



U.S. Department  
of Transportation

Federal Highway  
Administration

# MASH Roundtables



## Summary of Proceedings



Cover photos source: FHWA

**ZERO** IS OUR GOAL  
A SAFE SYSTEM IS HOW WE GET THERE

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## I. Introduction

In response to a call for service request first initiated by the Colorado Division, the Federal Highway Administration (FHWA) hosted a series of three roundtables regarding implementation of the *American Association of State Highway and Transportation Officials' (AASHTO's) Manual for Assessing Safety Hardware (MASH)*.<sup>1</sup> The purpose of the roundtables was to provide venues for State Departments of Transportation (DOTs) and Federal Land Management Agencies (FLMAs) to share information to improve their knowledge of crashworthy safety hardware and implementation of MASH as it relates to:

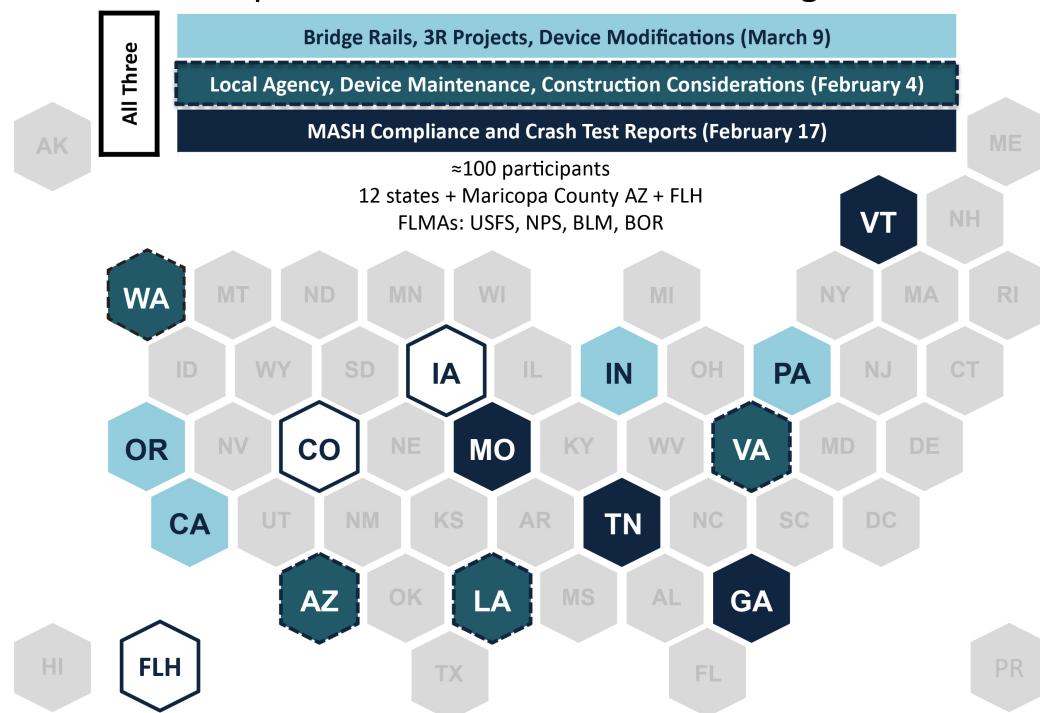
- Local agencies, maintenance of devices, and construction considerations.
- MASH compliance and evaluating crash test reports.
- Bridge rails, 3R (resurfacing, restoration, rehabilitation) projects, and device modifications.

Tori Brinkly, FHWA, facilitated the three roundtables and was supported by representatives from FHWA Division Offices, FHWA Office of Safety Technologies, FHWA Office of Safety Research & Development, and FHWA Resource Center Safety & Design Team who assisted with the discussion questions. Participants represented the following agencies:

- Arizona DOT (ADOT).
- Bureau of Land Management (BLM).
- Bureau of Reclamation (BOR).
- California DOT (Caltrans).
- Colorado DOT (CDOT).
- Federal Lands Highway Division (FLH).
- FHWA Division Offices, Headquarters, and Resource Center.
- Georgia DOT (GDOT).
- Iowa DOT.
- Indiana DOT (INDOT).
- Louisiana DOT and Development (LADOTD).
- Maricopa County DOT (MCDOT).
- Missouri DOT (MoDOT).
- National Park Service (NPS).
- Oregon DOT (ODOT).
- Pennsylvania DOT (PennDOT).
- Tennessee DOT (TDOT).
- United States Forest Service (USFS).
- Vermont DOT (VTrans).
- Virginia DOT (VDOT).
- Washington State DOT (WSDOT).

Figure 1 provides a graphical representation of the roundtable participating agencies and in which roundtable each agency participated.

## 2021 MASH Implementation Information Exchange Roundtables



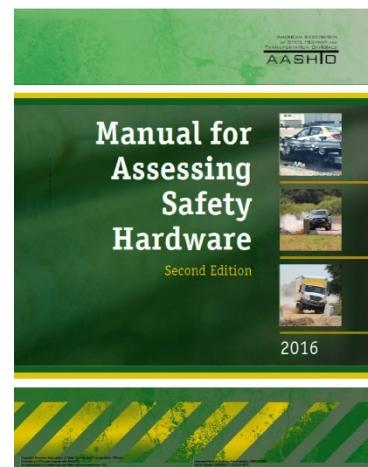
Source: FHWA

**Figure 1. Graphic. Roundtable Map.**

FHWA conducted the virtual roundtables in February and March of 2021 and included brief presentations from invited speakers followed by open discussion among the participants, who were able to ask questions, share resources, and discuss their agency's perspective.

Representatives from FHWA's Office of Safety Technologies provided an overview of MASH at each virtual event. AASHTO's *MASH* (Figure 2) presents uniform guidelines for crash testing permanent and temporary highway safety features. The manual also recommends evaluation criteria to assess test results. Through a joint implementation agreement, AASHTO and FHWA have recognized the importance of ensuring the installation of the most advanced roadside safety equipment that has been successfully tested in accordance with MASH.

Together the two agencies formed a partnership focused on addressing questions and MASH interpretations from manufacturers and crash test labs. AASHTO is currently looking to the next



**Figure 2. Graphic. AASHTO MASH Cover.<sup>2</sup>**

iteration of MASH—exploring new topics, organization, vehicle specifications, and testing requirements.

Local and State DOTs experience challenges to meet MASH compliance dates for different reasons. For example, a DOT's ability to evaluate MASH compliance crashworthiness and understand the test reports are important components in the process to meet MASH compliance. Transportation agencies are also challenged with lack of hardware knowledge or lack of staff expertise to determine the crashworthiness of a device.

Research agencies, manufacturers, and public agencies can submit crash test results from accredited crash testing laboratories to FHWA for review. If FHWA finds that all of the testing was conducted in accordance with MASH, an eligibility letter is issued. The findings in the letters are limited to the crashworthiness of a system, as determined by FHWA's review of crash test results and certifications submitted by roadside hardware manufacturers. The letter does not offer a determination that a crash involving the device will result in a particular outcome or guarantee safety performance. Eligibility letters are issued as a service to State DOTs but are not required for roadside safety hardware to be eligible for Federal-aid reimbursement; however, many States/agencies have roadside safety hardware acceptance policies that require the FHWA letter as part of their acceptance process and FHWA will continue to carefully follow MASH and prepare letters for the foreseeable future.

