, there was significant damage to the four-bar design under Test 4-11 conditions (i.e., single unit truck impact at 56 mph and 15 degrees). Recommendations for minor design improvements were provided to enhance the crash performance. The recommended improvements involved increasing the size of the HSS rails to improve system strength, revising the splice design to minimize lateral movement in the splice connections, and tapering the tops of the posts to mitigate snagging when parts of a vehicle, such as the cargo-box on single-unit trucks, overhang the top rail and contact the tops of the posts.

2.2 ISPEs Methodologies

The first formal comprehensive guide to performing ISPEs of roadside hardware was published as NCHRP 490 in 2003. (Ray, Weir et al. 2003, Ray, Weir et al. 2003) Carrigan *et al*. recently completed NCHRP Project 22-33, "Multi-State In-Service Performance Evaluations of Roadside Safety Hardware" which included the development of stand-alone "*Guidance for the Assembly and Analysis of In-Service Performance Evaluation Data"* (i.e., *ISPE Guidance Document*). The *ISPE Guidance Document* provides: "(1) a basis for researchers and user agencies to assess the field performance of safety features, (2) guidance for the collection and/or assembly of in-service data, (3) the evaluation of in-service data, (4) guidance for the uniform documentation of ISPEs, and (5) guidance regarding the interpretation and application of ISPE results." (Carrigan and Ray 2022 [expected]) A methodology for combining the results of multiple ISPEs conducted for the same safety feature is also presented.

The *ISPE Guidance Document* assesses the field performance of safety features such as the NETC Steel Bridge Railings through consideration of the (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicle trajectory and vehicle orientation in observed crashes. These assessment criteria are generally consistent with the crash test evaluation criteria within MASH. The four-step methodology in the *ISPE Guidance Document* is that:

1. The safety feature under evaluation is identified,
2. The data is assembled and compiled into the standardized ISPE dataset,
3. The data is assessed using the standard evaluation measures, and
4. The results are interpreted and implemented.

The safety feature under evaluation in this report are the three NETC bridge railing designs and the associated AGT. The following sections describe the execution of the next three steps.

3 Assemble Data and Compile ISPE Dataset

The research team coordinated with the NETC member states to obtain available bridge inventory data as described in the next section. The team then worked with the individual member states to mine the data to identify and isolate the locations of NETC steel bridge railings and transitions. A combination of bridge inspection photos and reports along with Google Earth Street View were used to identify the types of NETC bridge rail and AGT system at each location. The result was an inventory of NETC bridge railing and associated AGT locations in the six New England states.

A minimum of five years of crash data was collected from each state and linked to the bridge inventory data to identify all crashes that occurred within close proximity to a bridge with a NETC bridge rail or AGT system. The state partners provided the available crash data and, when requested, the available police reports. Crashes with the NETC rails and AGTs were then identified by the research team and compiled in the standard ISPE Dataset as outlined in the NCHRP 22-33 ISPE Guidance Document, Final Draft version, dated October 2021.

3.1 Bridge Inventory

When developing the NETC bridge railing inventory, thoughtful consideration of the specifics for the inventoried elements was essential to minimize the collection of irrelevant data elements and maximize the usefulness of the inventory. The research team collaborated with each member state to develop the list of data elements that would be the most useful for this ISPE. It was important for the inventory to include data elements that would distinguish between each type of NETC steel bridge railing and each style of AGT. Some of the inventory data fields were collected from the data assembled and maintained at the state level for the National Bridge Inventory (NBI) while inspection reports, inspection photos, and publicly available roadway photologs were consulted for the remainder of the inventory fields.

3.1.1 MaineDOT

An inventory of the bridges in Maine that have NETC style bridge rails and/or approach guardrail transitions (AGTs) were compiled from the Excel spreadsheet file named *NETC Steel Bridge Rail Updated.xlsx* (*ME List*) provided by MaineDOT on May 20, 2021. The *ME List* file contains a list of all bridges in the State suspected of having NETC bridge rails. This file contained 295 bridges. The full list of bridges was reduced, as outlined in Figure 3, to only those bridges with NETC bridge rails or AGTs on at least one side of the bridge.

The data reduction involved review of the inspection photos and inspection reports available on the AssetWise web portal as well as Google Earth Street View imagery when available. Each bridge rail and AGT listed in the data was categorized based on the descriptive information. Most of the bridges contained in the original *ME List* file did have NETC type bridge rails and/or AGTs (i.e., 254 of the 295 were confirmed to be NETC bridge railings). The 42 bridge railings that were some other type of bridge railing were removed from the dataset.

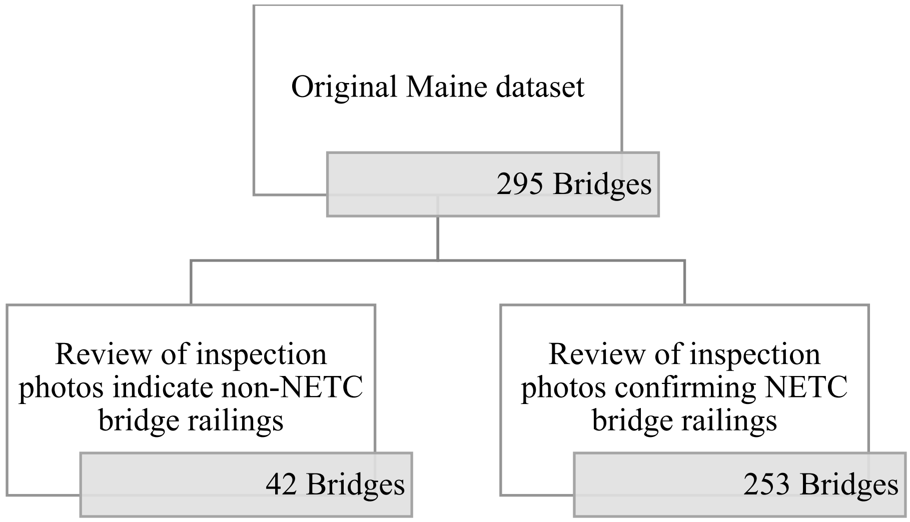


Figure 3. MaineDOT Bridge Inventory Data Reduction

The 253 bridges that were confirmed to having NETC type bridge railing were compiled into a single dataset. As mentioned earlier, the bridge rails and AGTs were categorized and identified through a visual review of available photographs and Google Earth Street View images. A detailed as-built drawing review of each structural element and rail component of each bridge was not performed so some detailed dimensions like the diameter of baseplate bolts, top tubular rail height, post embedment depth of the AGT sections, and other specific design dimensions could not be verified.

3.1.2 NHDOT

An inventory of the bridges in New Hampshire that have NETC style bridge rails and/or approach guardrail transitions (AGTs) were compiled from the Excel spreadsheet file *qryChelseaAllRail.xlsx* (*NH List*) provided by NHDOT on June 18, 2021. The *NH List* contains a list of all bridges in the State with bridge railings. A large database of bridge photos was also provided to the research team. The original intention was to identify bridge railings using the provided photographs but generally only one photograph per bridge was included and often it was not possible to identify the bridge rail from the photograph. Google Earth Street View imagery was used instead to identify NETC bridge rails and associated AGTs. The original *NH List* of 3,091 bridges was reduced to only those bridges with NETC style bridge rails or AGTs on at least one side of the bridge, as outlined in Figure 4.

The first step was to remove bridges with non-metal railings. The *NH List* ELEM_KEY codes are equivalent to the Manual for Bridge Element Inspection (MBEI) bridge railing element codes as shown in Table 1 so only bridges with the code 330 entered in the ELEM_KEY field of the *NH List* were retained. (AASHTO 2019) Removing non-metal bridge railings reduced the dataset to 2,588 bridges.

Table 1. MBEI Railings Element Codes Equivalent to the NH LIST ELEM_KEY Field (AASHTO 2019)

Element	Code
Metal Bridge Railing	330
Reinforced Concrete Bridge Railing	331
Timber Bridge Railing	332
Other Bridge Railing	333

Masonry Bridge Railing	334

The second step was to remove bridges with metal bridge railings that were not NETC type bridge railings based on the *NH List* ELEM_NOTES field. This field is a text field that contains inspection observations and, in some instances, the bridge rail type. Bridges that had ELEM_NOTES indicating aluminum bridge rails, steel balusters, w-beams, T 100, steel channel rail, or other non-NETC designs were removed from the dataset. This resulted in retention of 868 bridges with either NETC type bridge rails or inconclusive railing designs.

The final data reduction step was to view each of the remaining 868 bridges using Google Earth Street View and categorize each bridge rail as a NETC bridge railing or AGC or something different. Bridge rails that were not NETC type were removed from the dataset, resulting in 497 bridges which were categorized as NETC designs.

The 497 bridges that were identified as having NETC bridge railings were compiled into a single dataset. As in the Maine data collection, bridge rails and AGTs were identified and categorized visually. A detailed review using as-built drawings was not undertaken.