FHWA would like to improve transportation agencies' knowledge of hardware and determining the crashworthiness of a device and is available to support State and local agencies throughout the process. FHWA developed the series of roundtables to educate the agencies while also helping FHWA understand agency needs. This document provides a summary of best practices and how agencies overcame challenges regarding MASH implementation, as discussed at the roundtables. Topics include notable resources and trainings, best practices as reported by the roundtable participants, challenges associated with the topics, and greatest needs identified by the participants.

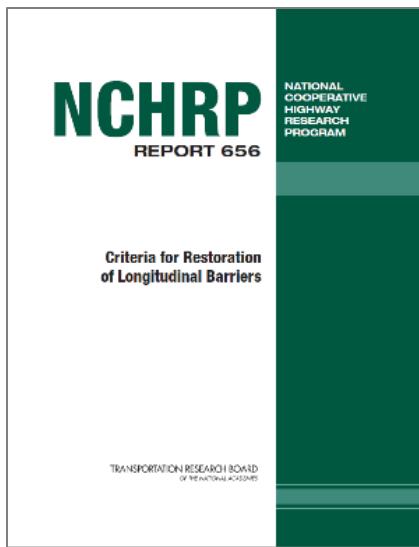
## II. Resources and Trainings

States and local agencies often develop internal trainings for specific projects or topics. However, over the course of the roundtables, both FHWA and the participants noted the value of several widely available trainings and resources to assist with specific topics. The following section provides more detail on those resources, including FHWA-supported trainings, a consultant-led training, and two Pooled Fund Studies.

### A. FHWA-Supported Trainings

The Fixing America's Surface Transportation (FAST) Act Guardrail Safety Training Program supports two training opportunities: State-specific training and more general training. The State-specific training will provide a contractor who reviews the State's design standards, conducts inspections in the field, and then designs a course consisting of both design and maintenance topics. Manufacturers are invited to speak specifically about the devices the State installs. The

training is intended as a snapshot in time and States are expected to update the training as needed and continue to deliver it to their staff. There is also mentoring training, which is designed to maintain momentum from the State-specific training. Representatives from Arizona, Indiana, and Louisiana all reported success with the FHWA FAST Act training. In a typical year, FHWA provides up to four State-specific trainings. More information on the FAST Act Guardrail Safety Training is available online.<sup>3</sup> If a State is interested in the trainings, they can contact their FHWA Division Office.



*NCHRP Report 656: Criteria for Restoration of Longitudinal Barriers (Figure 3) is the original source for many of the graphics in the FAST Act training materials and pocket guides.<sup>3</sup> The report provides detailed pictures of hardware specifications and examples of damage and related maintenance needs and costs.*

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**Figure 3. Graphic. NCHRP report cover.<sup>4</sup>**

### **B. Consultant-Led Training**

When TDOT developed an evaluation process to determine crashworthiness of roadside hardware, they observed the manufacturer crash reports were often very detailed but also missed important information. Therefore, TDOT sought out training to educate the committee responsible for reviewing the evaluation packages they receive, which contain the crash test reports, material specifications, and other TDOT-required documentation. Tennessee DOT contracted with a retired roadside hardware expert to develop a comprehensive training on understanding MASH, new and proprietary products, modified products, and other topics that would arise related to the evaluation package.

TDOT worked with their consultant to develop the list of topics to cover in the training. Each department was responsible for identifying representative staff to receive the training and participate in an oversight committee, who were also invited to submit topics they thought would be important. The training provided the participants an understanding of the test criteria (what is required and why) and the reports. The training occurred over the course of one day but

was comprehensive and engaging through activities like crash test videos that provided baseline information for the participants to understand what to look for when reviewing the manufacturer reports: understanding critical impact point, component testing, computer simulations, evaluating justifications to omit a test, etc. Following the training, TDOT developed a Product Evaluation Submittal Form based on the training module.<sup>5</sup>

### **C. Pooled Fund Studies**

There are two pooled fund study opportunities for States—the Roadside Safety Pooled Fund (Texas A&M Transportation Institute [TTI]-supported) and the Midwest States Regional Pooled Fund Program (University of Nebraska-Lincoln Midwest Roadside Safety Facility [MwRSF]-supported).<sup>6,7</sup> States participating in the efforts pool money with others to determine what to evaluate and determine future research questions that would be valuable for larger audiences. The value is in the shared resources, and there are several States involved in both pooled funds.

The Roadside Safety Pooled Fund involves 26 States and the Ontario Ministry of Transportation (Canada), with an annual budget of \$1M. This group meets annually to determine priorities, with ongoing support from five working groups that provide networking and information-sharing opportunities. Additionally, the website includes details on what has been tested to MASH, includes links to reports and videos, and identifies if there is, or is not, an FHWA eligibility letter available.<sup>8</sup>

The Midwest States Regional Pooled Fund involves 21 States with an annual budget of \$1.4M. This group meets annually in the spring to select and prioritize projects, and they also meet in the fall to discuss project status. The MwRSF site also includes a “Research Hub” link where you can search through reports going back to 1977 for projects sponsored by the pooled fund or other agencies.<sup>7</sup> There are also options to search by recently asked questions or by keyword.<sup>9</sup>

Both Pooled Funds offer consulting services to some degree for the participating States and others. The Roadside Safety Pooled Fund provides professional opinions through a task order where any of the participating States can submit requests. In a professional opinion, a research engineer investigates crash tests, reviews the system, consults with other researchers, and provides an in-depth evaluation that references the crash tests and details the opinion. This results in a report that explains why tests were excluded and why specific configurations were tested. The documentation steps through the entire process, is diligent, and with a strong engineering perspective. While not a replacement for a crash test, States recognized the value of the opinions of national experts and use the reports as part of their documentation process. There is a similar function through the Midwest States Pooled Fund, where States can ask questions about device design or installation, and MwRSF provides answers or interpretations; however, these may not be considered a professional opinion. Several States reported relying on MwRSF for identifying reasonable modifications to roadside safety hardware.

#### D. Other Useful Resources

FHWA made note of several ongoing and upcoming research studies that may be of interest to the roundtable participants.

- The FHWA Office of Research and Development oversaw an [In-Service Performance Evaluation \(ISPE\) of Guardrail End Treatments pilot project](#) which included data from four States: California, Massachusetts, Missouri, and Pennsylvania. This project was final report will include methodology and protocols for designing and conducting an ISPE.
- National Cooperative Highway Research Program (NCHRP) Project 22-33, [Multi-State In-Service Performance Evaluations of Roadside Safety Hardware](#), included eleven States and expanded the FHWA ISPE pilot project by attempting to create a database that can be shared among States to identify types of hardware that is working or is not performing well.<sup>10</sup> This project is developing ISPE guidelines, training materials, and associated electronic tools (like a using a spreadsheet approach for managing an ISPE), which will be available after the study is complete.
- NCHRP Project 22-44, [A Transportation Agency Data Collection Practice for Use with ISPEs](#), will complement and coordinate with the research under NCHRP Project 22-33. The data collection methodology will explore data integration from other sources, like first responders and maintenance personnel who respond to crash scenes, and the potential for collecting photographs, hardware damage, and other data.
- NCHRP Project 15-53, [Roadside Barrier Designs Near Bridge Ends with Restricted Rights of Way](#), will develop guidance for barrier installations near bridge ends. Testing is complete and the final design met MASH crash test criteria. The research team is in the process of preparing the write up.
- FLH is conducting research on the issue of smaller bridges on very low-volume roads that often do not have enough width or roadway to allow for curbs (common occurrence for Bureau of Reclamation bridges) or Test Level 2 (TL-2) or TL-3 bridge rails. The goal of the research is to develop a guide on how to assess the bridge rails and develop recommendations for upgrades. The second outcome will be developing the type of rails, curbing, and transitions needed for these special cases. The research is underway and FLH anticipates that this will help several Federal agencies as well as other agencies with low-volume bridges in rural areas. One significant challenge is that taller MASH devices impact the viewshed or limit farming, military, or logging equipment movement.

Appendix A lists resources directly referenced by roundtable participants and Appendix B provides other useful resources, as noted by the roundtable participants. The list includes State resources, guides, and policies; Federal reference materials; and other research documents from industry agencies.

### III. Noteworthy Practices

At each of the three roundtables, FHWA invited two to three State and local representatives to briefly present on their agencies' successful experiences and lessons learned regarding specific topics. The presentations were also intended to initiate broader discussions and information sharing between peers. Both the presentations and roundtable sharing resulted in noteworthy practices that may be useful resources for other agencies exploring similar issues. The following section highlights the presentations and then briefly notes other State or agency practices.

#### A. Standardizing Requirements, Processes, and Checklists

INDOT and GDOT's presentations on their State practices created the opportunity for other participants to share their processes and identify opportunities within their agencies to create standardization.

To kick off the Bridge Rails, 3R Projects, and Device Modifications discussion, INDOT presented on "INDOT Standard Bridge Railing 2019." As the State was working through the process of determining the implementation of MASH in their State, they identified gaps in knowledge as staff who had previously worked toward implementing *NCHRP Report 350* were no longer with the DOT to answer questions. In addition, FHWA no longer provides the guidance and interpretation as they did when *NCHRP Report 350* was being implemented, so it is up to the States to determine what is important for implementing MASH. INDOT worked directly with their FHWA Division Office to identify what was MASH compliant, which meant spending time understanding the process and rules.

While working through the process, the State identified two technical issues: determining MASH compliance of the rail itself and determining the appropriate test level for a project. INDOT had been using a flow chart adapted from AASHTO's 1989 *Guide Specifications for Bridge Railings* which resulted in TL-2, 4, and 5 railings. INDOT knew that some railing would only meet MASH TL-3, so they decided to either bolster the railings to arrive at TL-4 and retain the current process for selecting the appropriate test level or reevaluate INDOT's process for the test level process. INDOT closely followed the guidance in the TTI Project 20-07, Task 395 Report for strength (impact forces based on test level), stability (of vehicle versus height, shape, and stiffness of barrier), and geometry (features that affect occupant risk).<sup>11</sup> Their bridge rail evaluation criteria also included the following:

- Question/Answer: INDOT engaged Maintenance and Construction to work through potential questions and issues.
- Research Crash Tests: INDOT reviewed crash tests and the TTI report.
- In-Service Performance and Frequency Use: INDOT examined their own records to determine how often rails were used and looked for gaps in the system.

The policy of a minimum TL-3 on a State route aligned with the national highway system (NHS) requirements INDOT developed under discussions with their FHWA Division Office. However, INDOT recognized local routes frequently use the MASH TL-2 'Texas rail' (the 411 rail from Texas

DOT's Bridge Railing Identification Guide).<sup>12</sup> They also found that side-mounted rails were commonly used on local public agency (LPA) and lower-volume roads. While INDOT ended up reducing their standards from 10 to 5 standard bridge rails, they kept the local route rails in their standards and decided to address those in the policy revision on how to select the appropriate test level.

To develop their Test Level Selection, INDOT reviewed the Texas DOT Bridge Railing Identification Guide and switched to starting with speed rather than strictly annual average daily traffic.<sup>12</sup> INDOT tried to provide objective considerations when designers should consider a higher test level for a particular application to assist designers with the transition from a clear flow chart to a process that allows for more flexibility. The selection process and evaluation criteria are covered in their [Design Memorandum 19-08](#) (excerpt in Table 1):

**Table 1. INDOT Bridge Railing Minimum Test Level**

If ...	And...	The minimum (MASH) test level is	INDOT Bridge Standards	Notes
Bridge carries interstate mainline or system interchange ramp traffic		TL-5	Type FT Type TF-2	
The design speed is $\geq$ 50 mph		TL-3	Type FC Type PF-1 Type PS-1	
The design speed is $\leq$ 45 mph	The route is on the NHS	TL-3	Type FC Type PF-1 Type PS-1	
The design speed is $\leq$ 45 mph	The route is not on the NHS	TL-2	Type TX (LPA only)	Once the minimum test level is determined, use the evaluation criteria listed below to assess if a higher test level is appropriate. A higher test level railing may be used to satisfy lower test level requirements.
<ul style="list-style-type: none"> <li>Highway design speed. Use the greater of posted speed or the design speed to establish the minimum test level. A lower test level may be acceptable for low volume roadways.</li> <li>Average annual daily traffic and percent trucks. Higher traffic volumes have inherently higher likelihood of crashes. High truck volumes (truck DDHV is 250 vph) are a consideration for selecting a higher test level.</li> <li>Highway geometry (grades and horizontal curvature). Steep grades (sustained longitudinal grades greater than 5%) and sharp curves (horizontal curve radius less than 1,500 ft) are considerations for using a higher test level.</li> <li>Type of land use below deck. Roadways under are higher risk than waterways under due to the risk of multiple injuries.</li> <li>In-service performance. Unsatisfactory in service performance is a consideration for selecting a higher test level.</li> </ul>				

In the MASH Compliance and Evaluating Crash Test Reports discussion, GDOT presented Georgia's *Process for Determining Crashworthiness*. They started with an overview of GDOT's previous process, which was primarily governed by standard specifications that referred to *NCHRP Report 350* and FHWA Eligibility Letters, but also included a qualified products list (QPL) and construction standards for standard drawings and non-proprietary devices. In 2018, GDOT considered how the State would determine crashworthiness if FHWA no longer issued eligibility letters. From this, GDOT developed a three-phase, forward-looking process:

- In Phase 1 – Evaluation, GDOT would evaluate manufacturer crash tests, analyze hardware aspects specific to Georgia, review other State DOT processes and hardware (which was more difficult prior to becoming a member of the Midwest Pooled Fund Study), and accept the products that would be added to the qualified product list.
- Phase 2 would focus on Installation, which was identified as a critical area for roadside safety hardware generally and more specifically for w-beam terminals. This phase was developed to rectify those issues and focus on installer and contractor training and certification. GDOT would consider if the manufacturer had a training and certification program and if the installers were certified for installing roadside hardware. GDOT would also ask the installers to provide an ID tag on end treatments, which would help establish a tracking system for this information if issues arise with specific installers or hardware.
- In Phase 3 – ISPE, GDOT staff—including Highway Emergency Response Operators (HEROs) and Coordinated Highway Assistance and Maintenance Program (CHAMP)—would take photographs of damage when responding to calls. This phase would involve several agencies evaluating the results to identify common issues with installation and asset management. GDOT also explored developing ID-tags for asset management to track locations of updated hardware and create an automated process.

As of the roundtable, GDOT implemented Phase 1, where FHWA eligibility letters are still required per GDOT policy, the State reviews MASH device crash tests, and a multidisciplinary team was established to determine device acceptance. GDOT had not implemented Phase 2 for installer training, certification, or end treatment ID tags, and had partially implemented Phase 3, including the ISPE data collection and review, but they have not implemented the ID tags for asset management.