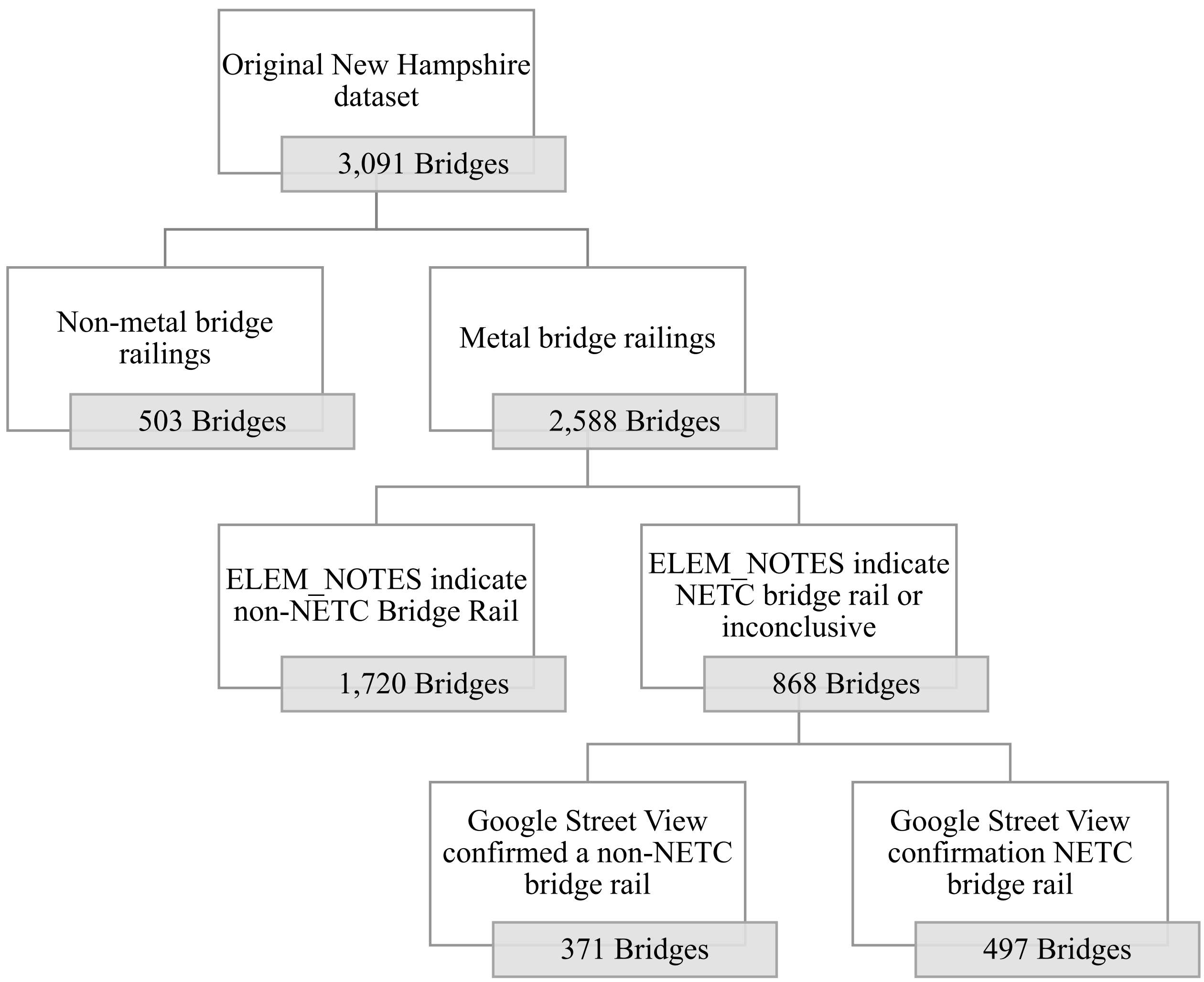


Figure 4. NHDOT Bridge Inventory Data Reduction

3.1.3 RIDOT

An inventory of the bridges in Rhode Island that have NETC style bridge rails and/or approach guardrail transitions (AGTs) was compiled by reviewing the Excel spreadsheet file *Element 330 Bridge Query.xlsx* (*RI List*) which was provided by RIDOT on March 24, 2021. This file is a list of all bridges in the State with MBEI Element coded as 330 (metal bridge railing) as describe earlier in Table 1. The *RI List* contained 315 bridges, the full list of bridges was reduced to only bridges with NETC bridge rails or AGTs on at least one side of the bridge in the steps outlined in Figure 5.

The first and only data reduction step was to review the inspection photos and inspection reports available on the RIDOT BrM web portal along with Google Earth Street View imagery when available. Using these data sources, identification and categorization of each bridge rail and AGT type was achieved. This resulted in the identification of 52 bridges with NETC type bridge rails and/or AGTs, however, some rails in the list were other steel or concrete and steel combination railings. Bridges with these non-NETC type bridge rails and/or AGTs were removed from the dataset.

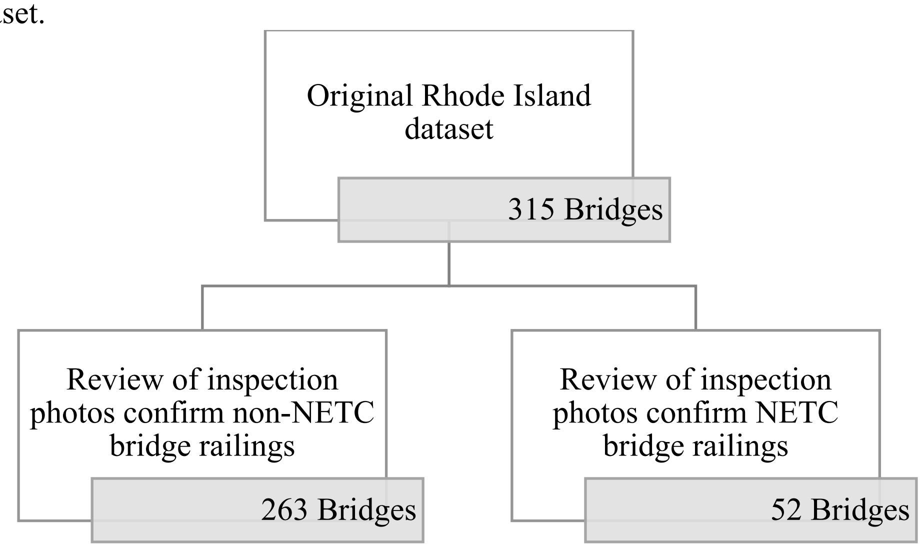


Figure 5. RIDOT Bridge Inventory Data Reduction

The 52 bridges that were identified as having NETC bridge railing were exported from the RIDOT BrM web portal into a spreadsheet using the "RIDOT Lat Lon" BrM web portal layout. The applicable data was then cross-linked to and compiled into a single dataset. As in the Maine and New Hampshire data collections, bridge rails and AGTs were identified and categorized visually. A detailed review using as-built drawings was not undertaken so some specific dimensions could not be determined.

3.1.4 VTrans

An inventory of the bridges in Vermont that have NETC style bridge rails and/or approach guardrail transitions (AGTs) was compiled. The inventory was generated by reviewing the Excel spreadsheet file *Railing.xlsx* (*VT List*) provided by VTrans on July 01, 2021. This file is a list of all bridges in the State with bridge railings and contains 4,042 bridges (2,682 long structures and 1,360 short structures). The list of bridges was reduced to only bridges with NETC bridge rails or AGTs on at least one side of the bridge in the steps outlined in Figure 6.

The first step was to remove bridges with non-NETC bridge rail material/designs. This was accomplished by retaining only bridges with the NETC applicable codes entered in the 221C field of the *VT List* shown in Table 2. Removing non-NETC bridge railings resulted in retaining 409 bridge railings on long structures and 9 on short structures.

Table 2. Material/Design of Rail Codes (221C) Retained in Dataset

221C Codes	Material/Design of Rail
06	Box Beam (Double)
08	2-Rail Clear View Box Beam
09	3-Rail Clear View Box Beam
12	Miscellaneous Steel Shapes (Angle Irons, Channels, or Other Structural Shapes)
28	Other

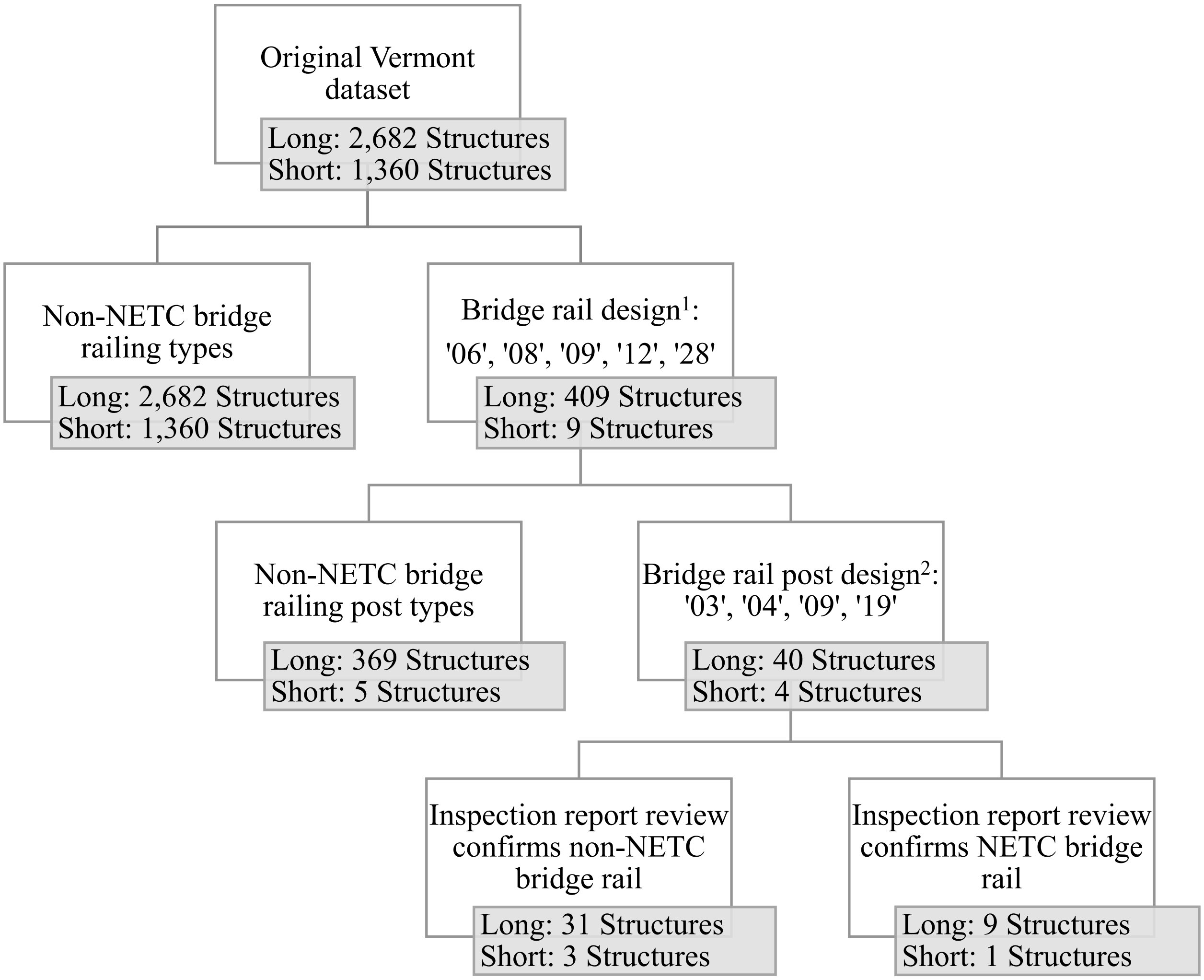
The second step was to remove bridges with non-NETC bridge rail post material/designs. This was accomplished by retaining only bridges with the NETC applicable codes entered in the 221A field of the *VT List* shown in Table 3. Removing non-NETC bridge railing post materials/designs resulted in retaining 40 long structures and 4 short structures in the dataset.

Table 3. Material/Design of Posts Codes (221A) Retained in Dataset

221A Codes	Material/Design of Posts
03	Steel WF (Pedestal Mounted/Driven - No Offset Blocks)
04	Steel WF (Pedestal Mounted/Driven - w/Offset Blocks)
09	Miscellaneous Steel Shapes (Angle Irons, Channels, or Other Structural Shapes)
19	Other

The final data reduction step was to review the inspection reports and photos on the VTransparency web portal for each of the remaining 44 bridges as well as reviewing the sites using Google Earth Street View imagery to categorize each bridge rail. Bridge rails that were not NETC type railings were removed from the dataset and the bridge rails on the remaining 10 NETC bridge railings were categorized according to their apparent design (e.g., two-bar, three-bar b ridge rails. There were no four-bar NETC bridge rails in Vermont). The 10 bridges that were identified as having NETC bridge railing were compiled into a single dataset.

As in the Maine, New Hampshire, and Rhode Island data collections, bridge rails and AGTs were identified and categorized visually. A detailed review using as-built drawings was not undertaken so some specific dimensions could not be determined.