Other States shared the following examples of standardizing processes:

- TDOT established a policy to fully replace terminals that experience even minimal damage and only installed MASH tangential terminals, all to reduce liability concerns. Additionally, TDOT developed a Product Evaluation Form that asks many questions regarding Product Submittal, Supporting Documentation, and Technical Review. A committee confirms and checks the responses in detail.
- WSDOT established a Roadside Safety Issues Group that meets quarterly and maintains a tracking sheet of hardware evaluations. The tracking sheet easily and concisely displays the MASH compliance on the systems and is based on all policy information concerning the devices and configurations, standard plans, and proprietary device list. WSDOT sees the value of putting the information in writing and maintaining the spreadsheet in a timely fashion as things evolve quickly.

## **B. Modifications**

At the Bridge Rails, 3R Projects, and Device Modifications discussion, CDOT provided a detailed synopsis of their State policy for modifying bridge rail with a presentation on "Doghouse Bridge Rail (CDOT Old Bridge Rail Type), Bridge Rail Type 10R MASH, and CO Bridge Rail TL-3 and

Lower Policy." CDOT explained the State 3R project policy is to replace an existing bridge rail that does not meet the minimum MASH TL-4 rail height or strength requirements, or upgrade it to meet MASH criteria. CDOT's challenge is making recommendations that do not result in further design changes due to lack of funding so any incremental change in safety is important.

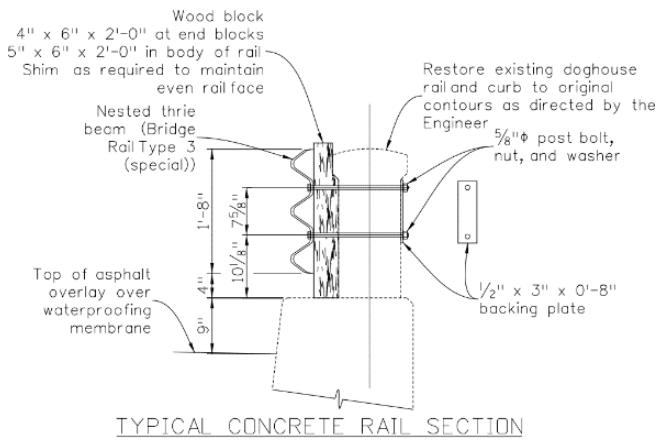
On a high level, CDOT provides guidance on upgrading existing guardrail to meet MASH criteria, considering key factors such as:

- raising the height to 31 inches
- offset blocks changed to 12-inches
- guardrail splice locations moved to mid-span
- use of an asymmetric transition to the concrete barriers and bridge rail
- traffic speed
- average daily traffic (ADT)
- existing rail capacity
- proximity to intersections
- roadway geometry
- crash history

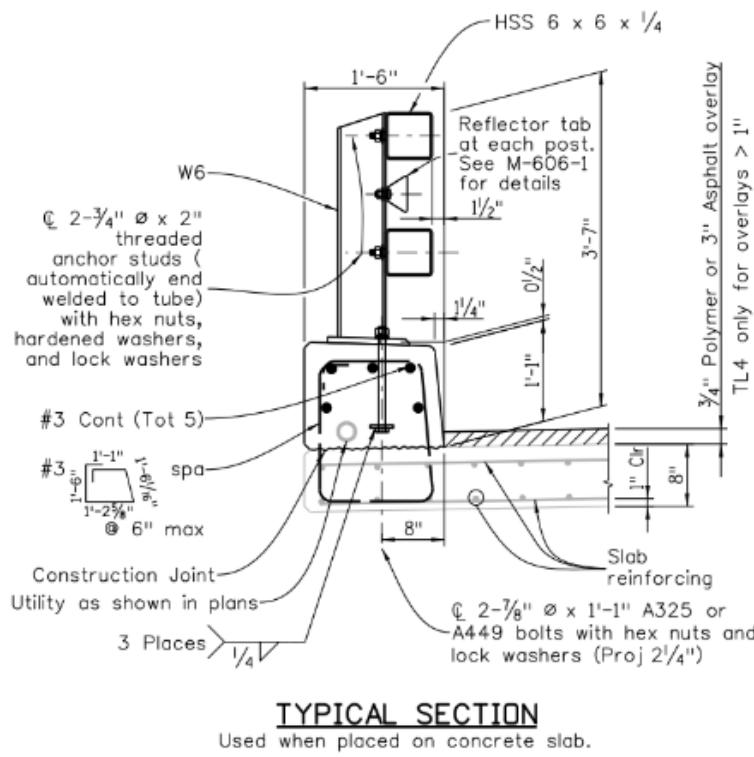
If there is a design modification, the designer/engineer of record will seal and stamp the rail design and a subject matter expert within Structures reviews and provides opinions on the modifications.

CDOT provided two examples of device modifications: doghouse bridge rail and bridge rail type 10R MASH (still under development).<sup>13</sup>

- In the first case study, CDOT provided two options for upgrading the existing doghouse bridge rail: replace the bridge rail (default option) or bridge-rail rehabilitation (install a thrie-beam) (See Figure 4). Replacements are costly but meet the current MASH standards, while rehabilitation is more cost-effective and safer compared to no action. Regions will go through a Bridge Railing Exception exercise to weigh the benefits of the two options and make the appropriate selection. The doghouse bridge rail was not crash tested but was assessed on engineering judgement of strength evaluation and height. CDOT notes that the ADT and speed are very low where they have done this retrofit. The structure itself often needs to be replaced as well; however, even the rehabilitation option will improve safety.



**Figure 4. Graphic. CDOT Doghouse Bridge Rail Repair.<sup>13</sup>**



© CDOT

**Figure 5. Graphic. CDOT Type 10MASH.<sup>13</sup>**

The second case study compared TL-4 bridge rail type 10R MASH to [Type 10 MASH](#) (Figure 5). Both designs are the same on the top but differ in the anchorage system on the curb and with the curb heights. Both bridge rails are composed of a continuous horizontal steel tube attached to steel tube posts. The posts are mounted on an existing reinforced concrete curb anchored to the bridge deck. The 10R MASH rail is intended for retrofits or rehabilitation of substandard rail systems and is anchored to the curb and the deck with washers and bolts. The Type 10 MASH is bolted to the deck and is designed for new bridges, moment slabs, and retaining walls.

- CDOT requires new MASH bridge-rail transition when a bridge rail and roadway guardrail is upgraded or replaced. Customized bridge-rail-to-guard-rail transitions may also be required to provide smooth transitions. The biggest issue is transitioning from new MGS guardrail to the existing bridge rail. CDOT staff from the Bridge Division are available to advise the Regions on the best options. There are times when CDOT's standard transition is simple, but on other projects CDOT Regions need to work with the structures group to determine the appropriate design.

In addition to CDOT's experience, other States shared their processes and policies regarding modifications.

- Caltrans headquarters office determines modifications due to the number of Districts and complexities with MASH compliance. Staff will consult with a Highway Safety

Features New Products Committee that includes multiple individuals with extensive experience with roadway safety devices, as needed.

- INDOT's most common modifications are for historic bridges in several scenarios for guardrails where standards will not fit, commonly intersecting roadways at the end of a bridge. INDOT relies on the Midwest Pooled Fund for identifying reasonable modifications.
- PennDOT procedures allow non-significant modifications to MASH compliant devices provided they can obtain an engineering opinion from an ISO 17025 accredited crash testing facility.
- WSDOT developed a process for modifications as part of their Roadside Safety Issues Group activities.