[1] ‘06’ = Box Beam (Double), ‘08’ = 2-Rail Clear View Box Beam, ‘09’ = 3-Rail Clear View Box Beam, ‘12’ = Miscellaneous Steel Shapes, ‘28’ = Other

[2] ‘03’ = Steel WF (Pedestal Mounted… No block), ‘04’ = 2- Steel WF (Pedestal Mounted… w/ Block), ‘09’ = Miscellaneous Steel Shapes, ‘19’ = Other

Figure 6. VTrans Bridge Inventory Data Reduction

3.1.5 ConnDOT

Through email discussions with ConnDOT, it was determined that Connecticut never adopted the NETC bridge rail designs but used some modified versions. ConnDOT provided the research team with a list of nine bridges with beam-type steel bridge railings. The research team reviewed these railings and determined that the designs were not similar to the crash tested NETC designs, therefore, ConnDOT does not have any bridge railings that are encompassed in the scope of this research project.

3.1.6 MassDOT

Like ConnDOT, MassDOT has not adopted the NETC bridge rail designs but uses other tubular post-and-beam designs. The research team performed a literature search of the MassDOT published standard details for railing/traffic barrier systems and confirmed that the steel tube railing designs used by MassDOT differ in multiple ways from the NETC designs (e.g., tube size, baseplate design, etc.).

3.1.7 Data Fields for Bridge Rail Inventory – NBI Fields

The layouts for each state's bridge rail inventory were standardized into the fields shown in Table 4. Definitions and the formats for each of the field inputs are also shown in Table 4. Additional discussion for each field as defined for each specific state can be found in the specific state's bridge inventory data dictionary. The fields identified in Table 4 were either imported directly from the publicly available NBI or from the bridge rail list provided by each of the states. These data fields include data for identifying and locating the bridges as well as classifications of the roadways that the bridges carry.

Table 4. Bridge Rail Inventory —NBI Fields, Definitions, and Formats

Column	Field Name	Definitions	Format
A	BRIDGE_NO	Identification of the bridge (linkable to NBI)	Unique number
B	CROSSING	Identification of the feature being crossed by the bridge	Text input
C	TOWN	Town where the bridge is located	Text input
D	ROUTE	Route that the bridge carries	Text input
E	LAT	Latitude of the bridge	Varies between States
F	LONG	Longitude of the bridge	Varies between States
G	AADT	Average Annual Daily Traffic on the route	Numerical input
H	OWNER	Owner of the bridge	Numerical code input
I	NHS	Is the bridge on the National Highway System	0 or 1
J	FC	Functional classification of the route	1, 2, 6, 7, 8, 9, 11, 12, 14, 16, 17, or 19

3.1.8 Data Fields for Bridge Rail Inventory – Bridge Rail and AGT Fields

The fields listed in Table 5 were populated by reviewing inspection reports, photographs, and/or Google Earth Street View imagery for each bridge. The code descriptions and example photos for the mount, bridge rail, AGT, and typical installation fields are provided in Tables 6 through 9.

Table 5. Bridge Rail Inventory – Bridge Rail and AGT Fields, Definitions, and Formats

Column	Field Name	Definitions	Format
K	N_E_MOUNT	Identification of what the bridge rail on the N or E side of the bridge is mounted to	1, 2, 3, 4, 99, or N/A
L	N_E_BRIDGE_ RAIL_TYPE	Identification of the type of NETC bridge rail on the N or E side of the bridge	a, b, c, j, k, m, n, o, 99, or N/A
M	N_E_AGT_TYPE	Identification of the type of NETC ATG on the N or E side of the bridge	d, e, f, g, h, i, l, q, r, s, t, u, v, w, 99, or N/A
N	N_E_TYP_ INSTALL	Determination of whether the installation of the bridge rail/AGT on the N or E side of the bridge is typical	0, 1, 99, or N/A
O	S_W_MOUNT	Identification of what the bridge rail on the S or W side of the bridge is mounted to	1, 2, 3, 4, 99, or N/A
P	S_W BRIDGE_ RAIL_TYPE	Identification of the type of NETC bridge rail on the S or W side of the bridge	a, b, c, j, k, m, n, o, 99, or N/A
Q	S_W_AGT_TYPE	Identification of the type of NETC ATG on the S or W side of the bridge	d, e, f, g, h, i, l, q, r, s, t, u, v, w, 99, or N/A
R	S_W_TYP_ INSTALL	Determination of whether the installation of the bridge rail/AGT on the S or W side of the bridge is typical	0, 1, 99, or N/A
S	INSTALL_YR	Earliest inspection report reviewed with NETC bridge rail installed	pre-****, ****, or ****-****
T	ADDITIONAL_ NOTES	Additional information that may be of interest	Text input, no restrictions or validation

3.1.8.1 Mount

The definitions for each of the MOUNT codes are shown in Table 6.

Table 6. MOUNT Code Definitions and Examples

Code 1 **Description:** Curb	**Code 2** **Description** Sidewalk (back)	**Code 3** **Description** Sidewalk (back)
		
Code 4 **Description** Deck	**Code 5** **Description** Facia	
		

3.1.8.2 Bridge Rail

The definitions for each of the BRIDGE_RAIL_TYPE codes are shown in Table 7.

Table 7. BRIDGE_RAIL_TYPE Code Definitions and Examples

Code	Description	Example	Code	Description	Example
a	NETC two-bar steel bridge rail *NETC T2 Steel Bridge Rail* *NHDOT T2 Steel Bridge Rail* *MaineDOT DWG 507(04)* *RIDOT DWG 10.30* *VTrans DWG S-360A-B*		b	NETC three-bar steel bridge rail *NETC T3 Steel Bridge Rail* *NHDOT T3 Steel Bridge Rail* *MaineDOT DWG 507(05)*	
c	NETC four-bar steel bridge rail *NETC T4 Steel Bridge Rail* *NHDOT T4 Steel Bridge Rail* *MaineDOT DWG 507(07)*		j	RIDOT four-bar steel bridge rail *RIDOT DWG 10.22*	
k	MaineDOT four-bar steel traffic/bicycle bridge rail *MaineDOT DWG 507(06)*		m	Two-bar bridge rail, non-NETC	
n	Three-bar bridge rail, non-NETC		p	Four-bar bridge rail, non-NETC	

3.1.8.3 AGT_TYPE

The definitions for each of the AGT_TYPE codes are shown in Table 8.

Table 8. AGT_TYPE Code Definitions and Examples

Code	Description	Example	Code	Description	Example
d	NETC two-bar AGT *NETC T2 Steel Bridge Approach Rail* *NHDOT T2 Steel Bridge Approach Rail* *VTrans DWG S-360B*		e	NETC three-bar AGT *NETC T3 Steel Bridge Approach Rail* *NHDOT T3 Steel Bridge Approach Rail* *MaineDOT DWG 507(20-26)*	
f	NETC four-bar AGT *NETC T3 Steel Bridge Approach Rail* *NHDOT T3 Steel Bridge Approach Rail*		g	MaineDOT two-bar concrete transition barrier *MaineDOT DWG 526(25-27)*	
h	MaineDOT three-bar concrete transition barrier *MaineDOT DWG 526(28-30)*		i	MaineDOT four-bar concrete transition barrier *MaineDOT DWG 526(34-36)*	

Table 8. AGT_TYPE Code Definitions and Examples (continued)

l	MaineDOT four-bar traffic/bicycle concrete transition barrier *MaineDOT DWG 526(31-33)*		q	Two-bar steel AGT, non-NETC *RIDOT DWG 10.32*	
r	Three-bar steel AGT, non-NETC	No examples available	s	Four-bar steel AGT, non-NETC	No examples available
t	Two-bar concrete transition barrier, non-NETC		u	Three-bar concrete transition barrier, non-NETC	
v	Four-bar concrete transition barrier, non-NETC		w	MaineDOT two-bar AGT *MaineDOT DWG 507(16-19)*	

3.1.8.4 TYP_INSTALL

The definitions for each of the BRIDGE_RAIL_TYPE codes are shown in Table 9 and examples of atypical installations are shown in Figure 7.

Table 9. TYP_INSTALL Code Definitions

Code	Description
0	Bridge Railing is not a typical installation
1	Bridge Railing is a typical installation
99	Bridge Railing installation status unknown

Figure 7. Examples of Atypical Installations

3.2 Assemble ISPE dataset

The research team worked with each member state to collect full crash databases for a minimum of five years. The full crash datasets for each State were then reduced into an ISPE dataset of only crashes which involved an NETC bridge rail or AGT based on the locations of the hardware in the inventory data as described below. The ISPE dataset was formatted in accordance with the guidance provided in the NCHRP Project 22-33 Guidance Document, Final Draft Version.

The most challenging aspect of the data collection was determining if the crash occurred with the bridge rail, the transition, or on the approach guardrail section near the transition. This challenge was mitigated by careful review of the applicable crash reports. The location attributes of the bridge inventory (i.e., TOWN, ROUTE, LAT, and LONG) were used to facilitate linking the crash data with the bridge rail and AGT inventory. In most cases the assembled data distinguishes between crashes with each of the inventoried bridge railings as well as the transitions.

3.2.1 MaineDOT

MaineDOT provided the 2013-2020 crash data for use in this project. Each year was contained in unique worksheet within the workbooks, and all worksheets had 267 fields (i.e., columns). Each row of data in the original Maine dataset represented a single person involved in a motor vehicle crash. The number of cases (persons) each year is shown in the upper left corner of Table 11. Next, only the person with the highest severity injury was retained in the dataset and other persons in the same crash were deleted. This resulted in each row of the dataset representing a single crash event with the most severe injury recorded. The data was reduced from the full dataset to only crashes with an NETC bridge rail or AGT in the steps indicated by the flags in Table 11 and described in Chapter 4 of the MaineDOT ISPE included in this report as Appendix A: Maine DOT ISPE. The critical step was to identify if a crash occurred on a bridge with an NETC bridge rail or AGT installed on the approach and if the crash involved the NETC bridge rail or AGT. Once the nearest bridge to each crash was identified and the locations (i.e., of the bridge and the crash) were compared, the police reports were requested. The crash narratives and diagrams along with the bridge inventory and Google Earth Street View imagery were reviewed to determine if the crash did occur on the bridge and if the roadside hardware impacted was in fact an NETC bridge rail or AGT. In some instances, it was necessary to adjust some of the crash data fields based on the review of the police reports. The two most common reasons for editing the crash data were:

1. "Motor vehicle in transport" was coded in Seq of Events 1 for single vehicle crashes. From reviewing the crash narratives, it is clear that in some cases officers code Seq of Events 1 the way that Pre-Crash Actions is intended to be used. This is most clear when "motor vehicle in transport" is coded as Seq of Events 1 and the crash is a single vehicle crash. When this change was made, it often led to adjustments in the FHE and FOHE fields.
2. Multiple impacts into the bridge rail were sometimes only coded as a single event. This was modified such that each vehicle interaction with the bridge rail was included as a separate event (i.e., each interaction with the hardware was included as a row in the dataset).

In some cases, there would be a mixture of NETC and non-NETC designs. For example, one side of the bridge may have a three-bar NETC bridge rail and the other a non-NETC bridge rail. Another example is an NETC bridge railing with non-NETC AGTs. The crash narrative was used in these cases to confirm that the vehicle interaction was with the NETC component of the system. If the case involved the non-NETC portion of the bridge rail or AGT the case was excluded.