### **C. Qualified Products List**

Although there was no formal presentation on QPLs (also known as Approved Products Lists, APL), the topic was discussed across several of the roundtables. Noteworthy practices from the participating States include the following:

- TDOT maintains an approved product list, categorized by allowable NCHRP 350 devices and MASH-compliant devices. Communication and collaboration with the research and construction divisions was key as they oversee the QPL and the associated item numbers, descriptions, and quantities. Only devices on those lists are allowed to be installed.
- MCDOT maintains an Approved Material List (AML) but refers to the ADOT QPL in situations where available products cannot be used for a particular condition. The new product will continue to reference ADOT's QPL until it is added to County's list.
- GDOT is moving toward a Professional Engineer stamped, standard drawing for a device and exploring tying those into the QPL.

### **D. Internal Coordination with Other Departments**

The roundtable discussions highlighted the importance of coordination and communication within an agency. Many of the notable practices depended on buy-in from multiple departments, and the expertise of others is essential for MASH maintenance and implementation.

During the Local Agency, Device Maintenance, and Construction Considerations discussion, LADOTD presented on "Why Use MASH?" LADOTD is in the process of updating guardrail, roadside concrete barriers, and permanent crash cushions to meet MASH compliance and their update process revealed several needs and unresolved questions. In response, LADOTD created a MASH Implementation Committee with representation from Road Design, Bridge Design, Safety, Maintenance, Traffic Engineering, Construction, and FHWA. The Committee was formed to engage all departments so there is shared understanding and a mechanism to vet and prepare for changes. Additionally, as the AASHTO MASH implementation deadlines were approaching, LADOTD realized not everything was MASH-compliant. LADOTD needed to make

judgement calls on existing devices and their comfort with using devices already in place that lacked an eligibility letter. The Committee helped LADOTD come to a consensus on policies and standards rather than relying on one group to make decisions.

The Committee meets on an as-needed basis to evaluate issues as they arise or consider different alternatives or changes. There is a policy that details the levels of implementation from an FHWA eligibility letter, crash testing, and professional opinion down to engineering analysis. To date, the Committee and process has been successful. The FHWA Division Office was supportive of the process and integrating crash data analysis.

Other examples of internal coordination efforts include the following:

- Caltrans' Highway Safety Features New Products Committee includes nine representatives from different divisions and areas of expertise within the State. The Committee is responsible for reviewing evaluation crash test reports, drawings, and videos for any devices on the State highway system.
- INDOT invited maintenance and construction groups to participate in the Pooled Fund meetings in an effort to institutionalize knowledge with the MASH process.
- TDOT developed a review process that included a committee of Design, Maintenance, Materials and Tests, Operations, and Construction Division representatives responsible for reviewing the evaluation package. The committee meets quarterly to review the evaluation packages from their different perspectives. One essential step was to train the committee on all the needed information—from basic crash testing and standards to FHWA eligibility letters.
- WSDOT established a Roadside Safety Issues Group that meets quarterly and maintains a tracking sheet of hardware evaluations.

#### **E. External Coordination with Other Agencies**

During the Local Agency, Device Maintenance, and Construction Considerations discussion, the MCDOT presented on "Process of the Implementation of FHWA/AASHTO MASH Requirements," which highlighted their process as a local agency working towards implementing MASH, and what that means for standards, details, and equipment approvals. The County sought to establish a strategy and plan to begin phasing in MASH-compliant hardware and then inform staff and stakeholders involved in specifying, supplying, installing, and maintaining the affected roadside hardware. MCDOT used defined maintenance districts already in place as a way to break the County's roadway system into manageable areas to assess roadside hardware and agency responsibility.

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*Maricopa County is the fourth largest county in the United States with a population greater than 24 States. The County includes 24 cities and towns, five Indian Reservations, 2,600 lane miles of paved county roads, and 24 miles of existing guardrail installations.<sup>14</sup>*

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Then MCDOT needed to update their standard specifications and details, as many of the details did not meet MASH standards. So, MCDOT updated their supplement to the Maricopa Association of Governments uniform standard specifications.. They also implemented new bid items and provided an approved material list even though MCDOT was challenged with finding new MASH equipment and terminals to add to their list.

There are several large cities within the County with their own roadways and there was a question regarding limiting responsibility to the County along with how to engage those cities regarding MASH. MCDOT noted there are many agencies who share intersections and streets with other jurisdictions that wanted to implement their own process. Smaller agencies asked for help with funding and then did their own work, while other agencies wanted to develop their own implementation plan, like the City of Phoenix. The County used cost sharing methods to fund projects and acted as the lead designer, identifying specifications for implementation.

Regarding outreach with Native American Tribes and the USFS, MCDOT reported that it is glad to help when asked and provides design and installation assistance. MCDOT also has agreements in place for when a road passes through the Tribal regions or USFS lands.

MCDOT applied MASH to all county roads as part of the system, with locations shared with other jurisdictions involving an agreement. There is a 5-year plan to apply MASH to all roads and it is the local agency's responsibility to implement MASH. The plan helps determine the next step depending on the amount of damage to a system. If 50 percent or more of the system is damaged, MCDOT will initiate a job order contract to turn it into MASH compliant. For damage that is less than 50 percent of a system, MCDOT will convert the system to MASH through the overall implementation plan with the local agencies providing the funding. MCDOT also reported a strong collaboration with ADOT and FHWA on their MASH implementation plan.

The following details examples of how States coordinate with external organizations and agencies.

- MASH applies to all CDOT-owned roads across the State. CDOT will put out a local agency bulletin that explains criteria if new information effects Federal funding or local administration. Other instances require direct contact. CDOT will communicate with the engineering regions, who communicate with their local agencies. CDOT also has dedicated staff for updating standards and specifications and posting updates to the website. Communication with local agencies is a case-by-case basis.
- GDOT's focus on installation includes installer and contractor training and certification.
- Iowa DOT worked with FHWA to develop an updated instructional memo, which referenced both MASH and NCHRP 350, explained test level for each, recommendations for use, and requirements on certain projects.<sup>15</sup> The State provided local agencies with the instructional memos, which provides the locals the ability to not install guardrail on certain roads if it meets specific requirements. The Design Bureau provides the information and experts are available to answer questions from the local agencies.

## F. Policies and Flexibility

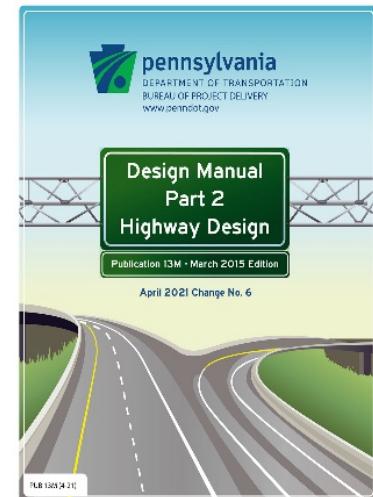
While many roundtable participants expressed interest in standardized processes, they also stated an overarching need for flexibility to address the various types of roadside hardware. Participants notably expressed concerns regarding work zone devices and the need for flexibility.

As part of Bridge Rails, 3R projects and Device Modifications discussion, PennDOT presented on "When Should Roadside Safety Hardware be Updated/Replaced?" PennDOT's Design Manual 2, Publication 13M, DM-2 (Figure 6), Section 12.3 details the State's policy that upgrades are triggered by the type of project (new and reconstruction, 3R, pavement preservation) and depends on the roadway classification (Interstates, NHS, non-NHS roadways with ADT greater than 2,000, non-NHS roadways with ADT less than 2,000).<sup>16</sup> PennDOT would prefer to upgrade all bridge rails to MASH but funding constraints limit the process to risk-based decisions. PennDOT's Pub. 13M, DM-2, Section 12.3 does not tell the highway designers to use MASH, but rather directs them to use the standards, which the State is working to update to MASH.