The final MaineDOT ISPE dataset contained 99 interactions with ten different types of NETC bridge rails or AGTs. Additional tabulations of the data contained in the MaineDOT ISPE dataset are provided in Table 10.

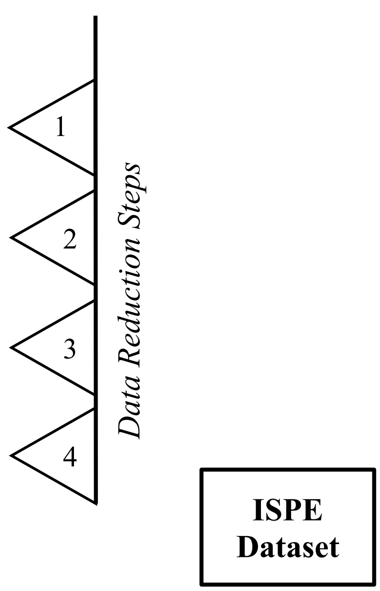
Table 10. MaineDOT ISPE Dataset Tabulations

Severity	Quantity	Vehicle Type	Quantity
K – Fatal	0	MC – Motorcycle	1
A – Suspected Serious Injury	5	PC – Passenger Car	53
B – Suspected Minor Injury	10	PU – Pick-up truck/SUV	40
C – Possible Injury	20	SUT – Single Unit Truck	0
O – No Apparent Injury	64	TT – Tractor Trailer	1
U – Unknown	0	OTR - Other	4

Table 11. MaineDOT Crash Data Reduction for ISPE of NETC Bridge Rails and AGT

Crash Year	Database Cases (persons)
2013	82,780
2014	86,129
2015	91,538
2016	90,346
2017	94,458
2018	93,344
2019	94,154
2020	71,412

Data Reduction			
	Intent/Codes Removed	Data Years	Cases (vehicles) Remaining
1	Retain crashes (one row per vehicle with most severe injury in the vehicle) coded with: '28' Bridge Pier or Support '29' Bridge Rail '35' Guardrail Face in the SEQ_OF_EVENTS1-4 fields.	2013	795
		2014	764
		2015	727
		2016	814
		2017	909
		2018	798
		2019	862
		2020	734
2	Retain only vehicles which crashed within 1 mile of a bridge with an NETC bridge rail/AGT.	2013	162
		2014	158
		2015	140
		2016	150
		2017	160
		2018	134
		2019	141
		2020	137
3	Retain only crashes which are likely to have occurred <u>on</u> a bridge with an NETC bridge rail/AGT.	2013	16
		2014	14
		2015	14
		2016	32
		2017	31
		2018	27
		2019	23
		2020	28
4	Retain crashes which are confirmed, based on review police report and photos, to have interacted with a NETC bridge rail or AGT. Also, add rows for crashes where the vehicle interacted with the SFUEs multiple times.	2013	7
		2014	6
		2015	10
		2016	18
		2017	21
		2018	13
		2019	11
		2020	13



Recent ISPEs of longitudinal barriers that have been performed using the NCHRP Project 22-33 method indicate point estimates ($\hat{p}$) for the Occupant Risk and Post Impact Trajectory Evaluation Measures vary between 0.02 and 0.05. (Carrigan and Ray 2022 [expected]) Using a precision of ±0.01 and an 85% confidence interval indicates the sample size would need to be between 406 and 985 crashes to distinguish between the specific systems as seen in Table 12. Assuming an average of 99 crashes on the three different NETC systems in an eight-year interval (i.e., 99/3 = 33 NETC crashes/yr →about 11 crashes for each NETC system assuming equal inventories), a sample size large enough to provide statistically significant different results for the three different bridge rails would require between 37 and 90 years of Maine data collection; clearly an infeasible amount of time. Instead, it was recommended that the ISPE not distinguish between specific variations of NETC systems, but rather considers the field performance of all the identified NETC rails and associated AGTs as a single system.

Table 12. Recommended Sample Size (n) for Investigative ISPE at 85% C.I.

	Precision (w)						
$\hat{p}$	0.001	0.002	0.003	0.004	0.005	0.01	0.02
0.005	10316	2579	1146				
0.010	20529	5132	2281	1283	821		
0.015	30637	7659	3404	1915	1225		
0.020	40643	10161	4516	2540	1626	406	
0.025	50544	12636	5616	3159	2022	505	
0.030	60342	15085	6705	3771	2414	603	
0.035	70036	17509	7782	4377	2801	700	175
0.040	79626	19907	8847	4977	3185	796	199
0.045	89113	22278	9901	5570	3565	891	223
0.050	98496	24624	10944	6156	3940	985	246
0.055	107775	26944	11975	6736	4311	1078	269

3.2.2 NHDOT

The NHDOT provided the 2010-2019 crash data to use in this project. Starting in July 2017 New Hampshire entered a transitional phase regarding their crash reporting forms. Due to this transitional phase, the 2017-2019 data presented challenges for assembling the ISPE dataset. Police reports were not available for 2012 and earlier. Therefore, only data from the 4-year period of 2013-2016 was used since that was all that was available. The data from NHDOT included crash data files, vehicle record files, and injury record files. These data were reduced from the full dataset to only crashes with an NETC bridge rail or AGT in the steps indicated by the flags in Table 14 and described in Chapter 4 of the NHDOT ISPE included with this report as Appendix B: New Hampshire DOT ISPE. The critical step was to identify if a crash occurred on a bridge with an NETC bridge rail or AGT installed on it and if the crash involved the NETC bridge rail or AGT. Once the nearest bridge to each crash was identified and the locations of the bridge and the crash were compared, the police reports were requested. The collision section of the police report, bridge inventory, and Google Earth Street View imagery were reviewed and compared to determine if the crash did occur on the bridge it was suspected to have occurred on, and if the roadside hardware impacted was in fact a NETC bridge rail or AGT. In some instances, it was necessary to adjust some of the crash data fields based on the review of the police reports. The two most common reasons for editing the crash data were:

1. Adding SPEED_LIMIT when coded as unknown based on SPEEDCARDS.kml file provided by NHDOT.
2. Changing PostHE, FHE, and FOHE vales based on the apparent sequence of events described in the crash narrative.

The final NHDOT ISPE dataset contained eight interactions with three different types of NETC bridge rails or AGTs. Additional tabulations of the data contained in the NHDOT ISPE dataset are provided in Table 13.

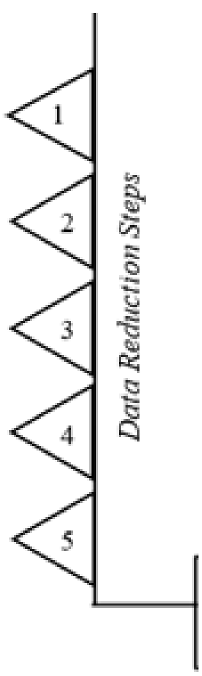
Similar to the discussion of sample size required to obtain statistically significant ISPE results for each individual NETC system in Section 3.2.1, an impossibly large number of years of crash data would have to be collected in New Hampshire as well. It was recommended that the NHDOT ISPE not distinguish between individual NETC systems, but rather consider the field performance of all the identified NETC rails and AGTs as a single system.

Table 13. NHDOT ISPE Dataset Tabulations

Severity	Quantity	Vehicle Type	Quantity
K – Fatal	0	MC – Motorcycle	0
A – Suspected Serious Injury	0	PC – Passenger Car	5
B – Suspected Minor Injury	0	PU – Pick-up truck/SUV	2
C – Possible Injury	0	SUT – Single Unit Truck	0
O – No Apparent Injury	8	TT – Tractor Trailer	0
U – Unknown	0	OTR - Other	1

Table 14. NHDOT Crash Data Reduction for ISPE of NETC Bridge Rails and AGTs

Crash Database	
Year	**Cases**
2013	29,721
2014	31,784
2015	33,895
2016	34,314



Data Reduction			
	Intent/Codes Removed	**Data Years**	**Cases Remaining**
1	Retain crashes coded with: Barrier/Fence Guard Rail Bridge/Pier '22' Bridge Pier or Support '23' Bridge Rail in the OBJECTSTRUCK field.	2013	1,367
		2014	1,375
		2015	1,349
		2016	1,431
2	No Sequence of Events fields available in the vehicle file so OBJECTSTRUCK was used. In multi-vehicle collisions it is not specified which vehicle collided with the SFUE, thus only single vehicle crashes were retained.	2013	1,321
		2014	1,327
		2015	1,288
		2016	1,372
3	Retain only crashes which occurred within 0.25 miles of a bridge with an NETC bridge rail/AGT.	2013	8
		2014	33
		2015	26
		2016	31
4	Retain only crashes which are likely to have occurred <u>on</u> a bridge with an NETC bridge rail/AGT.	2013	1
		2014	9
		2015	13
		2016	7
5	Retain crashes which are confirmed, based on review police report, to have interacted with a NETC bridge rail or AGT	2013	0
		2014	4
		2015	3
		2016	1

3.2.3 RIDOT

RIDOT provided the 2016-2020 crash data for use in this project. Each year was contained in a unique worksheet within the workbook and all worksheets had 24 fields (i.e., columns). Each row of data represented a single person involved in a motor vehicle crash, the number of crashes each year is shown in the upper left corner of Table 16. Next, only the person with the highest severity injury was retained in the dataset and other persons in the same crash were deleted. This resulted in each row of the dataset representing a single crash event with the most severe injury recorded. The data was reduced from the full dataset to only crashes with an NETC bridge rail or AGT as shown in the steps indicated by the flags in Table 16 and described in Chapter 4 of the NHDOT ISPE included with this report as Appendix C: Rhode Island DOT ISPE. The critical step was to identify if a crash occurred on a bridge with an NETC bridge rail or AGT installed on it and if the crash involved the NETC bridge rail or AGT. Once the nearest bridge to each crash was identified and the locations of the bridge and the crash were compared, the police reports were requested. The research team reviewed the crash narrative and diagram, bridge inventory data, and Google Earth Street View imagery to determine if the crash did occur on the bridge it was suspected to have occurred on, and if the roadside hardware impacted was in fact an NETC bridge rail or AGT. In some instances, it was necessary to adjust some of the crash data fields based on the review of the police reports. The two most common reasons for editing the crash data were:

1. Multiple impacts into the bridge rail were coded as a single event (i.e., one row). The dataset was modified such that each vehicle interaction with the bridge rail was included as additional row thereby capturing each interaction with the studied hardware.
2. Changing PostHE, FHE and FOHE based on sequence of events explained in the crash narrative.

The final RIDOT ISPE dataset contained 36 interactions with three different types of NETC bridge rails or AGTs. Additional tabulations of the data contained in the RIDOT ISPE dataset are provided in Table 15.

Similar to the discussion of sample size required to perform a statistically significant ISPE analysis distinguished by system (i.e., NAME field) above, an impossibly large number of years of crash data would have to be collected in Rhode Island. It was recommended, therefore, that the RIDOT ISPE not distinguish between systems, but rather considers the field performance of all the identified NETC rails as a single system.