PennDOT explored more stringent standards for non-NHS roadways with less than 2,000 ADT, but there is not enough funding to support the upgrades. Therefore, the policy states designers should consider upgrading to MASH on a project-by-project basis. A full reconstruction will trigger an upgrade, but this type of project rarely occurs on those roadways. Therefore, the State sets aside the equivalent of 0.8 percent of capital funding annually to support upgrades. District safety engineers are responsible for the evaluation and determination of the upgrades that get funded.

PennDOT's policies also offer flexibility for concrete median barriers, high-tension cable barrier, and guiderail to bridge barrier transitions. These three categories vary in terms of condition, project type, height, and other considerations. Many of the evaluation criteria is risk based—as sweeping policies requiring upgrades to all hardware on all roads would deplete all available funding. Districts often ask for a good condition definition in regard to when upgrades are required, but PennDOT did not want to provide a stringent chart to allow for flexibility. There are many scenarios of what could go wrong with a guiderail, so it would be difficult to cover all the potentials. If PennDOT's Pub. 13M, DM-2, Section 12.3 policy is followed, there is no formal approval for when to upgrade or not, and no documentation is required. However, for new guiderail installations that do not meet standards, there is more rigorous documentation required.

Other examples of how States develop policies that offer flexibility, including work zone devices, include the following:



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**Figure 6. Graphic. PennDOT publication 13M cover.<sup>16</sup>**

- INDOT does not have a standard for portable barrier for permanent installations on a structure. INDOT uses temporary concrete barriers for work zone applications.
- Iowa DOT adopted a policy for updating to MASH terminals on 3R projects. The exception is if a project was completed immediately prior to when MASH went into effect and the hardware is only a few years old.
- ODOT's policy states that if NCHRP 350-compliant hardware is in place, the assumption is it is compliant. ODOT will review hardware installed pre-NCHRP 350 and determine if it needs to be brought up to current standards.
- TDOT found that work zone devices were the most complicated topic since there are four different categories and include proprietary devices. TDOT treats the portable concrete barriers and terminals as permanent devices and installs higher-performing devices in temporary situations such as a permanent crash cushion in a temporary setting because they perform better.
- VDOT is working on provisionally approved MASH products for work zones.
- WSDOT relies on service life issue for work-zone devices. They require MASH devices if manufactured after December 2019 but allowing service life for NCHRP 350 devices. WSDOT does not have a qualified product list for work zone devices and depends on the field engineers to determine if a device is either MASH, NCHRP 350, serviceable, and beyond.

#### **G. Inventories and Maintenance Activities**

MCDOT's presentation also covered hardware inventory as part of their larger process for implementing MASH. Being such a large county with many types of jurisdictions and roadways, the County sought to establish a strategy and plan to begin phasing in MASH-compliant hardware and then inform staff and stakeholders involved in specifying, supplying, installing, and maintaining the affected roadside hardware.

To accomplish this goal, the first step was to conduct a thorough inventory of locations, types, and amounts of hardware currently installed. MCDOT explained how they used previous inventory data collected through the Road Information System and Cartograph asset management tool.<sup>17</sup> They supplemented the data with aerial mapping to identify and measure hardware by type and condition. MCDOT dispatched maintenance crews and technical support staff to conduct in-person checks, confirm missing data, and capture updated existing conditions. Determining maintenance needs often comes from the public who will contact MCDOT to notify of guardrail damage. Maintenance crews in the field will also call MCDOT Transportation Systems Management (TSM) safety branch to report a damaged guardrail, who will then review and make recommendations for repairs.

Other examples of inventories and tracking maintenance needs include the following:

- CDOT inventoried all terminals on the State highway system in response to a severe crash involving a terminal that did not have the appropriate components to perform

correctly. Maintenance forces collected and inventoried the guardrails; however, CDOT shared their biggest challenge is maintaining the database.

- GDOT's Georgia Asset Management System (GAMS) is an Agile Assets software but it does not include a complete guardrail inventory. In 2014, GDOT conducted a manned survey on all major four-lane and above interstates and arterials. Georgia Tech is looking at using deep learning to identify guardrail locations through video. GDOT is asking Georgia Tech to look at one district to identify locations as a pilot project.
- Iowa DOT referred to INDOT's pink tag program that marries crash data and repair data to reveal in-service performance.<sup>18</sup> As a result, the maintenance department is developing a database that will show the locations and the crash data associated with the locations. A maintenance document is being developed that states how much guardrail (as a percentage of an installation) needs to be damaged before the DOT will replace the system. The State generally replaces in-kind, but they will revisit the issue of replacing only one portion of a system with MASH if the rest of the system remains NCHRP 350 compliant.
- ODOT developed a full barrier inventory with support from college interns.
- TDOT instituted a proactive approach with inventories that identified installation issues, which TDOT then removed the products with issues.
- VDOT developed a geographic information system-based tracker of the guardrail inventory on interstates and secondary roads using a virtual video log collected as part of a pavement assessment. The statewide guardrail terminal inventory includes manufacturer and terminal type. The State reviewed the videos and developed the inventory within a few months and is using the information to identify and remove deficient terminal types.
- WSDOT's *State Maintenance Accountability Process and Maintenance Guidelines—Repairs and Replacement of Guardrail Terminals* explains policies and address common questions related to repairs.<sup>19</sup>

Several States also reported on their policies related to service life, a topic that was often discussed in association with inventories and maintenance triggers.

- CDOT's first effort is to update precast barrier based on condition rather than service life.
- GDOT's official plan for sunset dates is to use the device end of service life.
- MoDOT's initial plan is for sunset dates in place and is considering grouping items with similar service lives.
- VDOT requires all devices to be converted to MASH-compliant no later than January 1, 2030.

## IV. Challenges

Participants discussed several issues or challenges that inhibit their agency from advancing the practice or areas where they need assistance. This section provides a brief overview of the noted challenges with examples of how other States have addressed the concerns.

### A. Staffing

Roundtable participants most commonly stated staffing expertise, knowledge, and retention or turnover as one of the primary issues faced within their agency. Turnover often goes unnoticed or unmentioned, which results in lack of institutional knowledge for identifying issues and solutions. And general lack of understanding of the evaluation process and reports is a significant need for several States.

To address this challenge, several States reported conducting internal training for staff and external training for consultants and other personnel. LADOTD provides Local Public Agency training and includes MASH in the work-zone modules to enhance local understanding of the State on- and off-system bridge standards. MCDOT is educating engineers and contractors and including language in contracts that require training for in-the-field staff. GDOT is trying to implement a process that would determine if manufacturers have a training and certification program and if installers were certified for installing roadside hardware but have not yet implemented this plan.

In addition to the previously noted internal training course, TDOT worked with FHWA's FAST Act mentorship training program in 2015 and established a mentor within each office. The identified staff is responsible for sharing information with regional teams. As staff approach retirement, TDOT is identifying emerging personnel to engage in discussions to begin to learn the processes and policies.

VTrans was unique in that they have a limited number of products approved for the system to ensure they are easy to maintain and easy to install. They worked with FHWA to create the list and create strong relationships with construction and maintenance staff. By limiting the products, VTrans also addressed the issue of limited staffing capabilities and ensured an easy process.

## **B. Implementing or Maintaining ISPE and Inventories**

Despite the interest in developing and maintaining ISPEs or inventories, few existing practices emerged from the roundtable discussions. As previously detailed, the third phase in GDOT's process included developing an ISPE and collecting photographs of damage that could be used for evaluating device performance in the future. For those agencies that had inventories, maintaining their database, and keeping information current was a bigger challenge than starting an inventory.

With few States reporting successes with implementing an ISPE, FHWA noted several opportunities for consideration. As mentioned previously, the FHWA Office of Research and Design oversaw an ISPE and will publish the final report soon which will include methodology and protocols for designing and conducting an ISPE.

Arizona DOT is also soliciting States for a new pooled fund study, [ISPE of Roadway Safety Features](#), which will evaluate the performance of roadside safety hardware in the field. This pooled fund effort will build upon work done by the NCHRP 22-33 Project, Multi-State In-Service Performance Evaluations of Roadside Safety Hardware.

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*A new pooled fund effort on In-Service Product Evaluation (ISPE) of Roadway Safety Features has recently been funded.<sup>20</sup> The primary objective of this pooled fund study is to evaluate the performance of roadside safety hardware in the field through inter-state collaboration by using standardized data collection and data analysis with a uniform interpretation of results. The second objective is to provide a forum for states to share ISPE data, experiences, practices, information, and resources.*

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## **C. Financial Constraints**

Roundtable participants that conducted inventories reported calculating the costs for upgrading all roadside devices and determined the costs were not feasible within the currently available funding. Other States expressed interest in how participants used different funding streams, both State and Federal.

While INDOT cannot use Highway Safety Improvement Program (HSIP) funds for guardrail projects, the State's capital program absorbs the cost of guardrail within the project. Starting in 2018, Caltrans established set asides for guardrail upgrades (up to \$1M per agency) to upgrade existing guardrails and end treatments (bridge rails are not eligible). In Arizona, MCDOT uses the Transportation Improvement Program to fund individual upgrade projects. MCDOT is also exploring bundling several guardrail installation projects together in a MASH Implementation Study.

ODOT dedicates money each year for roadside upgrades, along with a set-aside program for upgrading guardrail, but requires creating a project to spend the money. ODOT will also add funds to 1R projects (similar to pavement preservation projects) to upgrade barriers. At this time, it is easier for ODOT to select a specific corridor rather than make systemic improvements.

PennDOT does not use HSIP funding for roadside hardware upgrades unless it is part of a safety project, but they use State roadway funding for guiderail along a roadway, including funding for local road projects on low-volume roads. Bridge funding is used for guiderail along a bridge, but bridge rail upgrades can be very expensive and may require an entirely new deck replacement. The funding is prioritized at the District level and it is up to the Districts to prioritize their guiderail locations based on risk—the most dangerous with blunt ends, damaged guiderail, and so on.

## V. Ongoing and Future Needs

Participating agencies identified several needs over the course of the discussion. Some needs were requests from FHWA like standardizing evaluation across States or providing more training opportunities, while others were guidance from other peer States on determining sunset dates. The following section summarizes the specific requests.

### A. State Resources, Examples, and Databases

Roundtable participants noted the following information would be helpful resources:

- Example processes for determining modifications and conducting evaluations for addressing non-MASH devices.
- A database of the approved bridge rails by State.
- Guidance for local agencies to adjust the rail for pedestrians and maintain the crash worthiness.
- During the ATSSA annual meeting, several States met to discuss a draft standard roadside device evaluation form that is under development. However, they observed that States ask more questions than what is on the form.
- Examples of how other States address innovation, specifically items that would not be tested and would carry some level of risk.

### B. Requests for Technical Assistance or Guidance

Time was reserved at the conclusion of the virtual roundtables for general requests and comments. Participants used this time to report specific needs regarding technical assistance or additional guidance from FHWA.

- Caltrans is looking for FHWA help regarding pre-fabricated bridges for emergency uses, like after a bridge has washed out. FHWA Office of Safety suggested reaching out to the FHWA Office of Bridges and Structures for advice.
  - FHWA does not have the authority to force manufacturers to crash test and clarified that proprietary devices need to demonstrate crash worthiness through crash testing.
- PennDOT noted that it is difficult for DOTs to make decisions on proprietary devices and the FHWA eligibility letters help with proprietary products and provides a level of comfort. The FHWA letters also provide manufacturers with a central clearinghouse for all 50 States.

- MoDOT suggested that for the next update to MASH, AASHTO could consider every State's processes and look at foundational aspects beyond crash testing videos and reports. There are distinct differences between States, so a more standardized outline for DOTs, manufacturers, and testers would help with continuity as there are products acceptable in one State but not another. FHWA noted that AASHTO's Task Force 13 has started working on a standardization of items and format for crash test reports.
- VTrans would be interested in a crash test report training, similar to what TDOT received.

### **C. FHWA Responses to Questions**

Several States asked specific questions of FHWA regarding existing processes. The following summarizes the requests and responses:

- CDOT asked FHWA if there will be a standardized minimum test level for the Interstate system. FHWA explained there is not requirement for a specific test level on the NHS. There was a memo several years back that appeared to require TL-3 as the minimum on NHS; however, that document does not relay a FHWA policy or state a regulatory requirement. The LRFD establishes the test levels for bridge rails, which is an adoptive standard by FHWA for the NHS. The document says States are responsible for determining the test level they will use on their systems, including the NHS.
- INDOT was interested if there is reconsideration for revisiting the 2015 change in eligibility letters process to relax the requirement for all MASH tests to be run in order to receive an eligibility letter. FHWA does not anticipate revisiting the eligibility letter processes again since the letters are not required. If manufacturers want to receive letters, they need to submit the request to FHWA. Some States are submitting eligibility requests and they will still be required to conduct all the tests.

At the conclusion of the roundtables, FHWA reiterated that their role is to provide States information to make the best decisions and they invited participants to share resources with one another. Appendix A provides links those resources shared over the course of the roundtables.

FHWA will continue to work with AASHTO in their efforts to update MASH criteria and potentially change it into more of a technical specification. Participating agencies were encouraged to continue to use FHWA and other Federal resources in their MASH implementation efforts and contact FHWA directly with questions or training and research ideas. FHWA thanked the participating agencies and noted that they will use the results of the roundtable to look for more opportunities to MASH trainings and general information on MASH implementation.