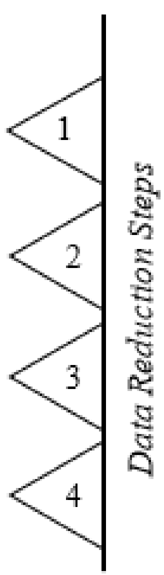
Table 15. RIDOT ISPE Dataset Tabulations

Severity	Quantity	Vehicle Type	Quantity
K – Fatal	0	MC – Motorcycle	0
A – Suspected Serious Injury	1	PC – Passenger Car	30
B – Suspected Minor Injury	8	PU – Pick-up truck/SUV	6
C – Possible Injury	3	SUT – Single Unit Truck	0
O – No Apparent Injury	24	TT – Tractor Trailer	0
U – Unknown	0	OTR - Other	0

Table 16. RIDOT Crash Data Reduction for ISPE of NETC Bridge Rails and AGTs

Crash Database	
Year	**Cases (Persons)**
2016	83,659
2017	80,036
2018	78,444
2019	88,278
2020	64,166

Data Reduction			
◁	**Intent/Codes Removed**	**Data Years**	**Cases Remaining (Vehicles)**
1	Retain crashes coded with: 'Guardrail Face' 'Guardrail End' 'Other Traffic Barrier' 'Bridge Rail' 'Bridge Pier or Support' in the Sequence 1-4 fields.	2016	658
		2017	648
		2018	589
		2019	720
		2020	692
2	Retain only crashes which occurred within 0.25 miles of a bridge with an NETC bridge rail/AGT.	2016	59
		2017	66
		2018	54
		2019	53
		2020	42
3	Retain only crashes which are likely to have occurred on a bridge with an NETC bridge rail/AGT.	2016	19
		2017	30
		2018	27
		2019	32
		2020	23
4	Retain crashes which are confirmed, based on review police report and photos, to have interacted with a NETC bridge rail or AGT	2016	6
		2017	7
		2018	5
		2019	9
		2020	9

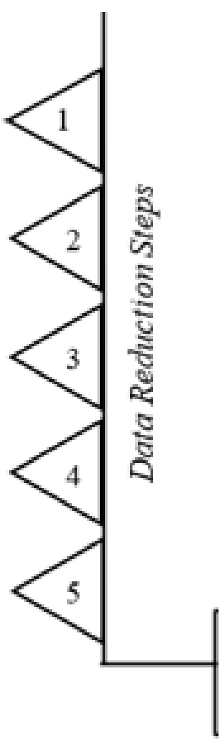


3.2.4 VTrans

Vtrans provided the 2015-2019 crash data to the research team. Each row of data in the vehicle file represented a single vehicle involved in a motor vehicle crash; the number of vehicles involved in crashes each year is shown in the upper left corner of Table 17. The data was reduced from the full dataset to only crashes with an NETC bridge rail or AGT in the steps indicated by the flags in Table 17. The critical step was to identify if a crash occurred on a bridge with an NETC bridge rail or AGT installed on it and if the crash involved the NETC bridge rail or AGT. There were some issues with the way crash location was recorded in the crash data making the process of locating the crashes difficult and somewhat questionable. Once the nearest bridge associated with each crash was identified to the best of the researcher's ability, and the locations (i.e., of the bridge and the crash) were compared, the police reports were requested. The research team reviewed the crash narrative, along with the bridge inventory and Google Earth Street View imagery to determine if the crash did occur on the bridge it was suspected to have occurred on, and if the roadside hardware impacted was in fact an NETC bridge rail or AGT. As seen in the lower right portion of Table 17, no crashes were identified and confirmed to have occurred with an NETC bridge rail or AGT in the 5-year period from 2015 through 2019.

Table 17. VTrans Crash Data Reduction for ISPE of NETC Bridge Rails and AGTs

Crash Database	
Year	**Vehicles**
2015	24,567
2016	22,407
2017	19,879
2018	19,534
2019	22,416



Data Reduction			
◁	**Intent/Codes Removed**	**Data Years**	**Cases Remaining**
1	Retain crashes coded with: 'Guard rail, curb' in the Veh 1 Collided With 1 or 2 field.	2015	467
		2016	531
		2017	487
		2018	484
		2019	469
2	Retain crashes which occurred in a town listed on the bridge inventory: Bennington, Bristol, Castleton, Concord, Londonderry, Marlboro, Richford, Townshend, Hubbardton	2015	29
		2016	33
		2017	24
		2018	33
		2019	20
3	Retain only crashes which occurred within 0.25 miles of a bridge with an NETC bridge rail/AGT, or questionable GPS.	2015	8
		2016	6
		2017	3
		2018	6
		2019	1
4	Retain only crashes which are likely to have occurred on a bridge with an NETC bridge rail/AGT or questionable GPS.	2015	7
		2016	6
		2017	3
		2018	1
		2019	1
5	Retain crashes which are confirmed, based on review police report and photos, to have interacted with a NETC bridge rail or AGT.	2015	0
		2016	0
		2017	0
		2018	0
		2019	0

3.2.5 ConnDOT

As discussed in the Section 3.1.5, ConnDOT did not use the standard NETC bridge railings or AGTs so ConnDOT did not have any bridge rails that fell within the scope of this research project. No Connecticut crash data was reviewed and an ISPE dataset was not assembled.

3.2.6 MassDOT

As discussed in the Section 3.1.6, MassDOT did not use the standard NETC bridge railings or AGTs so MassDOT did not have any bridge rails that fell within the scope of this research project. No Massachusetts crash data was reviewed and an ISPE dataset was not assembled.

4 Conduct ISPEs

An ISPE of the NETC bridge railings and AGTs was conducted using the assembled ISPE datasets. The evaluation measures were established according to the *ISPE Guidance Document* for longitudinal barriers. The evaluation measures considered: (1) the structural adequacy of the NETC bridge railings and transitions; (2) occupant risk through consideration of the crash severity; and (3) post impact vehicle trajectory and vehicle orientation.

The assembled ISPE dataset was reviewed to determine if assessing each of the relevant evaluation measures was feasible. The *ISPE Guidance Document* explains "it is conceivable that a jurisdiction does not have the necessary data available to complete each of these evaluation measures. It is suggested that each of the measures be attempted using the prepared dataset." (Carrigan and Ray 2022 [expected]) This approach allows for quantifying when data are and when data are not available. It was determined, through review of the assembled ISPE dataset and the *ISPE Guidance Document*, that the following Evaluation Measures are applicable to longitudinal barrier and may be assessed using the assembled data:

- Evaluation Measures for Structural Adequacy
    - Evaluation A (Safety Feature Breach): "Longitudinal barriers (i.e., SFUE=1) are installed to contain and redirect an impacting vehicle and thereby reduce the instances of vehicles crossing from the traffic side to the field side of the barrier. This evaluation measure is limited to longitudinal barriers. Both single and multivehicle crashes are included in this measure to include the full range of impact conditions the safety feature is exposed to while in-service."(Carrigan and Ray 2022 [expected])
- Evaluation Measures for occupant Risk
    - Evaluation F (Rollover): "Evaluation F is intended to evaluate influence of and propensity for rollover that results from interaction with the safety feature under evaluation. For this evaluation measure, only single vehicle crashes are used. Evaluation F is applicable to all SFUEs." (Carrigan and Ray 2022 [expected])
    - Evaluation H (Vehicle Mix): "Evaluation H is intended to evaluate occupant risk across and within the vehicle and speed mix the safety feature is exposed to while in-service. Evaluation H assesses the crash severity in terms of the maximum injury experienced by the impacting vehicle's occupants. This evaluation measure is limited to single vehicle crashes." (Carrigan and Ray 2022 [expected]) Evaluation H considered crashes where the impact with the safety feature is listed anywhere in the crash event (AHE), as the first harmful event (FHE), the most harmful event (MHE), and where the impact with the safety feature is listed as the first and only harmful event (FOHE).

- Evaluation Measures to Assess Vehicle Trajectory and Impact Orientation
    - Evaluation J (Secondary Impact on Roadside): "Evaluation J is intended to evaluate the relative risk of post-impact secondary crashes with fixed objects and terrain to crashes with no secondary impacts. For this evaluation measure only single unit crashes are used." (Carrigan and Ray 2022 [expected])
    - Evaluation K (Secondary Impact on Road): "Evaluation K is intended to evaluate the relative risk of post-impact secondary impacts with vehicles, pedestrians, terminals, crash cushions, and roadside barriers compared to no post-impact secondary impact. Each of these crash types indicate the vehicle

was redirected back onto the roadway. For this evaluation measure, multiple unit and single unit crashes are used." (Carrigan and Ray 2022 [expected])

- Evaluation M (Impact Orientation): "Evaluation M is intended to evaluate the relative risk of the impact orientation for [longitudinal barriers]. For this evaluation measure single unit crashes are used." (Carrigan 2021 [expected])

Several Evaluation Measures (i.e., B, C, and L) are not applicable to longitudinal barriers, therefore, they were not assessed. Information was not available within the assembled ISPE dataset to apply Evaluation Measure D (Occupant Compartment Penetration). Only the Rhode Island data included the information to complete Evaluation Measure M (Impact Orientation).

Two types of calculations are conducted for each Evaluation Measure: effect size (ES) and point estimates ($\hat{p}$). The calculated point estimates ($\hat{p}$) include R0, R1, and R2.

R0 = The proportion of fatal and serious (KA) crashes to total crashes when an expected outcome occurs.

R1 = The proportion of KA crashes to total crashes when an expected outcome does <u>not</u> occur.

R2 = The proportion of cases where the unexpected outcome occurred divided by total number of outcomes of the variable identified.

Each Evaluation Measure compares the proportion of KA crashes when an unexpected outcome occurs to the proportion of KA when the expected outcome occurs (i.e., ES = R1/R0). The expected outcomes conform to the design objectives of MASH crash tests. For example, Evaluation Measure A examines what happens when a vehicle breaches a longitudinal barrier in a crash (i.e., the unexpected outcome) to what happens when the vehicle is contained and redirected by the longitudinal barrier (i.e., the expected outcome). If the ratio of KA crashes where the barrier was breached to KA crashes when the barrier was not breached (i.e., contained or redirected) is greater than 1, then breaching is shown to be a harmful outcome. In other words, if the crash data show that fatal or severe injury is more likely to occur when the barrier is breached, then breaching is shown to be a more harmful outcome.

The consideration of the above Evaluation Measures is used to determine the actual in-field performance of roadside hardware and can be used to inform jurisdictional decisions about the continued use of each bridge rail and AGT or the need for design, construction, or maintenance improvements.