## VI. Appendix A – References

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2. AASHTO Manual for Assessing Safety Hardware, Second Edition  
<https://store.transportation.org/item/collectiondetail/211>
3. FHWA FAST ACT – Guardrail Safety Training [https://safety.fhwa.dot.gov/roadway\\_dept/countermeasures/reduce\\_crash\\_severity/docs/fast\\_act-guardrail\\_safety\\_training.pdf](https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/docs/fast_act-guardrail_safety_training.pdf)
4. NCHRP Report 656: Criteria for Restoration of Longitudinal Barriers  
<http://www.trb.org/Publications/Blurbs/163512.aspx>
5. Tennessee Department of Transportation Product Evaluation Submittal Form  
<https://www.tn.gov/tdot/materials-and-tests/research--product-evaluation-and-qualified-products-list.html>
6. Roadside Safety Pooled Fund <https://www.roadsidepooledfund.org/about/>
7. Midwest Roadside Safety Facility, Q&A <https://mwsrf.unl.edu/q&a/index.php>
8. Roadside Safety Pooled Fund MASH <https://www.roadsidepooledfund.org/mash-implementation/>
9. Midwest Roadside Safety Facility <https://mwsrf.unl.edu/pooledfundq&ahome.php>
10. NCHRP 22-33: Multi-State In-Service Performance Evaluations of Roadside Safety Hardware  
<https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4213>
11. TTI Project 20-07, Task 395, MASH Equivalency of NCHRP Report 350-Approved Bridge Railings [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07\(395\)\\_FR.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07(395)_FR.pdf)
12. Texas Department of Transportation Bridge Railing Identification Guide  
<https://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/bridge/railing.pdf>
13. Colorado Department of Transportation Staff Bridge, Bridge Detail Manual  
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14. Maricopa County Department of Transportation, 2018 Annual Report  
<https://mcdot.maricopa.gov/DocumentCenter/View/44001/MCDOT-2018-Annual-Report>
15. Iowa DOT Instructional Memorandums to Local Public Agencies: Traffic Barriers (Guardrail and Bridge Barrier Rail) [https://www.iowadot.gov/local\\_systems/publications/im/3230.pdf](https://www.iowadot.gov/local_systems/publications/im/3230.pdf)
16. PennDOT Publication 13M Design Manual Part 2 Highway Design  
<https://www.dot.state.pa.us/public/pubsforms/Publications/PUB%2013M/Pub%2013M%20Title%20Page.pdf>
17. Maricopa County, GIS Mapping Applications <https://www.maricopa.gov/3942/GIS-Mapping-Applications>
18. Iowa DOT Pink Crash Tag Project <https://iowadot.gov/crashtag/Home>
19. Washington State DOT Maintenance Accountability Program  
<https://wsdot.wa.gov/maintenance/accountability-process>
20. In-Service Performance Evaluation (ISPE) of Roadway Safety Features  
<https://www.pooledfund.org/Details/Solicitation/1551>

## VII. Appendix B – Other Resources

ATSSA Guidance Documents <https://www.atssa.com/Training/Work-Zone-Safety-Grant/Guidance-Documents>

Alaska Department of Transportation and Public Facilities Standard Specifications for Highway Construction – 2020 Edition

<http://dot.alaska.gov/stwddes/dcsspseas/assets/pdf/hwyspecs/sshc2020.pdf>

Colorado Department of Transportation Guardrail Systems Field Guide For Construction Engineers and Inspectors <https://codot.gov/programs/tetp/assets/2018-2019/guardrail-field-guide.pdf>

Colorado Department of Transportation Staff Bridge, Bridge Detail Manual  
[https://www.codot.gov/library/bridge/bridge-manuals/bridge\\_detail\\_manual/bdetc\\_16\\_repair\\_details\\_2010\\_12.pdf](https://www.codot.gov/library/bridge/bridge-manuals/bridge_detail_manual/bdetc_16_repair_details_2010_12.pdf)

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Florida Department of Transportation Approach Terminal Identification Guide  
<https://www.fdot.gov/docs/default-source/maintenance/e-maint/docs/ApproachTerminalIdentificationGuide.pdf>

Illinois Center for Transportation, Improving the Safety of Moving Lane Closures – Phase II  
<https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.390.9229&rep=rep1&type=pdf>

INDOT 2013 Design Manual – Chapter 404, Bridge Deck  
<https://www.in.gov/dot/div/contracts/design/Part%204/Chapter%20404%20-%20Bridge%20Deck.pdf>

Iowa DOT Instructional Memorandums to Local Public Agencies  
[https://iowadot.gov/local\\_systems/publications/im/imtoc.pdf](https://iowadot.gov/local_systems/publications/im/imtoc.pdf)

Iowa DOT Instructional Memorandums to Local Public Agencies: Traffic Barriers (Guardrail and Bridge Barrier Rail) [https://www.iowadot.gov/local\\_systems/publications/im/3230.pdf](https://www.iowadot.gov/local_systems/publications/im/3230.pdf)

MaineDOT's Guardrail Inspection Training

FLEAT from Road Systems, Inc <https://www.youtube.com/watch?v=IVO-UGbxCqI>

MSKT from Road Systems, Inc <https://www.youtube.com/watch?v=7W9KvWHA6Gc>

SRT-350 from Trinity Highway Products <https://www.youtube.com/watch?v=JpZgxfjNIEU>

X-Lite from Lindsay Corporation <https://www.youtube.com/watch?v=t588OuMec00>

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Midwest Roadside Safety Facility, Development of a Standardized Buttress for Approach Guardrail Transitions <https://mwrssf.unl.edu/researchhub/files/Report415/TRP-03-369-20.pdf>

Midwest Roadside Safety Facility, Q&A <https://mwrssf.unl.edu/q&a/index.php>.

Midwest Roadside Safety Facility, Research Hub <https://mwrssf.unl.edu/researchhub.php>.

Minnesota Department of Transportation Roadside Hardware Identification & Inspection Handbook

[http://www.dot.state.mn.us/design/roadsidesafety/documents/pdf/roadside\\_hardware\\_handbook.pdf](http://www.dot.state.mn.us/design/roadsidesafety/documents/pdf/roadside_hardware_handbook.pdf)

NCHRP 15-79: Development of Guidance for Non-Standard Roadside Hardware  
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NCHRP 22-12(03) Recommended Guidelines for the Selection of Test Levels 2 through 5 Bridge Railings [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP22-12\(03\)\\_FR.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP22-12(03)_FR.pdf)

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Ohio Department of Transportation Quality Standards for Temporary Traffic Control Devices and Acceptable Delineation Methods for Vehicles  
<https://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/qualityguidelines/Documents/Quality%20Standards%20January%202020.pdf>

PennDOT Bureau of Maintenance and Operations, Maintenance Manual  
<http://www.dot.state.pa.us/public/PubsForms/Publications/PUB%202023/PUB%202023.pdf>

Roadside Safety Pooled Fund <https://www.roadsidepooledfund.org/about/>

Roadside Safety Pooled Fund, TL-2 Short Radius Guardrail Treatment  
<https://www.roadsidepooledfund.org/terminal/tl-2-short-radius-guardrail-treatment/>

Roadside Safety Pooled Fund, TL-3 Short-Radius Guardrail  
<https://www.roadsidepooledfund.org/longitudinal-barrier/short-radius-guardrail/>

Task Force 13 <https://www.tf13.org/>

Tennessee Department of Transportation Product Evaluation Submittal Form

<https://www.tn.gov/tdot/materials-and-tests/research---product-evaluation-and-qualified-products-list.html>

Texas Department of Transportation Bridge Railing Identification Guide

<https://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/bridge/railing.pdf>

Texas Department of Transportation Roadside Safety Field Guide 2014

<https://ftp.dot.state.tx.us/pub/txdot-info/des/guides/roadside-safety.pdf>

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<https://www.fhwa.dot.gov/bridge/pubs/nhi15047.pdf>

TTI Project 20-07, Task 395, MASH Equivalency of NCHRP Report 350-Approved Bridge Railings

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<https://wsdot.wa.gov/Design/Standards/PlanSheet/default.htm#TB>

Washington State DOT Design Manual, Ch. 730.04(7b)

<https://wsdot.wa.gov/Publications/Manuals/M22-01.htm>

Washington State DOT General Special Provisions, Division 8 Miscellaneous Construction

<https://wsdot.wa.gov/publications/fulltext/projectdev/gspspdf/egsp8.pdf>

Washington State DOT Standard Specifications

<https://wsdot.wa.gov/publications/manuals/fulltext/M41-10/Division1.pdf>



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