Four performance assessment levels were computed for each Evaluation Measure as proposed by Carrigan et al. (Carrigan and Ray 2022 [expected]):

1. The performance assessment was not limited by design vehicle or speed.
2. The performance assessment was limited to the design vehicles for which the safety feature was crash tested.
3. The performance assessment was limited to the design speed for which the safety feature was crash tested.
4. The performance assessment was limited to both the safety feature design vehicle and design speed for which the safety feature was crash tested." (Carrigan and Ray 2022 [expected])

4.1 Individual State Results

4.1.1 MaineDOT

As discussed previously in this report, the MaineDOT data was used to perform an investigative ISPE of NETC bridge railings and AGTs. Crash data collected included all reported crashes occurring on public state-maintained and locally maintained roads within the State of Maine. The data collection period began on January 1, 2013 and ended on December 31, 2020, encompassing eight full years of data collection. An inventory of bridges with NETC steel bridge rails and AGTs was developed. The ISPE was limited to crashes occurring on those bridges where either an NETC bridge rail or associated AGT was installed. The MaineDOT ISPE considered the following Evaluation Measures:

- A Safety Feature Breach
- F Rollover
- H Crash Severity - Vehicle Mix
- J Secondary Impact on the Roadside
- K Secondary Impact on Roadway

The MaineDOT NETC bridge rail and AGT ISPE evaluated the structural adequacy, occupant risk, and vehicle trajectory for NETC rails and AGTs using the evaluation measures listed above. The results of the MaineDOT ISPE are summarized below in Table 18 where the point estimates are shown in the right-hand columns as percentages with the 85th percentile confidence range shown are shown in brackets. For example, the first row in Table 18 presents the results of Evaluation Measure A, breaching the barrier. The results for breaching the barrier in a collision where the NETC system is the first and only harmful event are shown to be 1.3 (0.4, 4.9). This is interpreted as 1.3 percent of the vehicles that struck the NETC system in a first and only harmful event breached the barrier. The 85th percent confidence interval is between 0.4 and 4.9 percent.

The first Evaluation Measure listed in Table 18 (A: Barrier Breach) examines the likelihood of breaching the NETC system. NCHRP Project 22-12(03) summarized available literature on the risk of breaching various bridge rails and found that approximately 10.6 percent of passenger vehicles breach 27-inch tall bridge rails while 2.5 percent of passenger vehicles breach 32-inch bridge rails. (Ray and Carrigan 2015) The risk of breaching the studied NETC bridge rails and AGT was found to be 2.0 (0.8, 5.3) percent for all vehicle types which impacted the hardware on roads with all posted speed limits. For design vehicles at the design posted speed limit, 1.3 (0.4, 4.9) percent breached the barrier. The NETC bridge rails in this study have top rail heights of 34 inches (NETC two-bar), 42 inches (NETC three- and four-bar), and 55 inches (MaineDOT four-bar traffic and bicycle rail). The risk of a fatal or serious injury occurring increase by a factor of 12 when the barrier was breached indicating the serious consequences of breaching the barrier system. The in-service performance of the NETC systems with respect to containment of vehicles impacting the studied NETC rails and AGTs is similar or a little better than other studied bridge rails.

Vehicle rollover is assessed with Evaluation Measure F in Table 18. The highest percentage of rollover events was 4.1 (1.5, 10.4) percent for design vehicles at design speeds. The increased risk to vehicle occupants could not be assessed because there were no fatal or serious injury crashes involving a rollover in the MaineDOT data.

Evaluation Measure H examines the risk of fatal or serious injury to vehicle occupants. The occupant risk is the most important evaluation measure since it is a direct indication of how effective the hardware is at minimizing fatal or serious injuries. There were no fatal crashes with the NETC bridge rail and AGT within the assembled dataset covering 2013-2020, however, serious injuries were observed for some sequences of events. While there is not a national benchmark for occupant risk, a recent meta-analysis of ISPEs which studied the occupant risk of interaction with rigid New Jersey barriers found the risk of a serious or fatal crash when the interaction with the rigid barrier is the first and only harmful event in the sequence of event is 4.1

(3.5, 4.6). (Carrigan and Ray 2019) No fatal or serious injury crashes were observed with NETC systems when the vehicle collision was the first and only harmful event for any of the four performance levels although the 85^{th} percentile confidence ranges were all between zero and 6.6 percent. Notably, the risk of a serious or fatal crash when the hardware was impacted anywhere in the sequence of events, first in the sequence of events, or is the most harmful event is the sequence are also lower than the risk found previously for rigid barriers. The in-service performance of the NETC hardware with respect to occupant risk in the MaineDOT data is similar and somewhat better than other similar rigid longitudinal barriers.

Secondary collisions on the roadside (Evaluation Measure K) were always 2 (0.5, 7.4) percent or less. The increased risk could not be evaluated since there were no fatal or serious injury crashes where a secondary collision on the roadside occurred. These data are also consistent with the earlier breach evaluation (Evaluation Measure A) that showed that breach was relatively rare (i.e., two percent or less of the cases0.

This study found post impact secondary collisions on the roadway (Evaluation Measure K) are higher than other post impact secondary collisions for this hardware (e.g., rollover or secondary collisions on the roadside). Previous studies of rigid longitudinal barriers have indicated that the post impact secondary collisions on the roadway have a 0.75 risk of occurrence and a three times increase in severity. (Ray, Michie et al. 1987) The risk of post impact secondary collisions on the roadway with the NETC hardware was found to be 22.2 (16.0,30.0) percent, which is considerably lower than other rigid barriers but still quite large. When a second crash occurs on the roadway after an interaction with NETC hardware, the risk of a fatal or serious injury crash increases by a factor of 3.0 (1.1, 7.7). While MASH crash testing acceptance criteria has removed secondary roadway collisions as an evaluation factor, the NETC and other similar hardware appear to have demonstrated a reduced risk of post-impact secondary collisions on the roadway when compared to other rigid longitudinal barriers. The in-service performance of the NETC hardware appears from these MaineDOT data to be better than other similar rigid longitudinal barriers with respect to secondary events on the roadway.

The MaineDOT data did not include information on vehicle orientation at impact so Evaluation Measure M was not assessed.

The MaineDOT ISPE found that the studied systems have similar or better field performance than other similar systems across all performance outcomes using all the evaluation measures that could be assessed. (Ray, Michie et al. 1987, Ray and Carrigan 2015, Carrigan and Ray 2019) This ISPE evaluated the structural adequacy, occupant risk, and vehicle trajectory for NETC rails and AGTs using the breach, rollover, occupant risk, secondary collision on the roadside, and secondary collisions on the roadway. This field performance evaluation demonstrates the crashworthiness of the studied systems and supports their continued use. The full MaineDOT ISPE report can be found in Appendix A: Maine DOT ISPE.

Table 18. Results of the 2013-2020 MaineDOT ISPE of NETC Bridge Rails and AGTs (99 crashes)

			Percent of unexpected event			
Evaluation Measure	**Unexpected Event**	**Increased risk of a fatal or serious injury event when the unexpected event occurs for all vehicles and posted speed limits**	**All vehicles and posted speed limits**	**Only design vehicles and all posted speed limits**	**All vehicles and only design speed limits**	**Only design vehicles and design speed limits**
A	Barrier Breach	12.0 (3.5,41.4)	2.0 (0.8, 5.3)	2.2 (0.8, 5.6)	1.3 (0.3, 4.8)	1.3 (0.4, 4.9)
F	Rollover	0.0 (Null)	3.0 (1.1, 7.7)	3.1 (1.2, 8.0)	3.9 (1.5, 10.0)	4.1 (1.5, 10.4)
H	A fatal or serious injury event involving an NETC bridge rail or AGT in:					
	- Any harmful event		2.4 (0.9, 6.1)	2.5 (1.0, 6.5)	3.0 (1.1, 7.7)	3.1 (1.2, 8.0)
	- First harmful event		1.5 (0.4, 5.4)	1.5 (0.4,5.7)	1.9 (0.5, 7.0)	2.0 (0.5,7.3)
	- Most harmful event		1.3 (0.4, 4.9)	1.4 (0.4, 5.1)	1.6 (0.4,6.0)	1.7 (0.4, 6.2)
	- First and only harmful event		0.0 (0.0, 4.0)	0.0 (0.0, 4.1)	0.0 (0.0, 5.3)	0.0 (0.0, 6.6)
J	Secondary Collision on Roadside	0.0 (Null)	1.5 (0.4, 5.5)	1.6 (0.4, 5.8)	2.0 (0.5, 7.2)	2.0 (0.5, 7.4)
K	Secondary Collision on Roadway	3.0 (1.1,7.7)	22.2 (1.6, 30.0)	21.7 (15.5, 30.0)	23.6 (16.4, 32.8)	24.5 (17.1, 33.9)

M	Non-oblique impact angle	NA	NA	NA	NA	NA

4.1.2 NHDOT

The NHDOT investigative ISPE of NETC bridge railings and AGTs included all reported crashes occurring on public state-maintained and locally maintained roads within the State of New Hampshire. The study area was further limited to bridges which NHDOT is responsible for inspecting. The data collection period began on January 1, 2013, and ended on December 31, 2016, encompassing four full years of data collection. An inventory of bridges with NETC steel bridge rails and AGTs was developed; the ISPE was limited to crashes occurring on those bridges which also involved either the NETC steel bridge rail or AGT.

Eight interactions with the NETC bridge rails and AGTs were observed in New Hampshire in the 2013 through 2016 NHDOT data. There were no observed serious or fatal injuries and there were no observed breaches. There were no observed post-impact secondary collisions or rollovers. Due to the very small number of cases and the absence of any fatal or serious injury crashes, the evaluation measures were not calculated. Similarly, future performance goals have not been established since there was insufficient data.

Although data exists in the NHDOT ISPE dataset, more observations are needed to form actionable conclusions. It is recommended to combine the results from the NHDOT NETC Bridge Rail ISPE Report with the results from Maine and Rhode Island in a meta-analysis which is anticipated to provide more robust results.

4.1.3 RIDOT

The RIDOT investigative ISPE of NETC bridge railings and AGTs included all reported crashes occurring on public roads within the State of Rhode Island. The bridges for which RIDOT are responsible for inspecting defined the study area. The data collection period began on January 1, 2016, and ended on December 31, 2020, encompassing five full years of data collection. An inventory of bridges with NETC steel bridge rails and AGTs was developed; the ISPE was limited to crashes occurring on those bridges which also involved either the NETC steel bridge rails or AGTs. The RIDOT ISPE considered the following Evaluation Measures:

- A Safety Feature Breach
- F Rollover
- H Crash Severity - Vehicle Mix
- K Secondary Impact on Roadway
- M Impact Orientation

The results for the ISPE of NETC systems in Rhode Island are summarized below in Table 19. As discussed above for the MaineDOT dataset, previous studies have shown that approximately 10.6 percent of passenger vehicles breach 27-inch tall bridge rails while 2.5 percent of passenger vehicles breach 32-inch bridge rails. (Ray and Carrigan 2015) As in Maine, the NETC bridge rails in Rhode Island had top rail heights of 34 inches (NETC two-bar) ,42 inches (NETC three- and four-bar), and 55 inches (MaineDOT four-bar traffic and bicycle rail). The risk of breaching the studied NETC bridge rails and AGT in Rhode Island was found to be 8.6 (3.8, 17.9) percent for all vehicle types which impacted the hardware on roads with all posted speed limits. For design vehicles at the design posted speed limit, 11.1 (5.1, 22.7) percent breached the barrier. These values are larger than those observed in Maine although the 85th percentile confidence limits overlap indicating they are consistent, and the larger values are likely due to the small sample size of 36 cases versus 99 cases in Maine. The risk of a fatal or serious injury when a barrier breach occurs could not be calculated because there were no fatal or serious injury crash observed in Rhode Island. The in-service performance of the NETC systems with respect to containment of vehicles impacting the studied NETC rails and AGTs is similar or a little better than other studied bridge rails.

The highest percentage of rollover events (Evaluation Measure F) was 11.1 (4.3, 26.0) percent for design vehicles at design speeds. Again, the point estimate was much higher in Rhode Island than in Maine but the 85th percentile confidence intervals overlap so the results are consistent. The increased risk to vehicle occupants could not be assessed because there were no fatal or serious injury crashes involving a rollover in the RIDOT data.

There were no fatal crashes with the NETC bridge rail and AGT within the assembled RIDOT dataset covering 2016-2020, however, some serious injury crashes were observed. As discussed for the Maine data above, the risk of a serious or fatal crash (Evaluation Measure H) when the interacting with a rigid New Jersey barrier a first and only harmful event crash has been found to be 4.1 (3.5, 4.6). (Carrigan and Ray 2019) Analysis of the NETC bridge rails and AGTs in the RIDOT data found the fatal and serious injury risk in crashes where the interaction with the NETC hardware was judged the most harmful event for design vehicles at the design speed limits was 4.6 (1.2, 15.7). The fatal and serious injury risk in first and only harmful events and first harmful events was zero because there were no observed fatal or serious injury crashes in those categories. As for the other evaluation measures, the RIDOT estimates are higher than observed in Maine although the 85th percentile confidence intervals overlap. The NETC hardware in-service performance in terms of occupant risk appears to be similar to other rigid concrete bridge railings.

The RIDOT data indicated that there is a higher risk of post impact secondary collisions on the roadway (Evaluation Measure K) than other post impact secondary collisions for this hardware (e.g., rollover (Evaluation Measure F) or secondary collisions on the roadside (Evaluation Measure J)). Previous studies of rigid longitudinal barriers have indicated that the post impact secondary collisions on the roadway have a 0.75 risk of occurrence and a three times increase in severity. (Ray, Michie et al. 1987) The risk of post impact secondary collisions on the roadway with the NETC hardware for design vehicles at design speeds was found to be 35.0 (21.7, 51.1), which is lower than other rigid barriers and a little higher than what was observed in Maine. While MASH crash testing acceptance criteria has removed secondary roadway collisions as an evaluation factor, this hardware has demonstrated a reduced risk of post-impact secondary collisions on the roadway when compared to other rigid longitudinal barriers. The increased risk of fatal and serious injury in secondary roadway impacts could not be calculated since there were no fatal or serious injury crashes in that category.

The RIDOT data indicated that nearly 55 percent of impacting vehicles impact the barrier in an unexpected orientation (Evaluation Measure M) suggests that impacts on the roadway are more variable that what is accounted for in crash testing. Despite this fact, the low effect size (i.e., null) shows that crashes with unexpected orientation are not leading to dramatically more severe outcomes in the studied crashes.

This ISPE evaluated the structural adequacy, occupant risk, and vehicle trajectory for NETC rails and AGTs using the six evaluation measures shown in Table 19. The RIDOT ISPE shows that the studied systems have demonstrated similar performance to other similar systems across all three performance outcomes. This exemplary field performance demonstrates the crashworthiness of the studied systems and supports the continued use of the NETC bridge rails and AGTs.

Table 19. Results of the 2016-2020 RIDOT ISPE of NETC Bridge Rails and AGTs (36 crashes)

			Percent of unexpected event			
Evaluation Measure	**Unexpected Event**	**Increased risk of a fatal or serious injury event when the unexpected event occurs for all vehicles and posted speed limits**	**All vehicles and posted speed limits**	**Only design vehicles and all posted speed limits**	**All vehicles and only design speed limits**	**Only design vehicles and design speed limits**
A	Barrier Breach	0.0 (Null)	8.6 (3.8, 17.9)	8.6 (3.9, 17.9)	11.1 (5.1, 22.7)	11.1 (5.1, 22.7)
F	Rollover	0.0 (Null)	8.0 (3.1, 19.4)	8.0 (3.1, 19.4)	11.1 (4.3, 26.0)	11.1 (4.3, 26.0)
H	A fatal or serious injury event involving an NETC bridge rail or AGT in:					
	- Any harmful event		3.0 (0.8, 10.8)	3.0 (0.8, 10.8)	4.0 (1.1, 14.0)	4.0 (1.1, 14.0)
	- First harmful event		0.0 (0.0, 07.7)	0.0 (0.0, 7.7)	0.0 (0.0, 10.3)	0.0 (0.0, 10.3)
	- Most harmful event		3.5 (0.9, 12.2)	3.4 (0.9, 12.2)	4.6 (1.2, 15.7)	4.6 (1.2, 15.7)
	- First and only harmful event		0.0 (0.0, 12.2)	0.0 (0.0, 12.2)	0.0 (0.0, 15.9)	0.0 (0.0, 15.9)
J	Secondary Collision on Roadside	0.0 (Null)	0.0 (0.0, 7.7)	0.0 (0.0, 7.7)	0.0 (0.0, 10.3)	0.0 (0.0, 10.3)
K	Secondary Collision on Roadway	0.0 (Null)	37.0 (25.0, 50.9)	37.0 (25.0, 50.9)	35.0 (21.7, 51.1)	35.0 (21.7, 51.1)

M	Non-oblique impact angle	0.0 (Null)	54.2 (39.8, 67.9)	54.2 (39.8, 67.9)	47.1 (30.9, 63.8)	47.1 (30.9, 63.8)

The RIDOT NETC bridge rail and AGT ISPE evaluated the structural adequacy, occupant risk, and vehicle trajectory for NETC rails and AGTs using the evaluation measures listed above. The RIDOT ISPE found that the studied systems have similar or better field performance than other similar systems across all three performance outcomes. (Ray, Michie et al. 1987, Ray and Carrigan 2015, Carrigan and Ray 2019) This exemplary field performance demonstrates the crashworthiness of the studied systems and supports their continued use. The full RIDOT ISPE report can be found in Appendix C: Rhode Island DOT ISPE.

4.1.4 VTrans

The research team was unable to identify or confirm any crashes with NETC bridge rails or AGTs in the State of Vermont during the 5-year period from 2015 through 2019. Therefore, an ISPE of NETC bridge rails and AGTs could not be conducted in Vermont.

4.1.5 ConnDOT

As discussed in the Section 3.1.5 of this report, ConnDOT does not have any bridge rails that fall within the scope of this research project, therefore, an ISPE of NETC bridge rails and AGTs was not conducted in Connecticut.

4.1.6 MassDOT

As discussed in the Section 3.1.6 of this report, MassDOT does not have any bridge rails that fall within the scope of this research project, therefore, an ISPE of NETC bridge rails and AGTs was not conducted in Massachusetts.

4.2 Meta-Analysis ISPE Results

The NCHRP Project 22-33 *ISPE Guidance Document* was developed specifically to promote collaboration and sharing of data between jurisdictions. The *ISPE Guidance Document* not only provides a methodology to assess the in-service performance of the NETC steel bridge rails and AGTs but also provides the methodology for NETC member States to collaborate and document whether acceptable field performance has been achieved. This collaboration allows agencies to combine data sets and achieve more statistically meaningful results by increasing the effective sample size.

Meta-analysis is a systematic way of combining knowledge from multiple previous studies while considering the study quality of each in arriving at a final estimate. Combining the datasets allows for calculation of the effect sizes and point estimates of the evaluation measures with higher statistical precision due to the increased number of cases. As discussed in previous sections, there were no NETC bridge rails or AGTs found in Connecticut, Vermont, or Massachusetts. Ninety-nine cases were observed in Maine, 8 in New Hampshire, and 36 in Rhode Island. The data from Maine, New Hampshire, and Rhode Island were combined into a single dataset for a meta-analysis. Combining the data is appropriate in this case since the same hardware is studied in each jurisdiction and the data collection method was the same in each jurisdiction.

The Maine and Rhode Island ISPEs contained sufficient data to perform a meta-analysis of Evaluation Measure A, F, H, and K. Evaluation Measure H was limited to those crashes where an NETC bridge rail or AGT was listed anywhere in the sequence of events or as the most harmful event in the sequence of events because there were no fatal or serious injury first harmful event crashes in New Hampshire and Rhode Island. Similarly, there were no fatal or serious injury crashes where the vehicle had a secondary crash on the roadside so Evaluation Measure J could also not be calculated. The orientation data needed for Evaluation Measure M was only available in Rhode Island, so Evaluation Measure M was not calculated. The results are shown in Table 20.

The results of the NETC bridge rail and AGT ISPE meta-analysis evaluated the structural adequacy, occupant risk, and vehicle trajectory for NETC rails and AGTs using the evaluation measures listed in Table 20. The meta-analysis provides evidence that the studied systems have similar or better field performance than other similar systems across all three performance outcomes. (Ray, Michie et al. 1987, Ray and Carrigan 2015, Carrigan and Ray 2019) This exemplary field performance demonstrates the crashworthiness of the studied systems and supports their continued use. The full NETC bridge rail and AGT ISPE meta-analysis report is provided in Appendix D: Evaluation of NETC Bridge Railings and AGTs – Meta-Analysis.

Table 20. Meta-Analysis of NETC Bridge Rails and AGTs in Maine, New Hampshire, and Rhode Island for All Vehicle Types and All Posted Speed Limits

			Percent of unexpected event			
Evaluation Measure	**Unexpected Event**	**Increased risk of a fatal or serious injury event when the unexpected event occurs for all vehicles and posted speed limits**	**All vehicles and posted speed limits**	**Only design vehicles and all posted speed limits**	**All vehicles and only design speed limits**	**Only design vehicles and design speed limits**
A	Barrier Breach	0.0 (Null)	0.0225	0.0242	0.0143	0.0150
F	Rollover	0.0 (Null)	0.0325	0.0341	0.0425	0.0444
H	A fatal or serious injury event involving an NETC bridge rail or AGT in: - Any harmful event - Most harmful event		 0.0242 0.0143	 0.0260 0.0149	 0.0308 0.0177	 0.0322 0.0184
K	Secondary Collision on Roadway	0.0 (Null)	0.2362	0.2328	0.2472	0.2562

5 Implementation and Technology Transfer Strategy

The objective of this work was to determine the in-service performance of the NETC steel bridge railings and AGTs. Basing roadside hardware decisions and policy on observable data ensures that scarce agency resources are targeted at policies and design decisions that will achieve the lowest practical risk to highway users. The next critical step is to implement the findings broadly within the New England Transportation Agencies to support informed design and policy decisions with respect to the NETC bridge railings and AGTs. An additional step may be to disseminate the methodology and results to a larger national audience to allow other transportation agencies to benefit from this research. The following sections describe a detailed implementation plan for the products of this research.

The leadership of the NETC Technical Committee and individual Transportation Agencies will be essential for the implementation of this research. Each of these agencies have the potential to benefit from this confirmation that the studied hardware is performing in the field as expected.

The following implementation plan identifies the desired outcomes of implementing these research findings. Each of the following section titles indicates a particular desired outcome. A specific recommendation to achieve the outcomes is presented at the end of each section in an italic font. Suggestions have been made for the parties best suited to execute each identified recommendation. The conclusion of this plan summarizes the identified recommendations to achieve the following desired outcomes:

- Propose additional data fields for bridge inventory and police reports.
- ISPE dataset is populated as crashes occur allowing for continued performance monitoring.
- ISPE results are used in decision making and policy development.
- ISPE results are shared among transportation agencies.
- Keeping all NETC states updated on future implementation efforts.
- Join the In-Service Performance Evaluation of Roadway Safety Features pooled fund.

5.1 Desired Outcomes

The best possible outcomes of implementing this research have been outlined in the following sections. The outcomes are indicated by the section titles and the specific recommendations are provided at the end of each section in an italic font.

5.1.1 Propose Additional Data Fields for Bridge Inventory and Police Reports

Additional data fields can be collected to increase the accuracy and completeness of ISPEs like this one. Generally being able to link between inventory databases and the electronic crash database by using either route, direction and milepost, or GPS coordinates will ensure that crashes in the vicinity of different roadside safety features can be more readily identified. Including the type of bridge railing and installation date within bridge inventories will support identifying the type of bridge rail installed at the time of the crash. Data fields that could improve crash data include a field which indicates if the vehicle breached the barrier (similar to a field in the Washington State crash data), if the safety feature penetrated the occupant compartment (similar to a filed in the South Carolina crash data), and the initial contact point of the vehicle with the safety feature. The initial contact point is included in the MMUCC form. *The NETC member states are encouraged to consider updating bridge inventory and crash report forms to collect additional data which can lead to more robust ISPE studies.*

5.1.2 IPSE Dataset is Populated as Crashes Occur Allowing for Continued Performance Monitoring

The initial step of developing an inventory of NETC steel bridge railing and AGT crashes was undertaken during this research. Standardized data collection fields and methodologies as well as inclusion criteria were developed. Continuing to populate the ISPE dataset using the developed methodology and inclusion criteria will provide a dataset which can be used to monitor the field performance of the NETC bridge railings and AGT over time. *The NETC member states are encourages to continue to populate the ISPE dataset as crashes with NETC bridge railing and AGTs occur.*

5.1.3 ISPE Results are Used in Decision Making and Policy Development

Roadside hardware decisions and policy based on observable field performance ensure that resources are most effectively used to reduce fatal and serious injury run-off-road crashes. This hardware was found to have acceptable field performance, therefore, the ISPE provides support for the continued use of the current hardware policy. The continued monitoring of this hardware will provide data-driven support for the continued or discontinued use of this hardware and reduce to need to continually "upgrade" to the next crash testing standard. *The NETC member states are encouraged to periodically update the ISPE analysis to monitor in-field performance of the studied hardware. The NETC member states are encouraged to use the ISPE results now and into the future to support decisions to maintain existing hardware, when practical, in addition to reliance on evolving crash testing guidance.*

5.1.4 ISPE Results are Shared Among Transportation Agencies

ISPE results generally do not receive wide circulation. Transportation Agencies working together can increase not only the pool of data, but also make others aware of what is being studied in other regions. Meetings such as the Transportation Research Board (TRB) Annual Meeting and the AKD20 Committee on Roadside Safety Design mid-year meeting provide excellent opportunities to disseminate the results of this project to a broad range of transportation officials. *The NETC member states are encouraged to share their ISPE results among other transportation agencies and present these findings at meetings and conferences.*

5.1.5 Keep All NETC States Updated on Future Implementation Efforts

There is value in the NETC states scheduling a recurring or standing meeting to keep each other informed of their ongoing ISPE efforts. These meetings would prove especially useful as some states continue to collect data to discuss trends in hardware performance. It would also be useful for a member to take responsibility for updating the meta-analysis spreadsheet every five or so years and updating the meta-analysis as more data is collected and analyzed at the state level. *The NETC member states are encouraged to meet annually to discuss future progress in the NETC bridge rail in-service performance evaluation studies.*

5.1.6 Join the In-Service Performance Evaluation of Roadway Safety Features Pooled Fund.

States that are interested in pursuing in-service performance evaluations of other roadway safety features should consider joining the In-Service Performance Evaluation of Roadway Safety Features pooled fund being led by ADOT. This pooled fund will provide opportunity for partner states to help influence what roadway safety features are studied and contribute their valuable data to the analysis effort. *The NETC member states are encouraged to join the ISPE of Roadway Safety Features Pooled Fund.*

5.2 Summary

"Simply stated, each member of the community has a vested interest in the performance of hardware on the roadside and each member can play a valuable role in the institutionalization of ISPEs." (Carrigan 2015) AASHTO, through the NCHRP, has provided the catalyst to develop this collaborative approach to ISPEs through a series of recent research projects. The NETC member states are an early adopter of those research projects.

It is not enough to create the list of outcomes shown above. Successful implementation of this research will necessitate identifying and empowering champions for each of the outcomes. Recommendations have been provided in italicized text through this implementation plan that indicate the champions and stakeholders who might achieve the desired outcomes. The recommendations are summarized in Table 21.

Table 21. Summary of Outcomes, Recommendations, and Stakeholders.

Outcome	Recommendations	Stakeholders
Propose additional data fields for bridge inventory and police reports	The NETC member states are encouraged to consider updating bridge inventory and crash report forms to collect additional data which can lead to more robust ISPE studies.	NETC member states
ISPE dataset is populated as crashes occur allowing for performance monitoring.	The NETC member states are encourages to continue to populate the ISPE dataset as crashes with NETC bridge railing and AGTs occur.	NETC TC
ISPE results are used in decision making and policy development.	The NETC member states are encouraged to periodically update the ISPE analysis to monitor in-field performance of the studied hardware.	NETC member states
ISPE results are used in decision making and policy development.	The NETC member states are encourages to use the ISPE results now and into the future to support decisions to maintain existing hardware, when practical, in addition to reliance on evolving crash testing guidance.	NETC member states
ISPE results are shared among transportation agencies.	The NETC member states are encouraged to share their ISPE results among other transportation agencies *and present these findings at meetings and conferences*.	NETC TC
Keep all NETC states updated on future implementation efforts	The NETC member states are encouraged to meet annually to discuss future progress in the NETC bridge rail in-service performance evaluation studies.	NETC TC
Join the in-service performance evaluation of roadway safety features pooled fund	The NETC member states are encouraged to join the ISPE of Roadway Safety Features Pooled Fund.	NETC member states

6 Conclusions

"When acceptable performance is achieved, the safety feature is considered crashworthy regardless of which crash testing standard the safety feature was developed under." (Carrigan and Ray 2022 [expected]) Establishing that these long-standing designs are performing well in the field provides further confidence that the current designs adequately meet the higher performance criteria of MASH without further full-scale testing or FEA.

The ISPEs conducted under this research project found the containment of vehicles impacting the studied NETC rails and AGTs is similar or better than other studied bridge rails. This study also found the risk of post impact secondary collisions on the roadway with NETC bridge rails and AGTs is considerably lower than other rigid barriers. While MASH crash testing acceptance criteria has removed secondary roadway collisions as an evaluation factor, this hardware has demonstrated a reduced risk of post-impact secondary collisions on the roadway when compared to other rigid longitudinal barriers. This study also found the risk of a serious or fatal injuries when the studied hardware was impacted is lower than the risk found previously for rigid barriers. This studied hardware has demonstrated a reduced occupant risk when compared to other rigid longitudinal barriers. This ISPE shows that the studied systems have demonstrated similar or better field performance than other similar systems across all three performance outcomes. This exemplary field performance demonstrates the crashworthiness of the studied systems and supports the continued use.

7 References

AASHTO (1989). Guide Specifications for Bridge Railings. Washington, D.C., American Association of State, Highway and Transportation, Officials**:** 49.

AASHTO (2009). Manual for Assessing Safety Hardware. Washington, D.C., American Association of State Highway and Transportation Officials**:** 259.

AASHTO (2016). Manual for Assessing Safety Hardware. Washington, D.C., American Association of State Highway and Transportation Officials**:** 259.

AASHTO (2019). Manual for Bridge Element Inspection**:** 124p.

Alberson, D. C., C. E. Buth, W. L. Menges and R. R. Haug (2006). NCHRP Report 350 Testing and Evaluation of NETC Bridge Rail Transitions. College Station, TX, Texas Transportation Institute New England Transportation Consortium 122p.

Bronstad, M. E. and J. D. Michie (1974). Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances. Washington, D.C., Transportation Research Board, National Cooperative Highway Research Program.

Carrigan, C. E. (2015). "Research for AASHTO Standing Committee on Highways. Task 360. Development of a Strategic Plan for the Technical Committee on Roadside Safety (TCRS)."

Carrigan, C. E. (2021 [expected]). Multi-State In-Service Performance Evaluations of Roadsafe Safety Hardware. Washington, D.C., National Cooperative Highway Research Program, Transportation Research Board.

Carrigan, C. E. and M. H. Ray (2019). In-Service Performance Evaluation of Longitudinal Barrier to Study Occupant Risk. <u>Transportation Research Board</u>. Washington, D.C.

Carrigan, C. E. and M. H. Ray (2022 [expected]). Multi-State In-Service Performance Evaluations of Roadsafe Safety Hardware. Washington, D.C., National Cooperative Highway Research Program, Transportation Research Board.

Michie, J. D. (1981). Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. Washington, D. C., Transportation Research Board, National Cooperative Highway Research Program**:** 42 p.

Plaxico, C. A. and E. M. Ray (2020). Development of MASH Computer Simulated Steel Bridge Rail and Transition Details.

Ray, M. H. and C. E. Carrigan (2015). NCHRP Web-Only Document 307: Recommended Guidelines for the Selection of Test Levels 2 Through 5 Bridge Rails. Washington, D. C., Transportation Research Board, National Cooperative Highway Research Program.

Ray, M. H., J. D. Michie, W. W. Hunter, J. S. Stutts, I. Southwest Research and A. Federal Highway (1987). Ealuation of Design Analysis Procedures and Acceptance Criteria for Roadside Hardware. Volume V. Hazards of the Redirected Car. Final Report**:** 69 p.

Ray, M. H., J. Weir and J. Hopp (2003). In-Service Performance Evaluation Procedures Manual. <u>In-Service Evaluation of Traffic Barriers</u>. Washington D.C., Transportation Research Board, National Cooperative Highway Research Program. **NCHRP Report 490:** 199 p.

Ray, M. H., J. Weir and J. Hopp (2003). In-Service Performance of Traffic Barriers. Washington D.C., Transportation Research Board, National Cooperative Highway Research Program. **NCHRP Report 490:** 199 p.

Ross, H. E., D. L. Sicking, R. A. Zimmer and J. D. Michie (1993). Recommended Procedures for the Safety Performance Evaluation of Highway Features. Washington, D.C., Transportation Research Board, National Cooperative Highway Research Program**:** 142.

Appendix A: Maine DOT ISPE

Appendix B: New Hampshire DOT ISPE

Appendix C: Rhode Island DOT ISPE

Appendix D: Evaluation of NETC Bridge Railings and AGTs – Meta-Analysis